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Decision Analysis Framework for Distributed Generation in the Jamaican Industrial Sector

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Daneon Dillion Leroy

Technology Management, Economics and Policy Program
College of Engineering
Seoul National University

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지도교수 김연배

이 논문을 공학석사 학위논문으로 제출함

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Daneon Dillion Leroy

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위 원 장____________________(인)

부위원장____________________(인)

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Abstract

The global thrust embracing the use of Distributed Generation technology has not gone unnoticed with developed countries such as Germany, Great Britain and United States extensively employing it. Distributed generation was formerly used in direct current (DC) distribution systems in the early years of electric technology. The advent of large-scale alternating current (AC) transmission and distribution technology created an exodus from the use of micro grids to supply electricity. Distributed Generation (DG), characteristically employing a system where power generation is produced closer to the load, affords many advantages over large centralized grid network. Owing to the current trend and the considerable amount of research undertaken, the usefulness of this technology still bares sufficient appeal today.

Despite the undeniable relevance to use renewable energy sourced micro grids, Jamaica's electricity sector has experienced stagnated growth over the years, with generation units growing old and inefficient while energy prices soar due to unstable oil markets. Though the country has an abundance of renewable energy resources, still their profiteering as viable energy resources in the electricity sector is marginally capitalised. As the island struggles to revitalise the ailing electricity sector, DG provides an avenue for demand side benefaction to the system development.

The main goal of this study is to identify the best policy tool to achieve the greatest amount of benefits for both the Jamaica Public Service and its customers, selectively industrial and commercial consumers that totally rely on the national supply.

A survey of Jamaican experts is first conducted to solicit their views on energy policy priorities and determine criteria weights to assess current development programs in the island. Then using the Analytic Hierarchy Process (AHP), the research analyzes significant criteria to a successful energy development pathway focusing on a achievable shared vision encourages, sustained multi-stakeholder involvement. To further supplement AHP after subsequent selection of the best policy alternative, an analysis of Levelized Cost of Energy (LCOE) is performed to evaluate the policy's investment allurement/potential from all conceivable resources.

The experts, drawn from various fields of industry and governmental organizations, were grouped in the following categories:

- Environmental Protection and Safety
- Petroleum Refining and Retail
- Energy/Electricity Business Development Specialist in local Power Company
- Engineering and Power Control Specialist from Generation and Transmission Facilities

- University, Scientific Research and Development Institutes
- Government Ministry and Utilities Regulation Organizations

Five important characteristics, necessary for developing a policy promoting DG were selected as follows: Environment friendly, Rate reduction, Profitability, Infrastructure development and Reliability improvement. Based on research it was determined that the environmental criterion, with a weightage of 41%, was of greatest significance to the dissemination of DG programs. The assessment of the current electricity sector reveals that the current environmentally-friendly energy diffusion program is weak, resulting in slowed to reduced exploitation of renewable energy resources. Furthermore, the LCOE analysis confirms the suitability of the Feed-in Tariff (FIT) alternative over Foreign direct investment (FDI), Business as usual (BAU) or the Revenue Decoupling (RD) alternatives. The study shows that using renewable energy is not only a competitive investment option to traditional energy sources but moreover, it is sustainable into the future.

The use of a FIT would provide the proper market-pull stimulation to boost renewable energy adoption and innovation which is presently needed to match pace with infrastructure and economic development. The current policy being not clearly defined as market-pull or technology-push does not facilitate local Renewable Energy Technology (RET) and is not foreseen to achieve the goals of the sustainable energy growth plan at the time prescribed by the Government.

Quantitative empirical studies are needed to assess the current policies in place to determine if they are achieving set development goals and to identify significant variables to their success or failure. The present research is of academic importance as it shows the consequence of trying to gain energy sustainability without implementation of a plan to create indigenous local energy technology.

Keywords: Distributed Generation, Multi-Criteria decision analysis, Analytic Hierarchy Process, Renewable Energy Technology, Levelized Cost of Energy.

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Chapter 1. Introduction

1.1 Research Motivation

The development of the Power Generation and Distribution System has made significant growth since the days when direct current (DC) was distributed from Power Generation facilities. The work of Nicola Tesla and the alternating current power transmission and distribution network revolutionized the way in which we are supplied and use electricity today (Tesla, 2013). Since then, the scale of electricity operations has grown all over the world such that mammoth distribution networks exist in Developed Countries like Great Britain and the United States. So huge have these centralized generation networks grown such that grid operators struggle to cope with sudden load spikes during peak hours or periods of instability, that can cause outages due to storms or unexpected events (Woolf, Whited , Malone , Vitolo, & Hornby, 2014).

Governments in many countries are constantly exploring how to reduce the risk associated with the development of these large electricity networks. They present a constant challenge for grid operators that try to maintain the integrity of the system, which becomes increasingly difficult as these systems expand. As these large-scale electricity networks grow their cost, security vulnerabilities, environmental impact and waste in Generation and Transmission equally propagate, emphasizing the need for a system rehabilitation.

Researchers have realized that fundamental change is needed to achieve a resilient electricity system if the current long-distance central thermal power generation and transmission systems are to be employed (*A review of Solar PV Benefit and Cost studies, 2nd edition*, 2013). The use of a system of comparable characteristic in terms of size and distance of generating facilities to load centres, resembling that of the early DC distribution system is one of the options put forward by critics of the large-scale network. They advocate for a more distributed industry possessing a greater number of diminutive in scale and localized in nature generating facilities (Carley, 2009).

The maintenance of the aging and already antiquated infrastructure of many current electricity grids such as that present in Jamaica will require substantial investment. Equally, developed countries like the United States have realized that simply maintaining their current grid will require trillions of dollars in investment (*A review of Solar PV Benefit and Cost studies, 2nd edition*, 2013). As such, particular interest in the use of Distributed Generation (DG) is due to the more efficient use of the old aging distribution grid infrastructure by reducing unnecessary network reinforcement works that would most likely be borne by end customers (Anaya & Pollitt, 2017).

Additionally, the influence of DG in achieving Renewable Energy (RE) targets is playing a major role in its adoption globally in electricity systems as policies for their use frequently incorporates various sources (Anaya & Pollitt, 2017). Jamaica has many active industries that must be supplied with a reliable source of energy/electricity to ensure profitability and sustainability. The supply of electricity within the country is characterised predominantly by the use of oil in the form of either Heavy Fuel oil or Diesel oil to generate and supply electricity on the national grid. The dependence for oil is identified as one of the main deterrents of multi-national companies investing strongly in the country as the price of electricity is viewed as one of the highest overhead cost to business operators today (Makhijani, Ochs, Konold , Lucky , & Ahmed, 2013). Reducing the dependence on oil is therefore of major significance to the development of the industrial sector.

Studies on Jamaica's Energy sector have shown that electricity consumption/demand is somewhat income elastic and has a substantial impact on economic development (Ramcharran, 1990). It was determined that residential and commercial demand are respectively relatively income elastic and price inelastic with a slow rate of adjustment as electricity intensity increases over time. Results indicated that it would be fairly risk nominal to impose policies that would affect the price of electricity to commercial/Industrial customers.

The use of DG facilities has been argued as the solution to the large centralized distribution grid effects such as line losses, since DG reduces the load demand requirement from central generation stations (Woolf et al., 2014). Micro grid systems characteristically have their generation facilities built close to the serviced load in order to minimize electricity losses and inefficiencies and can connect to the electricity network or grid on the customer side most often called the distribution network (Carley, 2009).

The DG system frequently works on a premise of net metering; in this framework, commercial, industrial or residential customers connect their micro-grids to the country's main power grid. This is done with an option to facilitate electricity trading to the grid when the generated capacity allows based on customer electricity needs. These micro-grid systems are sized appropriately to their primary customer load, which is independent of the country specific load requirement.

The application of DG addresses some of the common difficulties of large centralised networks, the basis for its use hinges on its advantages. The motivation for the use of DG give rise to the identification of factors limiting its successful use based on Jamaica's inherent characteristics.

Throughout this study, factors that are distinguished as important limitations to be reckoned will be classified. Ideally, these factors address:

i. The benefits to be derived from DG and how they can be achieved.
ii. Determination of the traditional and renewable energy sources penetration levels of Jamaica's current electricity sector.
iii. Assessment of the adequacy or inadequacy of these energy sources

penetration levels in keeping with Jamaica's sustainable energy growth plan.

iv. Determination of the best policy tool to implement DG from the best energy source identified by experts.

v. Finally, based on policy goals and generation improvement plans a means of assessment of the investment interest the best policy identified can be used to allure investors.

1.2 Problem Statement

The use of Distributed Generation (DG) to complement the needs of the electricity sector in Jamaica with customer specific renewable energy sources has been identified as a viable solution to many of the problems that the public service is currently facing. The application of renewable energy resources to fulfil the goal of the sustainable energy growth plan and offset the huge dependence the island has on foreign energy is a key component of the Jamaica Sustainable Energy Road-map (Makhijani et al., 2013). However, despite a universe of benefits to the use of DG which includes:

- Load lessening and avoided energy costs
- Demand side reduction and avoided capacity costs
- Avoided compliance/environmental risk mitigation costs
- Avoided ancillary services such as volt-ampere reactive (VARS) and spinning reserves
- Utility operational savings
- Market efficiency returns
- Risk reduction such as fuel price volatility and load uncertainty,

DG has not been widely adopted for use within electricity sectors. This may be due mainly to the disincentive apparently present for large customers to invest in a system that is somewhat totally out of their range of expertise. From the studies detailing the best RE sources to be used in the island, integration of large amounts of distributed into the grid has also been assessed and documented (Makhijani et al., 2013).

The technical challenges associated with the use of DG along with the policy needed to create investor interest are the main threats to the adoption of micro grids. The challenges imposed by renewable energy sources are mainly the variability in production during normal operations induced by the intermittent nature of the renewable energy. The current electricity grid in Jamaica has been assessed to be designed robust enough to facilitate renewable energy sourced DG. The studies that have been done on the Jamaican energy sector with regards to fuel mix indicates that the penetration of renewables will significantly contribute to the future growth of the electricity sector (Barrett, Salazar, Chiliquinga, & Orbe, 2013; Makhijani et al., 2013). The long term forecast however reveals that renewables are not likely to be a dominant source of electricity in the sector before 2030 (O.U.R, 2010).

This study relying on previous studies that have assessed the present status of Jamaica's electricity generation system; evaluate the available generation alternatives that are/considered to be aligned with the sustainable energy road map. Using these alternatives, determine the best available policy to put the maximum amount of sustainable generation into operation and to keep the planned dominant RE penetration on track. Literature review has shown a gap in the studies that addresses how the 2030 maximum RE penetration will be achieved as assessment into the current generation expansion plan do not reveal a plan conducive to this goal (O.U.R, 2010). The reality of the situation is that based on the generation expansion plan, there is no real commitment for the integration of the planned renewable resources into the electricity sector. The analysis of the Jamaica electricity sector using the Wien Automatic System Planning Package (WASP-IV) model proposes to apply renewables in the energy generation mix of 11% by 2012, 12.5% by 2015 and 20% by 2030 (O.U.R, 2010). An important precept of the Generation Expansion Plan adopted by Jamaica is its Least Cost Expansion Plan (LCEP) policy, which indicates that any expansion strategy undertaken must be of such that it comes at the lowest conceivable cost of electricity. The undertaking to include RE will invariably be affected by this principal precept as RE technologies are most often quite expensive and will not be able to compete in terms of cost to fossil fuel technology.

The undervaluing of tariffs for the adoption and promulgation of RE Sources (R.E.S) has also been identified as a key deterrent in the use of RE based DG in the electricity sector of Jamaica. Jamaica currently does not have feed-in tariff so RE projects tendered before the issuing of the RFP were done under a non-competitive system calculated at the avoided cost of fuel plus a 15% premium; this approximates to 10.73 U.S. cents per kWh. These rates are projected to provide profits that are marginal and not enough to encourage investors (Makhijani, et al., 2013).

The feasibility of the DG can be analysed using several commercially available simulation software packages, one of them used globally being the Hybrid Optimization Model for Electric Renewables (HOMER). While customers having a distributed RE system will be able to improve reliability of energy supply, simulation software such as HOMER determines if this can be achieved even before investment into the system is done and determines if it is possible to operate at a positive net present value.

The ability of the system operator to recover revenues, which has been lost due to the load demand removed when a large Industrial customer converts to self-generation, is a critical factor for use of DG. Its use will cause loss of revenue, which must be addressed from whatever policy is used to implement this system. The study must incorporate or include policies which account for this critical issue and assess its viability under the generation expansion planning policy of Jamaica; assessing clearly if DG is beneficial and how. Revenue erosion to distribution network operators through the use of DG has been documented in several studies and mitigation measures included the use of policy tools like revenue decoupling and lost revenue adjustment mechanisms (Mokgonyana et al., 2017).

The Multi Attribute Decision Analysis Framework is a powerful tool to be used in making decision based on consistent analysis. The weakness or inability of policy makers to arrive at a decision for growth of the electricity sector and set plans into actions are a major problem as the bureaucracy involved normally cause windows of opportunity to open and close before any development is done. In light of this fact it is critical that decision makers are decisive but thorough in determining and crafting policies that will enhance or increase the likelihood of making a decision before these windows expire. The Analytic Hierarchy Process developed by Tom Saaty is particularly useful when the decision maker is unable to construct a utility function (Ishizaka & Nemery, 2013). Applying this technique critical information about the status of Jamaica's energy sector is ambitiously expected to be tackled. The penetration level of renewable energy in Jamaica must be ascertained and a determination of the adequacy determined. An understanding of how much energy can be conceivably attained from Jamaica's renewable resources is also of great interest and is necessary for policy development. The thrust by most countries to develop local renewable energy technology should be a part of any energy plan embarked on, this is a huge factor in policy development and currently Jamaica's energy plan does not highlight this as a goal. In answering these questions, one will be better able to conclude what the best policy is to implement DG, which should be beneficial to the energy sector on a whole. The subcritical goal of creating investor allure to encourage industrial customer interest into DG must also be recognized and elucidated from this study.

1.3 Research Objectives and Scope

1.3.1 Objectives

The primary objective of this study is to bridge the knowledge gap that exists between the extensive analysis already done on the Jamaican Electricity Sector on renewable energy allocation and disseminating it into the electricity sector using DG.

The oil dependence of Jamaica on imported fossil fuels has been identified to be of momentous concern to the development of the country. However, the country's generation expansion policy has been drafted centrally focused on imported fuels even though presently over 94% of the Island electricity is generated using fossil fuels (Energy Transition Initiative Islands, 2015a).

The identification of the best policy necessary to institute the goal of the National Energy Policy (2009 – 2030) is also an interesting theme of this study. Essential to policy development is the recognition/identification of criteria with the ability to achieve the country specific goals. Policy makers must carefully design programs disseminating renewable energy as well as traditional energy in a balance advantageous to achieve the goal of the national energy policy. Essentially one must be able to exploit the best resources that are readily available; this will be enabled using a Multi-Criteria decision-making tool. Integral to the procedure of the decision-making tool employed is the selection of criteria essential to the accomplishment of the goal; this study proposes using the Analytical Hierarchy Process (AHP) to do this. As a requirement of AHP the study will determine through expert feedback the integral criteria necessary for establishment of the research goal. These criteria will enable one to decide on the policy tools required for effective dissemination of DG in the Jamaican electricity sector.

This study, while adopting the theoretical groundwork encapsulated in the report presented by the International Renewable Energy Agency (*Renewable Energy Innovation Policy: Success Criteria and Strategies*, 2013), realizes that for a successful energy innovation policy inclusive of renewable energy, the policy must satisfy two broad criteria:

- The policy must promote sustained multi-stakeholder involvement sharing a common and conceivable vision.
- The policy must appropriately position the country or region to anticipate and benefit from renewable energy technology flows.

It is widely accepted that energy development is interrelated with economic growth, sustainable development among other social welfare factors and concerns such as urbanization education and even disease prevention. The shared theme in policy dialogues about energy development fluctuate into convergence around some typical goals.

This study has incorporated this goal in developing the policy criteria for DG dissemination. The six goals found within the report (*Renewable Energy*

Innovation Policy: Success Criteria and Strategies, 2013) along with consultation with experts in Jamaica were used to develop our AHP criteria, the goals were;

i. Energy Security. This goal is central to the accomplishment of a reduction in dependence on vulnerable energy supplies.

ii. Energy Access to encompass factors such electrification of a country/region, reduction of energy poverty and expansion of access to secure, reliable and low-cost energy.

iii. Energy Cost, vital in the energy generation expansion plan of Jamaica. This goal seeks to reduce exposure to persistently costly energy services.

iv. Competitiveness, pivotal to create investor interest both locally and internationally. This goal seeks to establish a sector that facilitates competitiveness, encourages growth in the energy market and development of a quality product.

v. Modernisation is predominant but not exclusive to most developing resource neutral country or region. The goal of modernising the sector will invariably change with economic growth and dependent on the rate of growth of the sector then economies will sure to be limited by it.

vi. Green-house Gas (GHG) emission reduction. This globally prevalent goal is a leading issue as the world tries to reduce its dependence on fossil-based fuels which are a leading source of GHG. These have been found to be hugely contributory to world environmental degradation influencing factors such as climate change inducing global warming.

Establishing criteria central to the AHP decision making analysis, the goals identified which ones can garner broadly shared support across a wide range of settings and common but not mutually exclusive to many countries, used as is or in combination within this study. Relying on the knowledge of experts through preliminary surveys that ratified the usage of criteria, born from the concepts of these goals.

1.3.2 Research Focus

This study will primarily focus on Distributed Generated that rely on sources such as wind turbine, which may be combined with the use of battery energy storage systems to provide the primary source of power. As one of the more favourable RE resource when compared to risk factors involved with DG, wind turbine exhibited slightly more risk than the practically risk-free energy efficiency programs determined by a study done in the U.S (Figure 1.1) below.

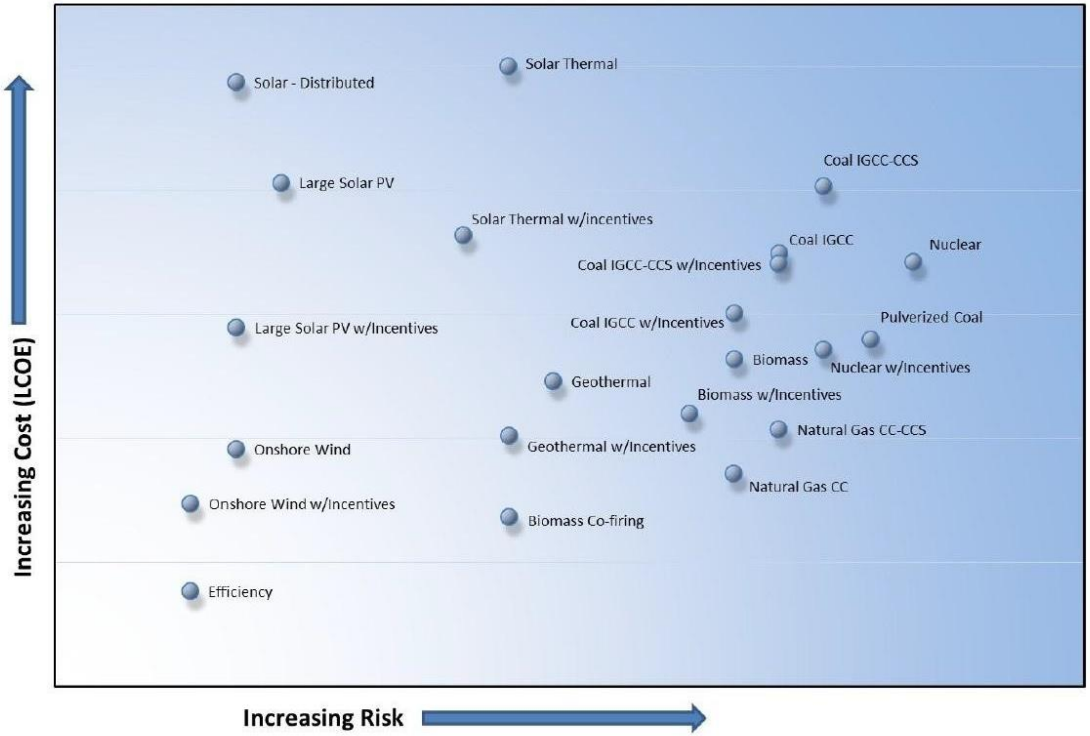


Figure 1. 1 2015 Utility Resources, Cost and Risk

The industrial sector was selected as the target for dissemination of this DG due to the relative ease of these large customers to be able to acquire capital to finance renewable or even traditional energy generating systems. Industrial customers are also considered more greatly impacted by the quality of energy generated as they normally have specialized equipment that are more greatly affected by power quality variations which impact company operations in terms of breakdown times and maintenance costs. The impact of electricity reliability is also of greater significance to Industrial customers, as this directly relates to operation activity and company productivity. Finally based on literature review studies have shown that the optimal size and location of DG can be determined which can more readily be accommodated by new or even existing Industrial customers.

1.4 Research Process and Methodology

The current study has already established the two foundational aspects of the research that are deemed instrumental to achieve the goal of a successful implementation of a distributed generation system to an industrial customer.

The flow chart in Fig. 1.2 identifies the research problem and establishes research objectives as the first blocks to be accomplished in the process. The research objectives are divided into key elements; these are necessary points of interest that must be satisfied to achieve our overall goal.

All the research is dependent on knowledge acquired either on our own or from previous researches. As such, literature reviews were conducted to determine the suitability of DG to improve the electricity sector and then for the use of Multi-criteria decision analysis as a suitable decision-making tool in the energy sector.

The foundation on which this study is built is gathered from prior researches on Multi-Criteria Decision Analysis as well as DG benefits to electricity sector improvement. The decision-making process employed is governed by theories related to studies in which researchers have placed considerable amount of details in addressing the complexities involved in them.

Arising from the factors listed in the problem statement, decision makers face the constant task of having to select for an electricity sector the most appropriate power generation technology for exploitation to achieve country specific goals.

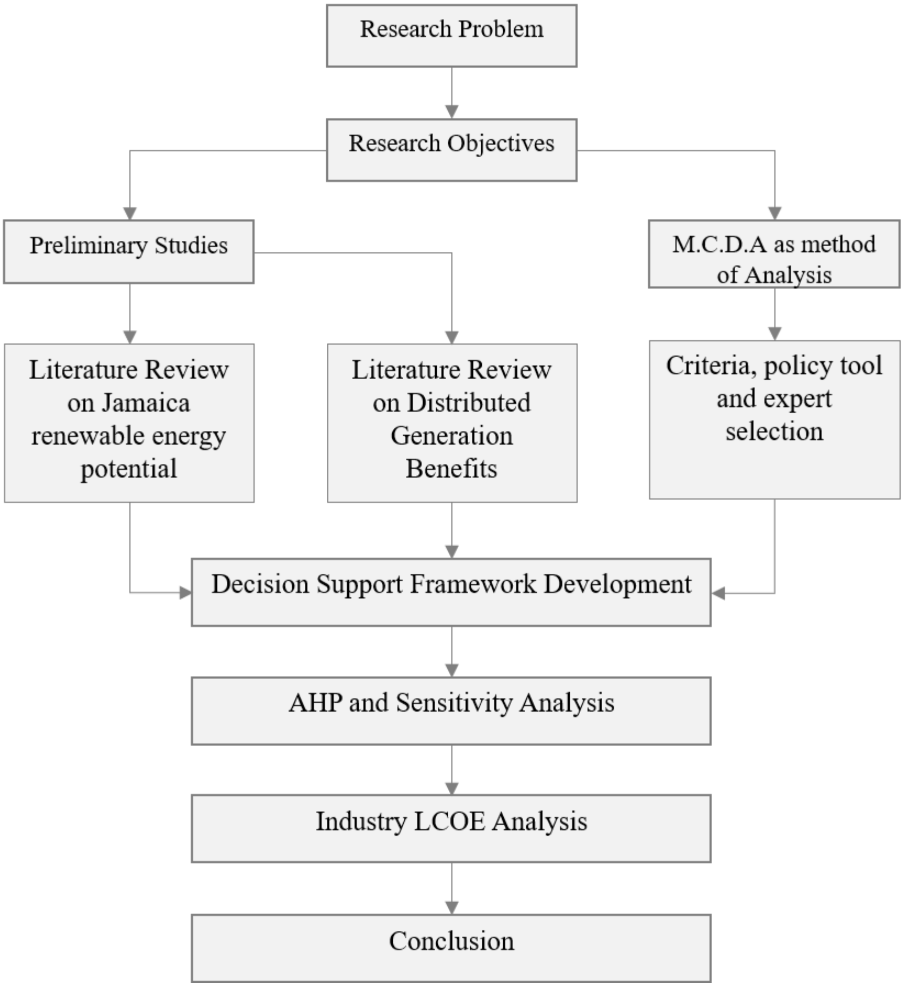


Figure 1. 2 Research Process

Jamaica is no less affected by the same decisions regardless of its diminutive size. Investment in the power generation field is too costly with limited resources for casual investment decision. As such Jamaica has undertaken many comprehensive studies to determine the ideal power generation technology to be selected.

This study will concentrate on precedent researches that identified the best renewable energy technology to be employed in Jamaica as well as traditional energy that is defined as key for the country's energy growth.

Previous renewable energy generation technology that has been implemented and used in Jamaica has been promoted for investor appeal by using one or a variant of the following tools;

- Feed in Tariff (F.I.T)
- Foreign Direct Investment (F.D.I) through (PPA)

The prolific use of these tools however has not been adopted with any regularity, notwithstanding the findings, done by researchers that modification and subsequent use could initiate greater investment of renewable energy generation technology, have not been executed.

The result of this is the overly slow rate of renewable adoption in the industry; in fact, since the Office of Utilities Regulation (OUR) Request for Proposal (RFP) in 2012, the amount of renewable energy technology that has been used has reduced and is evident in Fig. 1.3 (The World Bank Group, 2017).

The chart shows electricity generation by renewable energy as a percentage of total electricity generated from 1990 to 2014.

The Business as usual tool will include the options that from literature review includes ("Energy Transition Initiative Islands," 2015a):

- Net metering/Billing
- Interconnection Standards
- Tax reduction/exemption
- Green public procurement
- Build own and Operate (BOO) (Barrett et al., 2013)

These have been documented as tools that are predominantly used in promotion of electricity generating systems both renewable based and using traditional energy sources.

In summary, the first steps involved in this research will be on material found in the literature review. Then, the analysis from the Multi-Criteria Decision Analysis through the Analytical Hierarchy Process (AHP) will be done. The AHP analysis will comprise of a survey completed by experts that will determine the ideal criteria selected from literature review for the dissemination of a DG. The criteria identified will then be assessed from alternatives to determine their ability to promote each criterion. Finally. The study will be able to conclude which alternative tool should be most actively pursued to effect greater adoption of DG.

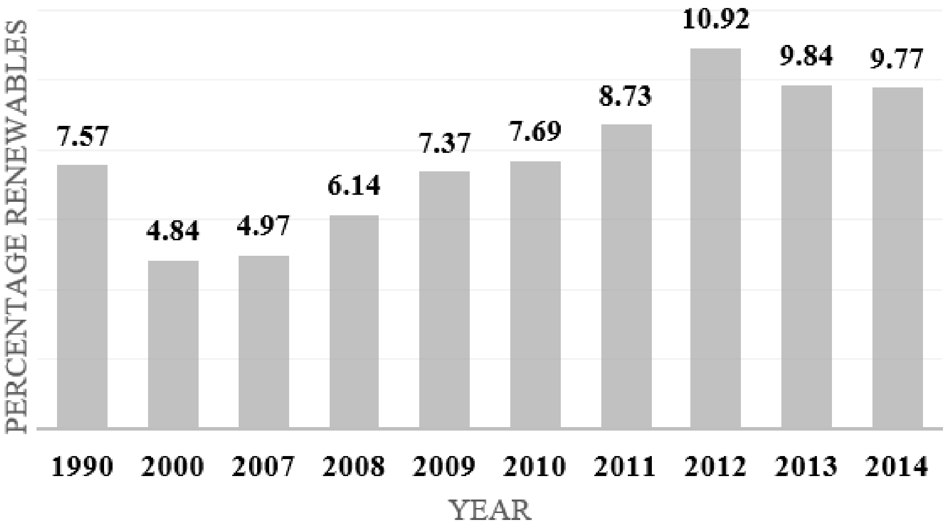


Figure 1. 3 Percentage of Renewable Electricity

A sensitivity analysis on the alternative selected based on a change in weight of the criteria identified will be used to assess the robustness of the results.

The benefits to be derived from our literature review on DG will be used to quantitatively verify their benefits. Finally, to analyse the source alternatives of the energy sector a Levelised Cost of Energy Analysis (LCOE) employing the alternative tool selected will be done.

Chapter 2. Preliminary Studies

2.1 Context of the Study Area

The Island of Jamaica, though only 10,991 km^2 in area and having a mere population of approximately 2.8 million people, is economically and creatively always alive with activity, requiring approximately 644 MW of gross peak demand and a load factor of 74% (*Generation Expansion Plan 2010*, 2010). The peak demand is expected to grow in the future with greater industrial activities. The ever-growing electricity sector within the island is rapidly developing because of globalization and country wide development. The energy needs of the country expand as the Industrial Sector thrive and new technology is introduced. To compensate for the growth of the nation, policy makers must project for the use of electricity and chart a course for generation transmission and distribution of the power needed to satisfy customer demand. The population of Jamaica has been struggling with cost of electricity as most of the electricity produced is done through the combustion of fossil fuel. The price range paid by consumers in Jamaica for electricity has historically reached US $0.39 per kilo watt hour compared to US $0.12 per kilo watt hour in some US state.

In previous years, Jamaica has spent as much as 15% of its GDP on Petroleum imports with high oil price volatility causing electricity rates to more than double within as short a space of time as it did between 2005 and 2011 according to the study done by the World Watch (Makhijani et al., 2013). The price of electricity was identified as a major barrier to Jamaica's economic success. The study went even further to point out that this factor is a major cause of business failure.

The reliability of the electricity supply was identified by business stakeholders as one of the key areas of losses experienced by the industrial customers whenever they experience unscheduled power-cuts in Jamaica. Independent studies have shown that Jamaica has one of the highest rates of both duration and frequency of electricity service interruptions within the Latin American and Caribbean region (Makhijani et al., 2013).

In 2016, the Jamaica Public Service (JPS) transmission reliability interruptions were at 10.92/100km of transmission line, while the industry standard set at 6/100 km per year. JPS would be equivalent to 73 interruptions/1217.6 km of transmission line per year (Jamaica Public Service, 2017). Based on a study conducted by the local utilities regulator, the Office of Utilities Regulation (OUR), the expected growth in demand of 3.8% per annum coupled with expected growth in forced outages and provision for planned grid reliability will invariable be compromised (*Generation Expansion Plan 2010*, 2010).

Losses within the Island power sector has been identified as a major source of revenue reduction by the JPS both from technical and non-technical sources, DG is expected to reduce this substantially. The Planning Institute of Jamaica reported that the rate of transmission and distribution losses worsened from 17.6% in 1998 to 24.7% in 2009 (Makhijani et al., 2013) and has been reported to have grown to 26.5% in 2016. As the implementation of DG is widely known to be able to foster loss reduction; some studies have made assumptions about DG penetration, generation load factor, generation mix, voltage limits network load etc. (Anaya & Pollitt, 2017). Anaya and Pollitt (2017) in their study estimated the losses reduced by DG associated with the different voltage levels connected to the system. The study indicated that as much as 33% of the average distribution losses can be achieved if DG are connected at the lowest system distribution level of 11 kV. Clearly, this speaks volume when one considers that for every DG facility that is installed on the 12-kV distribution network in Jamaica can potentially reduce the average system losses by 8.74%. There exists a significantly large portion of Jamaica's electricity network, which is operating on the 12 kV distribution lines as indicated in Figure 2.1.

The under-utilization of Jamaica's natural resources such as abundant sunshine and high wind potential has been the focal point of many RE protagonists' criticism of current energy policies, stating how these resources will lower electricity rates. The Island has a several highly favourable sources of RE available for electric energy exploitation.

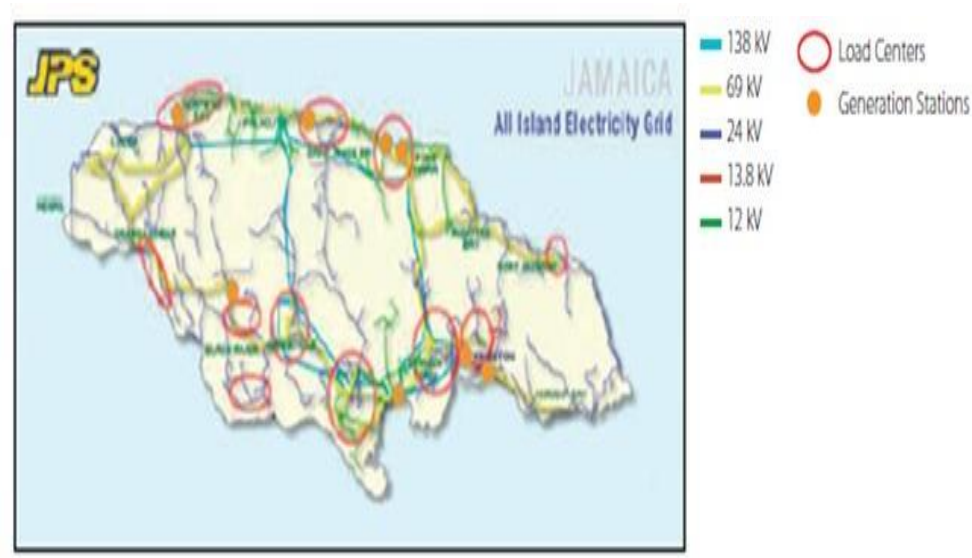


Figure 2. 1 Jamaica Electricity Grid (Makhijani et al., 2013)

Several studies have already been conducted concerning their relative abundance at various locations in the country, so investors willing to invest in the sector need not conduct in-depth study on their feasibility. The prolonged stagnation in the development of the electricity sector can no longer be facilitated because of bureaucratic red tape associated with not what but how the RE Sources identified ought to be exploited.

In November 2012, culminating from the studies done on Jamaica's renewable energy potential, the Office of Utilities Regulation (OUR) released a Request for Proposals (RFP) for up to 115 MW of Renewable generation capacities by 2015 (Makhijani et al., 2013).

The OUR identified the following technologies to be tendered for in the earliest renewable energy generation projects;

- Utility-scale solar PV
- Bagasse
- Waste-to-energy
- Wind
- Hydro

To date, the 115 MW capacity target of renewable energy implementation by 2015 has not been achieved. Though studies have shown that the electricity sector is perfectly poised for adoption of these technologies a stagnated rate of development has been achieved (Barrett et al., 2013).

The truth of the situation is that the lack of true commitment to a renewable energy development goal for the electricity sector has allowed investment to go in the path of least resistance which is to opt for traditional sources of energy. This is evident by the disinterest of investors to even propose to participate in the 115 MW renewable RFP that has been in place since 2012. For those proposals that were tendered before the RFP, they have been slow to come on stream without boost of an attractive renewable energy policy (Makhijani et al., 2013). Resulting from this study, policy makers will bolster the confidence needed to commit or abstain from a renewable policy that should improve the electricity sector. The policy alternatives that were selected as relevant to implement DG within the Island were limited to four types and were selected based on the characteristic of each to align to Jamaica's energy goals and attract available financial support. The ability of policy makers to attract the financial support to initiate these projects depends on their proficiency to attract the group of investors either locally or externally that will be interested in such investment opportunity. When considering investments; venture Capital and private equity investments are the logical and popular sources, which innovative and entrepreneurial firms rely on for financing (Gompers & Lerner, 1999). The study highlighted that the focus of these investors was traditionally fixated on projects such as biotechnology, information and communication technologies. However, in recent years they have switched attention to "clean tech" which primarily focuses on renewable energy technologies. The study determined that this group of investors are particularly adept at accelerating the diffusion of new technologies while assessing traditional or competitive technology to create a profitable niche that is sustainable for the life of a project. The study maintains that through their participation in early stage investment they help to innovate technology and stimulate the entire investment cycle. A decisive aspect of encouraging investment into technologies associated with early stage ventures such as DG is the ability to aid entrepreneurs in the most precarious stage of the innovation chain – "the technology valley of death" (M

Grubb, 2006). As such, this study based on the references gathered seek to use the policy alternatives, which are most attractive to this group of investors. The study by (Bürer & Wüstenhagen, 2009) which highlights the best renewable energy policy for venture capitalists separated the policy types into two broad headings. The study reviewed policies that were either technology -push or market-pull policies and ranked the different policies through survey questionnaire of 60 investment professionals from Europe and North America to determine the effectiveness of various policies in terms stimulating their enthusiasm to actively invest in any such technology. The peculiarity of this study lies in the fact that though DG is in somewhat early stage in terms of adoption it is not as susceptible to the challenges involved with surviving the "the technology valley of death" this is dependent on the energy generation technology employed. The challenge lies within the area where government-funding and self-sustaining funding requirement are needed to make these investments viable and will definitely apply to those investors that seek to employ DG in Jamaica. As such, the literature review on the alternatives that were considered in this study are directly related to those assessed in the study by (Bürer & Wüstenhagen, 2009). The policies described as technology-push policies were characterized as mainly government-funded and geared to increase the amount of technology "supply". While, market-pull policies were described as those presented geared at public procurement or involved production tax credits and would increase the "demand" for new technologies that would provide firms and consumers with economic incentives to apply them. The lucrativeness of these two types of policies in achieving long-term mitigation targets profitably are vehemently argued by researchers contesting opposing views on each (Hoffert et al., 2002, Anderson et al., 2000; Dowlatabadi, 1998; Michael Grubb et al., 1995). Though many experts believe the two types of policies are complementary, (Bürer & Wüstenhagen, 2009) in their study believed that both types of policies are needed or a mix of different policies from both spectrum. Their study empirically tested which policies among the entire set of technology-push or market-pull policies are perceptively more effective at stimulating interest to invest. The approach this study will take is effectively assessing the two broad categories of policies from our literature review, then define the alternatives which shall be assessed by our field of experts. Technology-pull policies included Government demonstration grants, public R&D, grants for small and medium size entities, investment subsidies, Private R&D, Tax breaks for Entrepreneurs, Tax breaks for investors, Incubators, government investment in private venture capital, soft support measures and government venture capital funds, these were used as the policies that mainly influenced the formation of the alternative used in this study called Foreign Direct Investment (F.D.I). A combination of these different policies was used to define FDI which predominantly encourages investors outside the country with a large amount of experience or knowledge on a particular technology to establish investments employing them within the country. The investors with their wealth of knowledge and high technology are given special incentives from the government to operate in the country. The investment opportunity from this policy is so structured to attract substantial investment, employing new but sustainable breakthrough technology.

Market-pull policies were placed under the heading as those that were characterised by Feed-in tariff (F.I.T) and were defined to include strategic deployment and barrier removal policies such as the one the name suggests. Other policies that were selectively combine into this policy type are reduction in fossil fuel subsidies, technology performance standards, Residential and commercial tax credits, renewable fuel standards, CO_2 trading, public procurement, production tax credit, CO_2 tax, renewable portfolio standards, renewable certificate trading, clean development mechanism and joint implementation. Feed-in tariff being the policy with the more imposing characteristic was used define this policy and was presented to our team of experts as one which seek to predominantly increase the amount of renewable energy system in the electricity sector. The RES will therefore be generally quite expensive and more susceptible to varying weather patterns even more so than those employed by FDIs. Thereby establishing the difference between the alternatives considered while still maintaining that a mix of those studied in the literature review exists. It is very important to note that there are only subtle differences between the alternatives due to the large/varied amount of policies that had to be incorporated in the considerations by the experts. However, the nature of each were clearly understood by each participant.

The Analytic Hierarchy Process will be used to determine the best alternative policy tools to encourage DG investment in Jamaica. This includes achieving the goals set out in Jamaica's sustainable energy growth plan, economic development and satisfy the country's commitment to the Paris agreement. From the team of experts surveyed the choice of alternatives considered includes; those already defined as well a rapidly developing tool that is being employed in several states in the United States called rate/revenue decoupling which has been found suitable to accomplish the growth plan goal using DG that incorporates renewable energy or traditional energy source as in the US cases use of natural gas (Brennan, 2010).

Revenue decoupling challenges the view point that price cap regulation is superior to profit guarantees (Mufson & Rein, 2007). Addendum to Jamaica's renewable energy campaign energy efficiency programs have also been a focal point. The energy experts believe that employing revenue decoupling with renewable energy technology will enable the local utility to recover the revenues lost from reductions in sales from the use of DG and removes the disincentive to offer energy efficiency programs to customers (Carter, 2001). It was recommended that a control alternative for a Business as Usual Tool to assess the impact of the current practice as against the other alternative tools proposed be assessed.

The use of DG (DG) has become common knowledge of being a key tool to facilitate improvement/Infrastructural development of the electricity sector at deferred or reduced investment cost. Relying on all the studies previously done on the RE capacity available on the Island and the advantages DG presents the best policy tool to be used to timely implement systems utilizing renewable resources will be determined.

2.2 Renewable Energy Potential

In the last decade, Jamaica has embarked on several fact-finding projects to assess/chart a road for development of the local energy sector. The first comprehensive long-term energy plan for the Island was published in 2009 and established a set of renewable electricity generation, energy efficiency and greenhouse gas emissions targets by 2030. The electricity sector today is dominated by one major player the Jamaica Public Service Company Limited (JPS) who has the license to solely transmit and distribute electricity through 2027, under the Electric Lighting Act of 1890. They however, supply power amounting to 57% of the energy needs from their own generation fleet and the remaining 43% purchased from independent power producers. The energy mix within the island highlights the heavy dependence on fossil fuel as the electricity is generated as in the figure 2.2 below.

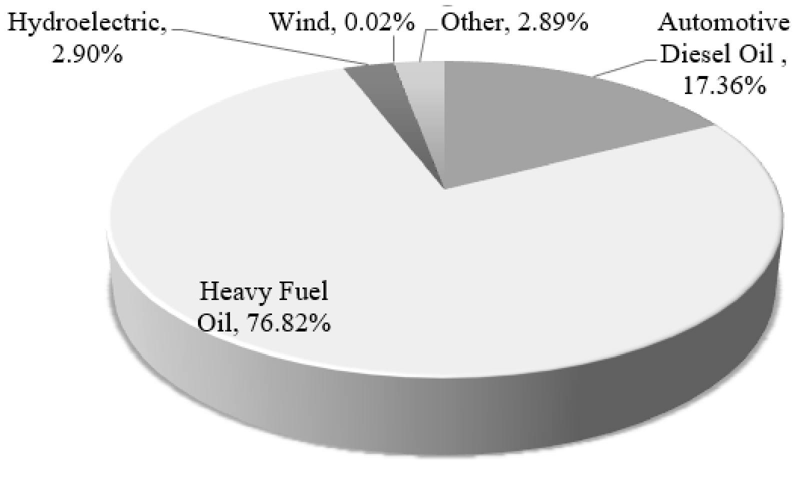


Figure 2. 2 Generation Energy mix

There is no doubt that energy is vital to growth and socio-economic development of the nation. The domestic energy market in Jamaica is highly susceptible to the worlds energy market disruption due to the fact that Jamaica imports > 90% of its energy needs. The studies that have been done present in summary the Jamaica's renewable energy potential as the following (Energy Transition Initiative Islands, 2015b):

- Wind; High Potential (>1000 MW), Installed Capacity: 41.7 MW
- Hydropower; High Potential (>80 MW), Installed Capacity: 30 MW
- Geothermal; Low Potential, Installed Capacity: 0 MW
- Ocean; Unknown Potential, Installed Capacity: 0 MW
- Biomass; High Potential, Installed Capacity: 0 MW
- Solar; High Potential, Installed Capacity: 23 MW

The potential for Geothermal and Ocean, though not given, is present as Jamaica is famous for several hot springs and mineral baths.

2.2.1 Hydropower

The Ministry of Science Energy and Technology has documented several studies on renewable Hydro Potential which has been spearheaded by the government owned Petroleum Corporation of Jamaica (PCJ). Though these hydro projects had previously been assessed, through funding from the World Bank they would be reassessed. If the projects are found viable at the pre-feasible level, they would be upgraded for feasibility study and proposed for small run of river hydro.

A modest generation expansion of 10 – 12 MW is expected from these within the near future granted government legislation uphold PCJ's development of the projects (Barrett et al., 2013). Jamaica is dependent on an up-to-date small hydro resource and feasibility assessment to fully utilize these resources.

Over the years Jamaica has increased hydroelectric capacity to approximately 30 MW (Esaparrago, 2016). However, from studies done up to 2010 (Barrett et al., 2013), a significant potential capacity exists which remains untapped as is presented in Tables 2.1 & 2.2 below

Table 2. 1 Installed Hydropower plants in Jamaica

Hydroelectric Plant	Installed Capacity
Roaring River	4.05
Upper White River	3.19
Lower White River	4.75
Rio Bueno-A	2.5
Rio Bueno-B	1.1
Magotty	6.3
Constant Spring	0.7
Total	22.59

Table 2. 2 Hydropower potential in Jamaica

Hydroelectric Scheme	Potential Capacity (MW)
Back Rio Grande (BRG)	28
Great River	8
Green River	1.4
Laughlands Great River	2
Martha Brae River	4.8
Morgan's River	2.3
Negro River	1
Rio Cobre	1
Spanish River	2.5
Wild Cane River	2.5
Yallahs River	2.6

2.2.2 Solar Potential

Jamaica’s solar potential cannot be over emphasized, being a tropical island in the Caribbean the solar irradiance across the entire Island is ideal for solar energy exploitation. The consistency of solar irradiation across the Island is relatively persistent throughout the year regardless of season (even in winter). The global horizontal irradiance (GHI) is a measure of the amount of power per cubic area that can be harnessed from the sun, studies have shown Jamaica ranges from 5 to 7 kWh/m^2 per day. Specific locations in the country reach up to $8kWh/m^2/day$ and compared with places such as Arizona in the U.S which is famed for its solar potential has only an average GHI of 5.7 kWh/m^2 (Makhijani et al.,2013). Figure 2.3 shows the average yearly solar Global Information Systems (GIS) irradiation of the Island of Jamaica. Solar technology studied for use in Jamaica represent those technologies that are sufficiently mature and includes not only solar panel which converts the energy from the sun directly to electricity. The technology used in concentrated solar power is also extended to Jamaica for use but the technology most suited to be used is the modular photovoltaic (PV) arrangement. The efficiency of these PV flat plate cell commonly achieves 12% and increases with technology improvement (Barrett et al., 2013).

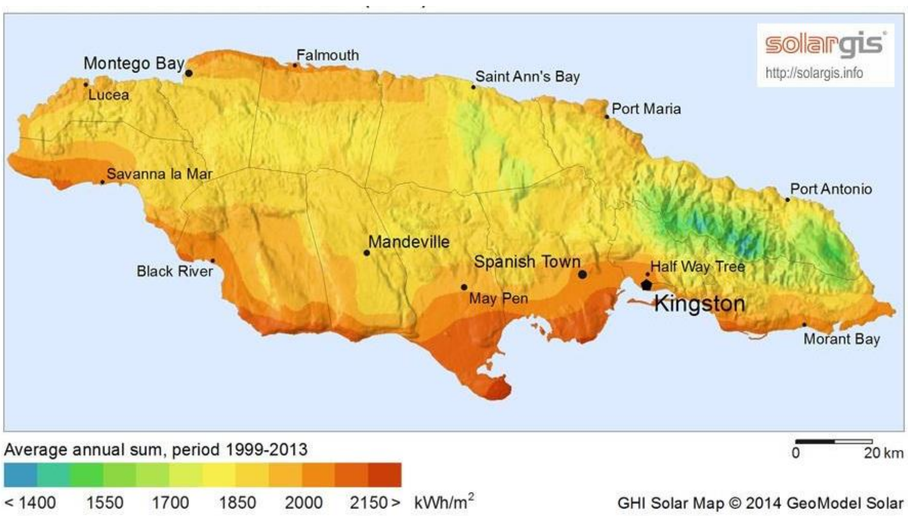


Figure 2. 3 Average yearly Solar Information in Jamaica (Map, 2014)

2.2.3 Biomass Potential

The prospect of incorporating biomass into the mix of exploitable renewable energy is heavily but not exhaustively hinged on the Sugar Industry. The bagasse produced as a by-product of the sugar refining process is the chief contributor of Biomass fuel.

The incorporation of the sugar refinery facilities as the sole provider of biomass is therefore dependent on the amount of sugar cane processed. The Island has 6 sugar processing facilities that are capable of producing energy from Biomass to be used in a auxiliary capacity to support the process and the excess may be exported to the public in the form of electricity.

The conditions of these sugar-processing facilities are now in a state of disrepair and their cogeneration facility has been abandoned due to inefficiency. However, these facilities based on their throughput of cane processing could efficiently produce enough energy for auxiliary supply and exporting to the grid.

The details are given in Table 2.3 below (Barrett et al., 2013). The aggregate installed capacity for these bagasse cogeneration facilities would be approximately 90 MW.

Table 2. 3 Co-Generation Potential of Sugar Refineries

Sugar Refinery	Co-Gen Capacity (MW)
Golden Grove	5.3
Everglades	3.1
Appleton	15.7
Worthy Park	6.5
Monymusk	9.8
Frome	18
Total	**58.4**

2.2.4 Municipal Solid Waste to Energy Potential

The potential for this form of energy has been assessed extensively by the Ministry of Science Energy and Technology and the use of different types of technologies has been assessed for conversion of different forms of waste. This study draws from several reports done the data regarding Jamaica’s waste content and collection for waste-to energy incineration facilities, Biogas Potential and Sewage energy potential.

Direct Waste-to-Energy Incineration

Previous assessment done determined that Jamaica Generates 1.5 million tons of waste annually having a composition of 69% organic matter see Figure 2.4.

The previous studies indicated that a typical WTE plant generates approximately 550 kWh per ton of waste (Barrett et al., 2013).

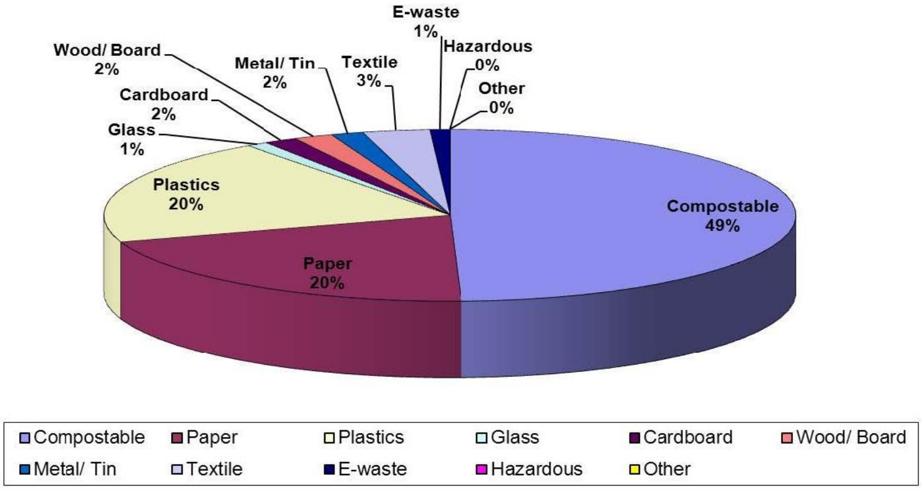


Figure 2. 4 Waste composition MPM Watershed 2010

Though there are currently no waste-to-energy plants in Jamaica, plans were made to construct two WTE with a total capacity of 65 MW at the Riverton dump. This facility would convert a little over half the country's annual waste per year to energy, just about 750,000 tons.

However, the winning bidder for the development of the facility went bankrupt (Makhijani et al., 2013).

The technical feasibility of a municipal solid waste (MSW) WTE facility in the Riverton waste disposal site in St. Catherine along with one at Retirement in St. James has been a possibility since 2010 when the study by (Barrett et al.,

2013) was conducted. The report however listed challenges such as current waste management regulation, the fiscal situation of the Government, the required growth rate of tipping fees or a feed-in tariff of approximately $0.169/kWh for Riverton and $0.167/kWh for Retirement. However, Jamaica does not have a feed-in tariff and the current avoided fuel cost plus 15% premium was insufficient at the time of the study.

The possible MSW WTE possibilities listed in the study were:

- Riverton, St. Catherine; 40-50 MW MSW coal-cofired
- Retirement, St. James; 20-25 MW MSW coal-cofired

Landfill Biogas

Compared to the electricity generation of a MSW WTE power facility the generation of electricity from biogas produced in landfills is a cleaner way to generate WTE power.

For a viable landfill gas operation, a landfill gas flow of 1,000 cubic meters per hour for at least 20 years is the typical minimum level. From the composition of the waste generated in Jamaica given in Figure 2.3, biogas electricity production and cogeneration are viable at the Riverton site. Estimating with the modest amount of 60% organic matter and anticipating 50% methane capture the reported annual waste stream at Riverton would yield 3,904 m^3 of methane (Makhijani et al., 2013).

The projected flow would be more than sufficient for cost- competitive generation.

Sewage biogas potential

The majority of Jamaica sewage compounds, approximately 150, is in huge disrepair and designed such that only 30% of domestic wastewater that is processed is minimally treated and released into the open sea or land and 70% goes untreated. Studies have shown that a sewage to biogas facility at the central wastewater disposal site in Kingston could deliver 840 – 6,300 MWh of surplus electricity to the grid.

2.2.5 Wind Power Potential

The wind potential in Jamaica was found to be overall very strong, from initial assessment done before installation of Jamaica first utility size facility the Wigton Wind Farm; several regions exhibit commercial size wind energy development. The initial assessment done by Wigton realized 15 locations that had average wind speeds in excess of 6 m/s detailed in Table 2.4.

The research group 3TIER in their assessment identified three surveyed zones that have stronger wind power and more than ideal average capacity factor from 50% to 59.6% which are well above the 30% threshold for suitable commercial wind development. The zones identified in the 3TIER assessment have a mean wind speed of 9.76 m/s and exhibit even better wind potential than the 15 identified in the first Wigton assessment.

Table 2. 4 Preliminary Average Windspeed (Makhijani et al., 2013)

Station	Average Wind Speeds by Site, Wigton Assessment Projected Average Wind Speed at 80 Meters (m/sec)
Winchester	9.7
Rose Hill	8.5
Top Lincoln	8.3
Kemps Hill	8.2
Fair Mountain	7.6
Rio Bueno	7.5
Juan de Bolas	7.0
Ibernia	6.8
Bowden	6.7
Pratville	6.7
Bengal	6.2
Mt. Oliphant	5.8
Groove Town	5.3
Oracabessa	5.2
Mount Dawson	5.0
Highgate	4.8
Albion	4.6
Victoria Town	4.2

The later assessment by 3TIER identified three zones which have even better prospects than those identified by Wigton and still remain undeveloped despite the success achieved by the Wigton utility now in operation illustrated in Table 2.5 (Makhijani et al., 2013). The three sites of interest identified in the 3Tier assessment are Portland Parish, Retrieve and an offshore location. The three sites assessed were analyzed to meet the total Generation demand for the Island of Jamaica. Assuming a 15% loss to account for slow wind speed due to interruption from other turbine, electrical losses and that 20 wind turbines will be installed in a wind farm occupying one square kilometer. Table 2.6 shows the ability for each of the sites identified to meet a total Generation demand of approximately 960 MW peak (Makhijani et al., 2013).

Table 2. 5 Average 3TIER Wind Assessment

Zone	**Average Wind Speed at 80 Meters (m/sec)**	**Average Gross Capacity Factor at 80 Meters (%)**
Portland Parish	9.76	59.6
Retrieve	8.60	50.0
Offshore	8.41	53.2

Table 2. 6 Wind Potential to Meet Generation Demand

Site	Average Net Capacity Factor	Average Annual Generation per 3 MW Turbine (GWh)	Annual Generation per Square Kilometre	Share of 2011 Generation from One-Square-Kilometre (60 MW) Wind Farm (%)	Number of Wind Farms Needed to Meet Total Generation
Portland Parish	50.6	13.3	266	6.4	16
Retrieve	42.5	11.2	223	5.4	19
Offshore	45.2	11.9	238	5.7	18

2.3 Distributed Generation Potential

2.3.1 Overview

The world has grown so accustomed to current technology they become oblivious to the fact of what made current technology popular and all other technologies inferior. Although the dominant technology may not necessarily be the only technology, what man has grown to love displaces what they have grown to deem less favourable. In 1828 the invention of the first model electric vehicle was made, attributed to various people. However, in 1832 Robert Anderson from Scotland invented the first electric carriage (Everyday Mysteries, 2017). The first practical electric car didn't come around till 1859 with the invention of the lead-acid battery by a French physicist Gaston Plante and Camille Alphonse Faure improving the design (Development of the Motor Car and Bicycle, 2003).

In 1885/86 the first Gasoline powered internal combustion automobile was invented by Karl Friedrich Benz (Everyday Mysteries, 2017). Today people tend to believe electric cars are new technology when they have been around before the internal combustion automobiles as we now know it. This is also the case when one considers how electricity is now generated, transmitted and distributed.

In the early years fierce competition between alternating current and DC power transmission and distribution saw the prevalent direct current technology being less favourable to alternating current. The low cost alternating current generator to transformer then transmitting at high voltage set up for one central generating facility adopted by George Westinghouse was much more economical compared to the distributed generating DC type operation proposed by Thomas Edison. However, as years progress the advantages of distributed generation on the AC and DC circuit has improved such that now more than ever the use of DG even with a large centralized network is advantageous to the growth of future electricity systems.

As a result, utility power systems that have dominated the world since that fierce technological war between AC and DC transmission tend to be large hierarchical systems which have a central generating facility. Typically, thermal plants using fossil fuels applying integrated transmission and distribution systems to serve customers.

This traditionally large centralised model contrasts with the alternate which was initially promoted by Edison and his DC system that because of the low voltage could not be transmitted over long distances. Hence, in early DC based systems the generating facility had to be close to the load in order to minimise the transmission and distribution distance.

In recent years technological innovations and a changing economic and regulatory environment has enhanced the popularity of DG which exhibits a universe of benefits to be derived. These benefits include;

- Load reduction from the centralised network and avoided energy costs
- Demand reduction and avoided capacity costs
- Avoided compliance costs in counties with strict environmental codes
- Avoided Ancillary services from providing spinning reserves etc.
- Electricity market liberalization allowing independent generation
- Increased demand for high reliability, low costs and price stable electricity supply
- Development in DG technologies to integrate Internet of things and smart grid technology.

The incorporation of all these attributes into current electricity systems are routinely desired by policy makers and as such the facilitation of distributed energy has been gaining tremendous popularity. This study has used an extensive literature review to compile a library of knowledge on the different studies done with regards to the benefits, disadvantages and uncertainties that remain with regards to the use of DG.

2.3.2 Distributed Generation Existing Studies

El-Khattam et al. (2004) introduced a model that effectively through a cost-benefit analysis determined the optimal sizing and siting decision for DG capacity investment planning. The study manipulated two scenarios of DG under competitive electricity market auction and fixed bilateral contract scenarios to arrive at the optimal feasible DG capacity to serve peak demand. The study highlighted that DG at the distribution network level is transforming the network from being a passive one to being active. DG is able to play a huge role in the distribution company's structure design and up gradation. DG is able to curtail the high cost of unserved power and very feasible alternative for new capacity in a competitive electricity market.

The reliability report (Reliability, 2007) commissioned by the U.S Department of Energy analysed several case studies done in the U.S in order to evaluate the benefits of DG. The direct impact on electric utilities brought by DG, benefits electric systems in terms of their influence on electric system planning and operations. Benefits arise due to their impact on; peak load reduction, ancillary services provision and improvements in quality of supply. Importantly, citing the existence of greater benefits for customer-owned DG compared to utility-owned DG this due to customer incentive benefits given to reduce electricity consumption during peak periods.

Harrison (Harrison et al., 2007), focusing on DG in UK the paper, explored the arrangement related to the connection of DG to the electricity grid, highlighting the DG incentives being offered as well as losses incentives and network deferral benefits. The study introduced a multi-objective optimal power flow tool that determined the optimal DG to be connected at different location and assessed the benefits gained by the distribution network operator and generators/developers with and without network deferral benefits. The study found that the optimal capacity and associated benefits vary with network deferral benefits and are quite similar without them.

Abou El-Ela et al. (2010) targeting the Egyptian network in the West Delta sub-transmission section the study, presented an optimal approach of estimating the sizing and siting of DG. The approach would optimize several objective functions including; improvements in the voltage profile, increases in spinning reserves and power flow reduction in critical lines as well as line-loss reduction. Zangiabadi et al. (2011), using an uncertainty study based on the Monte Carlo method explored the economics of customer owned DG units that have different load requirements (residential, industrial/commercial). The study assessed the effect of different electricity price scenarios on economics and employed a sensitivity analysis to test the robustness of the price varying results. An award payment policy above electricity market price was recommended for DG operators which would be greater during peak hours. This payment would benefit DG owners who generate during peak hours and reduce peak loads advantageous to the distribution network operator.

The study done by Amor et al. (2012) assessed the economic value of Renewable DG concentrating on wind and solar technologies for the province of Quebec in Canada. Economic value was defined as the difference between the life cycle cost and the average hourly market price of four jurisdictions adjacent to Quebec. Interestingly the studied produced results that suggested that DG has no economic benefits using the renewable energy sources studied even with an inflated carbon tax.

Pruitt et al. (2013) analysed and determined the economic viability of a combined heat and power (CHP) distributed generation technology. This was accomplished by comparing the total operational savings afforded by the specific distributed technology to its total installed cost. Using a comparison of eight scenarios the researchers were able to analyse the energy, emissions, operations and maintenance and peak demand savings provided by the DG system. The study determined that economic viability of the CHP system is dependent on a combination of building type, energy market and system design and dispatch within a given scenario.

The New York Public Service Commission (Woolf et al., 2014) established the benefits of DG and how they have been developed with increased energy efficiency and technology initiatives. The study included evaluating DG ability to provide low-cost, reliable and safe electricity service.

In the study by Yazdanie et al. (2016) DG and storage technology was evaluated to determine the performance and policy impacts in a rural setting in Switzerland. The study used a cost optimization modelling approach to determine the possible role of DG in the future energy system planning. The study determined that DG and storage technology was beneficial to the community studied in reducing its electricity grid usage.

Addressing the problem of expensive grid extension cost to electrification rural customers in India Amutha & Rajini (2016) explored the option of using independent micro grid DG with renewable energy alternative and estimated from load appraisals in a remote village the cost of electrification simulated using the HOMER software. The software demonstrated that a hybrid combination of wind/solar/hydro/battery is a techno-economically, environmentally and a cost efficiently viable alternative.

In the research study of Rouhani et al. (2016) an estimation of the cost and benefits of manipulating the 2020 California Renewable Portfolio Standard (RPS) target from 33% on electricity price, greenhouse gas (GHG) emissions, criteria pollutant emissions, electricity generation mix, the labor market, renewable investment decisions and social welfare was done. The study determined that the average 2020 price of electricity increases as the RPS targets rises and that the 33% RPS mandated by California would not provide the best cost benefit values among the possible targets or maximize the net social benefit objective.

The objective of the paper written by Mokgonyana et al. (2017) was essentially to provide a planning model for power distribution companies to maximize profit by determining the optimal network location and capacity for renewable energy source generating facilities. The categorization of these facilities as either Independent Power Producers or self-generators is defined based on the fact that they are not associated with the distribution network operator (DNO) and as independent entities are obliged to operate by some regulation that must be adhered to by the DNO. The study therefore was able to evaluate network capacity at the times when the distribution company (DISCO) must allow them access to provide power; while minimizing the DNO revenue erosion and cost of excess energy. The model proposed was superior as it outperforms the standard model in satisfying the binding technical constraints as well as maximizing profits. The relevance of this study was demonstrated in the identification of the relevance in determining the influence of DG in revenue losses that may be faced by JPS the sole transmission and distribution company in Jamaica and how this may be alleviated.

HA et al. (2017) focused on the optimal allocation of DG that considers the objective function of improving energy efficiency, power quality, reliability and security. The study determined how to achieve this objective through the use of a suitable optimization algorithm that was formulated from a comprehensive review on the optimal allocation of distributed generators for differing objectives, constraints and algorithms. The study showed how this technique from its optimization function also played an important role in improving the accuracy and efficiency of the desired objectives.

Smart connection use in Great Britain was explored by Anaya & Pollitt (2017) for applicative use with DG. The study explored and quantified the benefits of connecting with and without the smart connection. The study determined that the smart interruptible connection scenario is preferred option across all the scenarios in terms of acquiring a system which effected a positive net present value (NPV)/ Megawatt (MW).

2.4 Multi-Criteria Decision Analysis as Method

The selection of policies to affect an entire population is a complex process and unlike everyday problems that may be handled intuitively decision involving nation building often becomes too large and involves many often-conflicting objectives. In situations like this the desire for a formal procedure to take into account a wide range of parameters to make decision-making clear, fair and prudent to manage costly resources is of absolute necessity (Shetwan, Badi, & Aljamel, 2017).

The development of Multi-criteria Decision Analysis (MCDA) methods are effective in addressing the formal procedure needed to solve these decision-making dilemmas (Ishizaka & Nemery, 2013). The discipline involved in MCDA allows the decision maker a unique support system that sequentially applies techniques for finding a compromise solution to decipher the decision process. The use of MCDA should not be mistaken to be an automatable method that lead to the same solution for every decision maker at the centre of a process but incorporates subjective information which leads to the popular compromise solution (Ishizaka & Nemery, 2013). MCDA techniques have evolved with more academic publications involving their use in different types of problems and software availability containing method computations. In recent years specified tools and applications have been developed and used in a variety of implementations for decision making, this has made MCDA more accessible and has broadly encouraged use of the method in a wide variety of disciplines. The nature of a decision is complex and (Roy, 1981) defines four main types of decision problems;

- The Choice Problem; this involves the single best option out of many alternatives
- The Sorting Problem; which is aimed at regrouping problems of similar behaviour
- The Description Problem; Describing options and their consequence
- The Ranking Problem; it orders options from best to worse as a result of pairwise comparisons/scores

From this pool of decision problems, researchers have developed several methods to help policy makers to find a close to perfect way to solve a decision problem.

As the discipline within MCDA grows and research expands into its use and improvement additional problem types are added to elicit the preference parameters for a specific MCDA method. These decision problems grow in dynamism as research propagate in the field, frequently combining several of the problems listed above. Variations including elimination problem proposed by (Costa, 1996) which is a particular category of sorting problem or the Design problem by (Keeney & Keeney, 2009) which is based on response focused goal identification and creation to fulfil the objectives of the decision maker. Researchers have determined that one way for choosing the right method regardless of the chosen method limitations, particularities and perspectives; is to look at the required input information or data available commensurate of the method chosen and details associated with the expected outcomes (Guitouni et al., 1998). The resulting Table 2.7, summarized by Ishizaka & Nemery (2013), provides a summary of the work developed by researchers to effectively decide on the MCDA method chosen dependant on the required inputs and ranking each method by input effort.

The scope of this study leads one to a ranking problem decision analysis, from our goal to determine the best policy tool for DG adoption the Analytical Hierarchy Process is chosen as highlighted in Table 2.7, due to the nature of the decision that is to be made. Additionally, the output being a ranking problem and nature of the input variable being a pair wise comparison also influenced its selection. The nature of the input and output variable makes it possible for a cadre of questions of varying technical perplexity to be employed in a survey completed by experts of multiple disciplines and qualification to arrive at a multi-disciplined required decision. The use of the AHP is of particular value since the decision will be made by a group of experts of varying technical background as stated before, so a numerical judgement is not required as in other decision-making tools but rather a relative verbal appreciation, more familiar to daily life is sufficient. The AHP requires essentially four steps to obtain the ranking of alternatives (Ishizaka & Nemery, 2013);

i. Problem structuring
ii. Priority calculation from pairwise comparisons
iii. Consistency Check
iv. Sensitivity Analysis to confirm robustness of results

Significant to MCDA methods, the problem is structured according to the Hierarchy where the goal or central decision to be made is the apical element. Subsequent levels at second and third in the hierarchy is reserved for the criteria and alternatives respectively.

Central to the objective of AHP are priorities/weights, which describe the preference with respect to the subject variable, being defined, in AHP there are three types of priorities; (Ishizaka & Nemery, 2013)

i. Criteria priorities related to the importance of each criterion relative to the overall goal,
ii. Local alternative priorities which are criterion specific and
iii. Global alternative priorities, which rank alternatives with respect to all criteria and produces essentially the goal.

The criteria and local alternatives priorities have identical techniques for measurement that uses pairwise comparison of a criterion to another criterion as well as pairwise comparison of an alternative to another alternative with respect to a specific criterion. The establishment of criteria central to the goal development is selected from literature review and expert recommendation. The options are then ordered from best to worst by means of scores and pairwise comparison and then alternatives formulated having the criteria decided upon to achieve the goal.

Table 2. 7 Required Inputs for MCDA ranking choice method

Inputs	Effort Input	MCDA Method	Output
Utility Function	Very HIGH	MAUT	Complete ranking with scores
Pairwise comparison on a ratio scale	↑	ANP	Complete ranking with scores
Pairwise comparison on a ratio scale		AHP	Complete ranking with scores
Pairwise comparison on an interval scale		MACBETH	Complete ranking with scores
Indifference preference, veto		ELECTRE	Partial and complete ranking
Indifference and preference thresholds		PROMETHEE	Pairwise preference degrees and scores
Ideal Option and constraints		Goal Programming	Feasible solution with deviation and scores
Ideal and anti-ideal option	↓	TOPSIS	Complete ranking with closeness score
No subjective inputs required	Very LOW	EA	Partial ranking with effectiveness score

2.4.1 MCDA Existing Studies

Beccali et al. (1998) in their study applied a methodology from the ELECTRE methods family that employs the ranking problem decision analysis tool to organise and synthesize variables from judgement-based assessment. Their study demonstrated the versatility of MCDA techniques to synthesise variables critical to a decision maker, much like the tools needed in creation of a policy as it will be done in this study. However, their research was limited to only assessing the differences between MCDA techniques and that employing fuzzy logic with no real decision-making implication. Some studies, having a more practical application such as the research conducted by Xiaohua & Zhenmin (2002), used AHP in an appraisal of the rural energy sustainable development goal to accomplish the calculation of a set of weights for indices used to describe parameters essential to the energy sector. The use of AHP by these researchers for assessment of a development goal links the use of MCDA techniques to assessments, which could include existing policies. However, the study fails to extend these goals to any policy implications that extend to future development.

In the study conducted by Aras et al., (2004), centred on the construction of a wind observation station locations, the goal was related to the use AHP to determine the point of greatest convenience of installation. In this application we realise the usefulness of MCDA particularly AHP in the selection of a scope or study point of interest. Similarly, the present research will and creditably go further to assess the scopes' benefits from the decision process. The durable effects from the decision analysis was sadly absent in the study previously described. Nigim et al. (2004), focusing on the need to establish pre-feasibility ranking of local renewable energy sources; applied AHP in tandem with sequential interactive model for urban sustainability to analyse the resources available. Equivalently, this study will use AHP to assess and aid the development of criteria necessary to develop sustainable goals going pass the policy development pre-feasibility stage.

As a resource bank for MCDA, Pohekar & Ramachandran (2004) studied the energy-planning field to produce a catalogue focusing on sustainable energy planning. The researchers reviewed over 90 papers that used multi-criteria decision making to achieve their desired objective; sustainability being a most important virtue of energy development. Erdoğmuş et al. (2006) determined the most suitable energy resource for residential heating using the Analytic Network Process (ANP) to analyse the ranking problem involved in creating a sustained energy resource from mixed sources. Unlike the study done by Løken (2007) that focused on the decision-making challenges involved in energy planning exhibiting conflicting objectives, their study failed to prioritise alternative solutions. Løken, however evaluated alternative strategies in the field of energy supply and performed analyses based on three main categories: value measurement model e.g. multi attribute theory; goal, aspiration, and reference level models e.g. goal programming; and outranking models e.g. ELECTRE and PROMETHE. Their study however focused on a wide range or all-encompassing list of goals/benefits within a result set much like the study of Jaber et al. (2008). They analysed the ubiquitous residential, space and water heating option in Jordan that uses predominantly either LPG or Kerosene to assess their favourability. The research used fuzzy sets and AHP multi-criteria analysis; considering the benefits and cost of each heating systems as well as determining the overall benefit-to-cost ratio. In studies which produce simple value benefits the choice is clear by way of alternative selection however this study increments the complication when lowest cost or highest value is not a common unit for alternative selection.

A study transcending this deficiency was presented by Carrion et al. (2008) that surveyed the selection of optimal sites for the grid connect renewable energy technologies such as photovoltaic power plants with an assessment using a decision-support system based on AHP in Europe. Incorporating multicriteria analysis methods involving AHP with Geographical Information Systems (GIS) technology the study took into account criteria such as orography, location, climate features, environmental and legal aspects regarding protected areas of the land to achieve the goal. The study however failed to recognise policy impacts of the decision on long-term development of the study area. In many studies much like that within the article from Mirza et al. (2009) that outlined the barriers to renewable energy development in Pakistan and the measures used to address them, do so without establishing a connection between past decisions and future plans. The study by Lee et al. (2009) somewhat addressed the deficiency and selected a suitable wind farm based on identifying and developing critical success criteria. From the success criteria developed the benefits, opportunities, costs, and risks are proposed and by using expert opinion a performance ranking of the wind farms is generated. This addresses the deficiency by establishing a link between the future success to the alternative performance ranking.

An even stronger example is in the study by Heo et al. (2010), motivated by Koreas goal to fulfil a target of 11% RES in the overall primary mix by 2030 sought to identify the criteria and factors related to the dissemination of an effective renewable energy technology program by using fuzzy AHP method. The study identified five criteria and seventeen factors related to achieving the goal and from weights estimation derived four major conclusions. The five criteria: technological, market-related, economic, environmental and policy related were used to determine the importance of economic feasibility, advancement of target technology in the global market and resulted in the identification of a disagreement between policy maker and specialist group with regards to the dissemination program. The study exhibited profoundness in linking the results to future goals and past decisions yet failed to recognise the subjectivity of the MCDA results to change by conducting a sensitivity analysis on their results.

Chalúpková & Franek, (2014) in their study emphasised on the spontaneous, time consuming, detailed information reliant and often conflicting aspects of decision making that can be addressed using the AHP multi-criteria decision-making models to select the optimal form of asset acquisition. The study explored four alternatives of consumer loan and capital lease to find the optimal loan and assess the sensitivity of the second most favoured option. They demonstrated the robustness of their AHP results with a sensitivity analysis which could, from their study, be extended and used to forecast the future impact of their asset acquisition investment decision, this they however failed to perform.

Applying the same technique to the energy industry Shetwan et al. (2017) suggested that developing countries like Libya has overly limited opportunities to recover from investment in power generation technology that do not adequately perform to create nation building. The study through AHP multi-criteria decision analysis aimed to determine the best suitable technology for Libya. Assessing four main criteria: economic, environmental, technical and social; six alternative power generation technology were assessed with the aim of fulfilling those criteria and a sensitivity analysis performed on the alternative. The paper only failed to link criteria selection and alternative decision to sustainable development of Libya and policy implication from criteria weight and alternative selection.

The greater majority of the papers reviewed and validated the suitability of the use of Multi-Criteria Decision Analysis within the energy technology field, in particular relating to the use of renewable energy technology compared to fossil fuel/traditional technology to address energy sector shortfalls. Applying the MCDA method to determine qualitatively: criteria, factors or alternatives that are cognizant to achieving a specific research goal. In the case of this study; what is the policy to best disseminate the use of DG, and the policy implication of doing so.

The application of MCDA in the policy selection for DG was best demonstrated in the papers from the list of reviewed materials that were geared at disseminating RET in South Korea and Libya. As a result, these papers contributed greatest to criteria selection summarised in the table 2.8 below. Their direct contribution to the methodology employed as well as their qualitative extent is evident in our criteria selection. Their contribution to policy implication was also noteworthy.

Table 2. 8 Major Contributing Papers to Criteria Selection

Research Paper	**Relevance to Criteria Selection**	**Application to Research**
(Heo et al., 2010): Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP	Established the criteria and factors needed to establish an effective dissemination program to include renewable energy technology into Korea's Generation mix	Identified five criteria, which were used to formulate criteria needed for policy development in the Jamaica's energy policy scenario; through written consultation with Governmental Energy ministries and Organisations.
(*Renewable Energy Innovation Policy: Success Criteria and Strategies*, 2013)	Paper analyses how to create policies for Renewable Energy Technology Innovation	Identified six energy development goals that either alone or in combination was used to shape energy development pathways, which experts choose from as criteria needed in Jamaica.
(Shetwan et al., 2017): Using Analytical Hierarchy Process to Select the Best Power Generation Technology in Libya	Determined the best suitable energy generation technology from four main criteria that took into consideration performances of six technologies of power generation including renewable and traditional energy sources.	Identified four criteria which based on Jamaica's Energy Development growth plan is of viable interest; through written consultation with University, Banking and Finance and Petroleum Industry were used Identify and assess suitable criteria.

2.4.2 Criteria Selection

The use of experts was employed from corresponding Governmental Organisations in Jamaica. The institutions responsible for environmental affairs and natural resource protection, the National Environmental and Protection Agency (NEPA) in Jamaica and the Natural Resources and Conservation Authority (NRCA), were contacted. Policy makers in the Ministry of Science, Energy and Technology, the Office of Utilities Regulation as well as a specialist team in the local power company comprising of Engineers, Lawyers, Economists, Architects, Urban and Regional planners in the Business Development Team of the Jamaica Public Service also took part in this study. Representatives from the University of Technology (UTECH), the University of the West Indies (UWI) as well as the Caribbean Maritime Institute (CMI) participated in the survey. The draft survey as well as online discussions were conducted and reviewed from May to August of 2017 with the Final Survey being completed by October 2017 of the 32 experts surveyed 21 responded.

Five criteria were selected: environmental, infrastructure, profitability, rates and reliability, which from the criteria used in the studies indicated in literature review and discussion with the experts in Jamaica, were decided upon. These criteria were selected based on multiple discussions with the expert stakeholders that identified from the criteria used for optimal energy systems that the policy needed for DG must encompass all those factors in a broader sense within a policy. The description of the criteria relevant to the formulation of a DG dissemination policy were therefore defined as such;

Environment

This criterion describes the environmentally friendly nature of the policy. The criterion based on selection was designed such that emissions from whatever energy source is selected for DG must be able to reduce greenhouse gases and other pollutants. The land requirement or natural resources of water, air etc. from the option selected must not be significantly high to impose negatively on the environment adhering to the environmental laws and regulations of the country. Factors such as noise Abatement River and floodway encroachment and even the preservation of archaeological and historical sites must also be restricted to a minimum to none at all.

Infrastructure

Infrastructural development criterion was defined to include several factors identified from the previous studies selected, policy definition with regards to this criterion detailed how well the policy is designed be able to meet supply capability of the system. The raw materials needed to support the functioning of the DG system how well does the policy facilitate their procurement and use.

The ability of this policy to reduce traditional operation and maintenance cost by implementing systems that support growth of the electricity sector to improve efficiency, power transmission and the size and amount of power delivered safely and effectively to the user.

Profitability

The policy definition within this criterion would be focused primarily on the ability of the policy to encourage investment appeal based on not only financial allure but on the ability to grow several social elements within the sector and by extension the country. The longevity of the selected DG source must have supported by the policy, this criterion will inherently determine how well this policy effect enterprises that are participating in the program to last in the market and hence create long lasting participation of the selected source in the sector. Social effects such as job creation based on the support of the policy to proliferate growth in the selected DG because of its inherent capacity to creates profits will be assessed by this criterion.

Rates

The reduction in electricity rates is one of the key factors that is required by a policy for the realisation of the sustainable energy development goal of Jamaica. The policy criterion of rates will be focused on its ability to reduce rates through whatever technology the distributed generator employs. The dependence on the key rate driver of fossil fuel price instability will be influenced by this criterion not withstanding if the fossil fuels are able to more cheaply deliver the electricity need of the population it will not be foregone depending on its ability to do so into the future cheaply. The specific impact of Research and Development associated with this policy and its impact on the rates as a condition of the use of the policy is a huge factor. Copyright or licensing issue surrounding the DG technology employed should be facilitated by the policy that is; it should seek to exploit on research and development gaps to make a technology indigenous to the region thereby encouraging the not only mature technology but promising technology also.

Reliability

As the criterion implies the policy must enhance reliability of the electricity sector; that is, it should seek to employ technology that is mature enough that it can feasibly and effectively supply power when desired and as desired to the specific needs of the customer/society. The nature of the policy to support changes in technology that will support technological advancement must be apparent that is the technology should be dynamic enough to encourage DG use that can for example support changing a fuel source with relative ease to capitalise on any market change. The policy should be designed as such to proliferate by whatever means consistent replicable performance DG employed; for example, apply incentives to ensure a sound dependable system.

2.4.3 Analytic Hierarchy Process

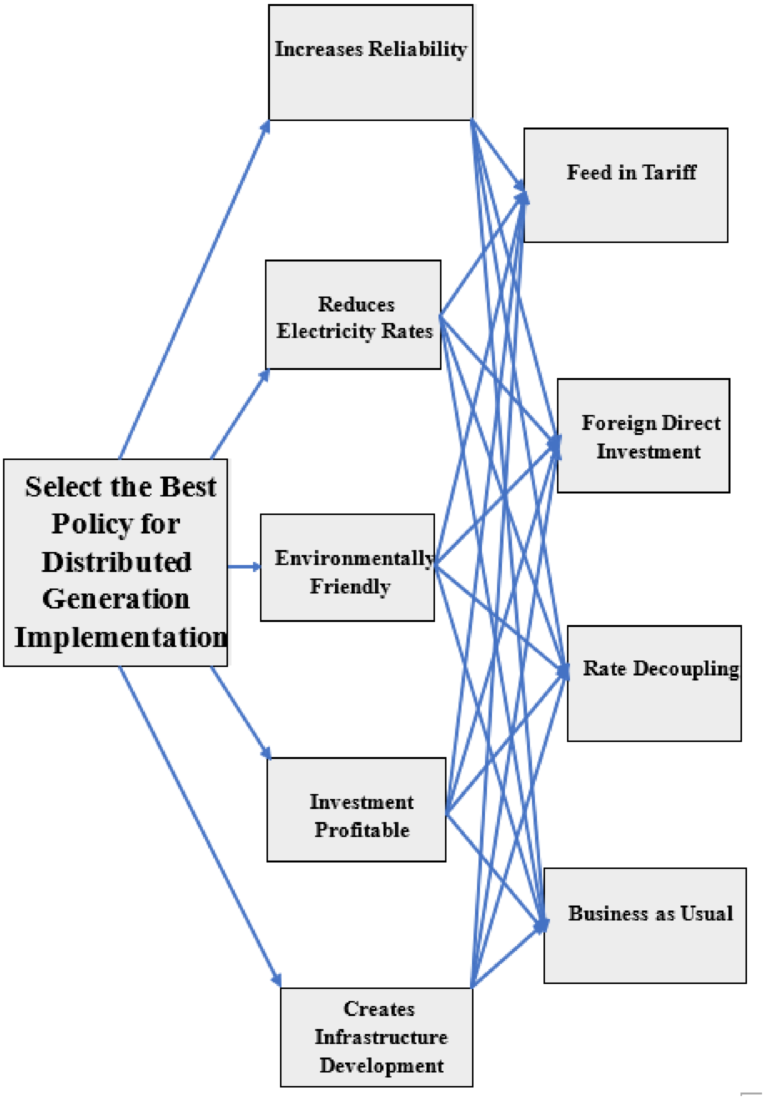


Figure 2.5: Hierarchy Structure of AHP Problem in this study

AHP fundamentally comprises of measurement through pairwise comparisons and depends heavily on the judgements of experts to derive priority scales. Having completed the preliminary steps of hierarchy design, which consist of goal definition, identification of alternatives, criteria assignment and finishing of the hierarchy.

The fundamental step of identification of priorities is done; this is where the application of pairwise comparison of criterion is done this is used to determine the point evaluation of significance this is followed by the repetition of the procedure for all the hierarchy levels.

The penultimate and final steps are combination of the expert point evaluation of significance and evaluation of the weighted values of alternative solutions (Chalúpková & Franek, 2014).

The decision-making is therefore summarised in a three-tiered structure of: hierarchy, priority and consistency which is depicted in Fig 2.5. Important to the success of the analysis, Saaty's method of pair-wise comparison must be applied on each level of the hierarchical structure.

In the first level of the hierarchy is the goal of the evaluation, which is critically the selection of the best alternative. The second level of the hierarchy is the criterion evaluation; the goal of the evaluation depends on which criterion is selected in this evaluation. The third level of the hierarchy is described by the alternatives comparison, which the decision analysis depends on the relationship of the alternatives to the criterion, selected in the evaluation.

Let a_{ij} (i=1,2, 3,…,M and j=1,2,3,…N) describe the performance value of the i^{th} (i.e., A_i) alternative in terms of the j^{th} criterion (i.e., Fj). W_j symbolises the weight of criterion F*j*. The decision matrix for the multi-criteria decision analysis can be represented by the following decision matrix given in Table 2.9. The pairwise concept of AHP will result in the matrix given in the table where the comparison within the hierarchy allows for two criteria in the pairwise comparison to be assigned a value rating which describes one criterion to the other. A value is also given

Table 2. 9 Comparison Matrix from Expert Survey

Criterion	C_1	C_2	C_3	…	C_n
Weight	W_1	W_2	W_3	……	W_n
Alternative					
A_1	a_{11}	a_{12}	a_{13}	……	a_{1n}
A_2	a_{21}	a_{21}	a_{23}	……	a_{2n}
A_3	a_{31}	a_{32}	a_{33}	……	a_{3n}
…	……	……	……	……	……
A_m	am_1	a_{m2}	a_{m3}	……	a_{mn}

With respect to each alternative to a criterion. A criterion compared with itself is given a value of one while a numerical rating was given for judgement of all other criterion with another based on the judgement preference given in table 2.10 below (Saaty & Vargas, 1991).

Table 2. 10 Numerical scale for verbal Judgement of Predilection

Importance Degree	Descriptions	Explanation
1	Equally Important	Criterion *i* and *j* are of equal importance
3	Moderate/weak importance to the other	Criterion *i* is weakly more important than *j*
5	Average/Strong importance to the other	Criterion *i* is strongly more important than *j*
7	Very Strong Importance	Criterion *i* is very strongly more important than *j*
9	Extreme Importance	Criterion *i* is extremely more important than *j*
2,4,6,8	Intermediate Values	Criterion *i* is more important than *j* but at intermediate values of the more important scale
Reciprocals	Values for inverse comparison	Criterion *i* less important than *j* where greater numbers have a higher degree of less important factor.

The elements of the matrix are generally not consistent, they are considered consistent if the corresponding consistency ratio (CR) is determined to be less than 10%. The CR is calculated by firstly evaluating the consistency index (CI), this is done by adding the values in the judgement matrix and multiplying the resulting vector by its priorities, this approximated priority is called eigen vector. This process yields the maximum eigen value denoted by λ_{max}. The consistency index can thus be calculated from the expression:

$$C.I. = \frac{\lambda \max - n}{n - 1}$$

Where n represents the number of independent rows of the matrix, the CR is obtained by dividing the CI by the Random Consistency index (RI) which is an average number that is selected according to a particular number of matrix rows as shown in table 2.11 (Chalúpková & Franek, 2014).

Table 2. 11 Random Consistency Index

n	1	2	3	4	5	6	7	8	9	10
RCI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

C.R = $\frac{C.I}{R.I}$

The final priorities of the alternatives are deduced from the following expression where A_{final}^{i} denotes this value:

$A_{final}^{i} = \sum_{j=1}^{m} a_{ij}\ w_j$, for i = 1,2…m

The optimal alternative is alternative calculated to have the highest aggregate weight.

2.4.4 Sensitivity Analysis

The final or acquired value of alternatives weighted sum criterion results in the alternative with the highest value concluded to be the best alternative. All alternatives can therefore be organised based on this calculation from best to worse alternative. It is therefore important to determine whether the selection of the alternatives in this manner is stable i.e. prone to changes in weights. The sensitivity analysis is done to determine the stability in the resulting rank of alternatives.

The sensitivity analysis will be done by evaluation of the alternatives according to the weights estimated for the criterion of highest priority. Recalling that this highest priority criterion was employed to deduce the value of alternatives weighted sum criterion the aim is to determine a minimal value that would cause a change in the ranking of alternatives.

If the weighted sum criteria of the individual alternatives A^{i}_{final} can be calculated according to the following expression:

$$A^{i}_{final} = \frac{\sum_{j=1}^{m} a_{i,j} * V_j}{\sum_{j=1}^{n} V_j} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Where V_j = the non-normalised weight of the jth criteria

$\sum_j V_j$ = sum of all non-normalised criteria weights

a_{ij} = evaluation of the ith alternative according to the jth

criterion

W_j = The normalized weight of the j^{th} criterion

$$W_j = \frac{V_j}{\sum_j V_j} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Then the weighted sum criteria of normalised weights is derived from the expression:

$$A_{final}^{i} = \sum_{j=1}^{m} W_j \; * \; a_{i,j} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Owing to the calculated values of the weighted sum criteria of all the alternatives the best alternative can be determined and consequently all alternatives organised in some measure such as from best to worse. The sensitivity analysis is therefore determined by using some exclusion methods to remove the least favoured alternatives and select the most competitive alternative for further analysis.

The stability of the selection is determined, which essentially is a confirmation of the best alternative by virtue of its capability or proneness to changes in weights. The alternatives will therefore be evaluated in terms of strength of rank by evaluating them according the weights of the estimated weighted sum criterion.

The approach this analysis will take is to determine a limited value that would cause a change in the weighted sum criterion that would cause a change in the ranking of alternatives *m* and *n (Chalúpková & Franek, 2014)*.

A^i(a$_m$) = Weighted sum criterion of alternative *m:*

A^i (a$_m$) = $\frac{\sum_j a_{m,j} * V_j}{\sum_j V_j}$, A^i(a$_n$) = $\frac{\sum_j a_{n,j} * V_j}{\sum_j V_j}$, ... (4)

Where A^i(a$_m$) > A^i(a$_n$). Varying the kth weight for alternatives m and n by the value $\alpha_k^{m,n}$ to some new value given by the expression v_k' = v_k + $\alpha_k^{m,n}$, producing an uneven relation to obtain A' (a$_m$) < A' (a$_n$). Solving for the new weighted sum criterion would yield:

A' (a$_m$) = $\frac{\sum_j a_{m,j} * v_j + a_{m,k} * \alpha_k^{m,n}}{\sum_j v_j + \alpha_k^{m,n}}$, A' (a$_n$) = $\frac{\sum_j a_{n,j} * v_j + a_{n,k} * \alpha_k^{m,n}}{\sum_j v_j + \alpha_k^{m,n}}$. . . (5)

Following the difference in the disparity and substitution of A' (a$_m$) < A' (a$_n$)

$\sum_j a_{m,j} * v_j + a_{m,k} * \alpha_k^{m,n} < \sum_j a_{n,j} * v_j + a_n * \alpha_k^{m,n}$ . . . (6)

A$_m$ = $\sum_j a_{m,j} * v_j$, A$_n$ = $\sum_j a_{n,j} * v_j$,. . . . . . (7)

A$_m$ – A$_n$ < $(a_{n,k} - a_{m,k}) * \alpha_k^{m,n}$ . . . . . . (8)

Further simplifying the expression above, we arrive at the means of varying the weighted sum criterion by the criterion weight and arrive at the following expressions for the determination of the sensitivity limits:

$\alpha_k^{m,n} > \frac{A_m - A_n}{a_{n,k} - a_{m,k}}$, for $a_{n,k} - a_{m,k} > 0$, ... (9)

$\alpha_k^{m,n} > \frac{A_m - A_n}{a_{n,k} - a_{m,k}}$, for $a_{n,k} - a_{m,k} < 0$,. . . . . .(10)

$\alpha_k^{m,n} = \infty$, for $a_{n,k} - a_{m,k} = 0$. . . . . . .(11)

The application of the sensitivity lies in the expressions in (9) and (10) when the coefficients of the variable $\alpha_k^{m,n}$ are smaller, the more sensitive the alternatives m and n become towards k. The expression at (11) represent the likely chance of the alternatives m and n are equal based on their weights in such a case the alternatives are insensitive to changes weights. This analysis enables a comparison not only about the best alternative but also about the other alternatives within the study. The evaluation of the limits $\alpha_k^{m,n}$ allows for the computation of the new weights of a parrticular alternative thus facilitating analysis of rank exchange (Zmeškal, 2009).

2.5 Levelised Cost of Energy Analysis

The final assessment by the study is a levelised cost analysis of the electricity sector of Jamaica, the analysis affords a quantitative look at how all generating options compare to each other on a price per unit of electricity basis. The Jamaica sustainable energy growth plan was developed around a timeline to achieve a set of predetermined goals within the electricity sector between 2009 to 2030. For the purposes of this study the timeline to the date of 2030 will be used in an effort to be able to compare Jamaica's progress to achieve the growth plan set out from 2009 to present. The estimated LCOE calculated for Jamaica's electricity sector is developed based on an extended Model for Electricity Technology Development (META) developed by the World Bank.

The team from World Bank developed an Energy Sector Management Assistance Program (ESMAP) that allows the input of common default values to calculate the LCOE while allowing the input of customized data to calculate country-specific costs (Makhijani et al., 2013). The advantage afforded by the LCOE tool is that; one is able to compare the economic viability and lucrativeness of the varying energy investment options assessed in the study. It has the ability to aid in policy making by presenting the long-term effects of important variables essential to each project such as fuel-cost development.

Importantly in future policy planning cost reductions due to technological development is always significant to a decision to invest this also factored into the LCOE tool used. The learning effect from different initial support instruments also play a huge role in the course of action decision makers choose and are not discounted in the LCOE analysis; for example, the knowledge afforded from grid integrity analyses as a prerequisite to future system factored in a LCOE analysis is a definite advantage. The META system developed is not an optimisation model however it gives policy makers and energy system planners an accurate cost overview of different supply options that should be used in systems planning for future development.

The LCOE analysis does not account for taxes and subsidies, it is not considered a true financial assessment. Instead of using a financial interest rate it applies a social discount rate, this unlike the former which is relevant in investment schedules for loan-financed projects is not a simple formulaic decision but is essentially a decision about time preference. The social discount rate takes into consideration the mean significance between short-term versus long-term costs and benefits. This means it will reflect the time preference associated with achieving the country's energy policy goals while maintaining the desired costs and benefits to the utility customers.

The calculation of the LCOE is depicted by the formula and in summary can be described briefly as the long-run marginal cost of electricity generation:

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where: I_t = Investment expenditure in the year t

M_t = Operations and Maintenance expenditure in the year t

F_t = Fuel Expenditure in the year t

E_t = Electricity generation in the year t

r = Discount rate

n = Amortisation period

Chapter 3. Research Results

3.1 AHP Analysis Results

The criteria selection from the survey yielded priority/weighting results assessing each criterion within the ideal policy tool alternative. This was achieved from the pairwise comparison of each criterion through AHP, to obtain metrics for the policy tool needed to encourage/promote DG. The survey engaged participants to prioritize the most favoured between two criteria to satisfy the ideal policy goal. Each expert considering the goal desired selectively chose which criterion will better able bring about the objective.

The responses must be consistent with respect to the ability of each criterion's influence in achieving the desired goal one from another. The consistency of the comparisons made by the participants were done using AHP consistency ratio presented by Saaty (Saaty & Vargas, 1991).

The consistency distribution results for the participants are presented in Figure 3.1; of the responses received and after reassessment by participants for consistency, only 6 respondents did not achieve full consistency. The inconsistent responses were excluded from the decision-making analysis and the 15 consistent responses combined by group geometric mean method. The number of interviews were determined to be adequate based on the recommendation of Adler & Adler. In their interview they believed for qualitative research a sample size of between 12 and 60 would be adequate with a mean of 30 (Baker, Edwards, & Doidge, 2012).

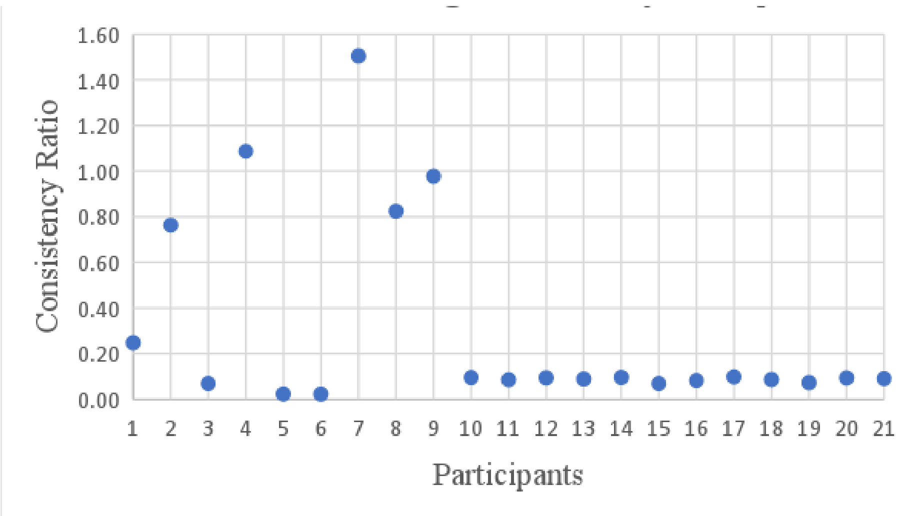


Figure 3. 1 Chart showing Consistency of Experts

3.1.1 Criteria Weighting Results

The geometric mean method was selected as the means of combination of the judgements in order to uphold one of the key social choice axioms the "universal domain axiom" crucial to the use of AHP in decision-making (Ramanathan & Ganesh, 1994). To uphold the first social choice axiom, which maintains the reciprocal relationship between the choices, made from two criteria; the geometric mean method must be maintained (Saaty & Vargas, 1991).

Previous researchers have argued against the use of the geometric mean method in-group preference aggregation, citing its failure to always uphold axiom 2 or the Pareto Optimality axiom (Ramanathan & Ganesh, 1994). These researchers advocate the use of the Weighted Average Mean Method (WAMM), which while upholding axiom 2, fails to satisfy the "independence of irrelevant alternatives" axiom. Furthermore, one must find "weightages" to the members of the group to properly apply the method proposed by (Ramanathan & Ganesh, 1994).

The suggested approach was described in much the same as the weightages of the criteria were found. The members/respondents of the expert group would perform an interpersonal comparison between group members to produce a "simple intuitive eigen vector approach". The resulting weightages from the expert would then be used to combine the results.

This study objectively prefers the method developed by Saaty the Geometric Mean Method (GMM) as the group of experts within this study were selected from various Institutions and Government entities that objectively believed all participants have equal weightages. The aggregated matrix Table 3.1 shows the geometric mean method combination of the selection from the experts surveyed, having made pairwise comparison of policy tool criteria. The consistency ratio indicates the nature of the selection made by each respondent indicating that the matrix of responses was consistently done. For consistency Saaty indicates that the CR must not exceed 0.1(Saaty & Vargas, 1991), from the aggregated matrix the CR achieved was 0.003 which is significantly lower than the value specified. The low CR indicates the comparisons given by the respondents exhibited an acceptable level of homogeneity.

Collectively the respondents ranked the Environmental criterion as the policy factor, which should be allocated the highest priority to promote DG. The environmental criterion had a weight of 0.41 making it the most desirable policy aspect followed by the criterion for lowering electricity rates, which had a weight of 0.25. The improving of reliability was next at 0.15 followed by infrastructure development 0.11 and finally profitability at 0.08. These specific results are attributed to the fact that Jamaica's ultimate energy policy goal is to develop an electricity sector that is environmentally sustainable with affordable and accessible energy supply ((MEM), 2009).

Table 3. 1 Geometric Mean Combination of Global Criteria Matrix

Geometric Mean Method of Combination for Criteria					
Global Criteria	**Reliability**	**Rates**	**Infrastructure**	**Environment**	**Profitability**
Reliability	1	0.50440935	1.494379588	0.392974131	1.803805445
Rates	1.982516778	1	2.259623538	0.629960525	2.608465471
Infrastructure	0.669174023	0.442551595	1	0.268642483	1.320558701
Environment	2.544696765	1.587401052	3.722419436	1	5.382071407
Profitability	0.554383514	0.38336716	0.757255243	0.185802068	1

Table 3. 2 Global Ranking of Criteria

Global Criteria	Priorities	Rank
Reliability	0.149247641	3
Rates	0.252646711	2
Infrastructure	0.107565411	4
Environment	0.406634535	1
Profitability	0.083905702	5

C.I: 0.00349145

R.I: 1.12

C.R: 0.00311737

As a result, the environment criterion is given the highest weight as it provides the means of divorcing the country from its current oil dependence without the risk of fuel switching (O.U.R, 2010). The basis of Jamaica's current generation expansion plan is centered around least cost addition of any additional generating facility (O.U.R, 2010). This would explain the reason the reduction of rates criteria is assigned the second most important criteria. Improving the reliability of the electricity supply was determined as critical factor behind the affordability of electricity for the operation of successful businesses.(Makhijani et al., 2013). The National energy policy which details the goals to be accomplished to secure Jamaica's energy future expands the accomplishment of achieving a modern and expanded energy infrastructure through the improvement of reliability, to provide affordable electricity from a sustainable energy supply ((MEM), 2009). This accounts for the weight assigned to the infrastructure development criteria., the policy determines that achieving these goals will result in profitable productive sectors. This national energy policy therefore realises that upon fulfilment of these criteria selected in the order indicated by this study the ease of realisation of the final criterion of profitability will be significantly enhanced ((MEM), 2009).

3.1.2 Alternatives Weighting Results

The study then turned to the selection of the alternative to achieve the desired objective; applying the AHP technique each alternative was ranked with respect to their ability to fulfil each criterion. Table 3.3 illustrates how each alternative were weighted in their ability to deliver the stipulated criteria. Table 3.4 presents the AHP result indicating which alternative would best achieve the goal based on its criteria weights.

The feed-in tariff alternative was selected as the best alternative to deliver the objective goal having a 35% priority. The results for the foreign direct investment and business as usual alternatives followed respectively with the priority between both alternatives shared at 23% priority indicating how close the perception about each were. The revenue-decoupling alternative at 20% priority was least favoured to achieve the desired objective. The FIT alternative was assessed by the experts to be able to best provide the environmental criteria due to the ability of the policy to increase the amount of renewable energy used in the electricity sector.

The tariff increases the environmental benefit by allowing users to sell electricity generated from renewable energy to the grid at a rate greater than the normal rate. This allows renewable energy generating facilities to recover the high capital cost associated with their investment. The only drawback to this is that it will be at a more expensive electricity rate this is confirmed by it receiving the third best weight of 0.21 in the rate reduction criteria assessment the worse being revenue decoupling with 0.17 weight. The BAU policy which has a weight of 0.16 on the environmental criteria does not offer this preferential rate and so the ability for this policy to increase the renewable base of the sector is considerably reduced.

The FDI alternative was less favoured to increase the environmental criteria (0.159 weights) and was second favoured to increase the rate reduction criteria behind the BAU option 0.23 and 0.38 respectively. This explains why both policy options were so closely favoured to deliver DG dissemination. The FDI and BAU policies seek to increase the environmental criteria through investor attraction policies which are promoted in Jamaica to encourage only the lowest risk renewable energy technology at average remuneration rates. These policies are the only renewable energy thrust currently pursued while the revenue decoupling seeks to increase renewable energy dissemination by promotion of energy efficiency programs. Currently there is little to no thrust behind energy efficiency programs.

Table 3. 3 Result of AHP for Different Policy Alternatives

Alternative	Alternative Weights with Respect to Criteria				
	Environment	**Infrastructure**	**Profitability**	**Rates**	**Reliability**
F.I.T	0.512992937	0.287758544	0.10812294	0.20868	0.3106879
F.D.I	0.159443773	0.247638197	0.3477692	0.23279	0.3151457
R.D	0.164145487	0.311138717	0.34583131	0.17405	0.1735169
B.A.U	0.163417804	0.153464542	0.19827654	0.38448	0.2006495

Table 3. 4 AHP Ranking of Different Alternatives

Alternatives	Overall Priority	Rank
F.I.T	0.347718192	1
B.A.U	0.226501991	3
R.D	0.19910119	4
F.D.I	0.226678627	2

3.2 Sensitivity Analysis Results

The assessment of the decision produced by AHP to determine if the results are stable and robust is checked by the sensitivity analysis. By varying differences in the criteria weights, one is able to determine the best alternative from the group of alternative selections. Thus, the ranking of the best alternative amongst them is known based on how sensitivity the ranking is to weight changes. The rank of the alternatives is tested by pair-wise comparison of another to find the minimal value to effect a change in the rank of alternatives. The analysis is based on the two best alternatives initially, using normalized values of both compared alternatives to compare with the ratio of the value difference in the sum criteria in both alternatives the analysis will be carried out. Essentially, determining the rank change of the best alternative the second best from the measure of weight change. The theory behind this is detailed in Chapter 2 and using formulas (9 & 10) one is able to determine the weight change between FIT and FDI and produce a sensitivity coefficient. The logics behind this analysis dictates that the smaller the value of the coefficient then the more sensitive the alternatives are to a change in weights. Table 3.5 shows the Sensitivity analysis of the evaluation of FIT to FDI for the environmental criteria. To produce an overall assessment of each Alternative a similar analysis is reproduced for all other criteria and alternatives. Table 3.6 is the resultant of this analysis and it compares each alternative weight rank change with respect to the best alternative selected according to the AHP result.

It is clear that the smaller the difference in the ratio (sensitivity coefficient $\alpha_k^{m,n}$) then the more sensitive (prone to rank change) are the alternatives to changes in the weights. Comparing the second best alternative FDI to FIT we realise that the weight changes are significantly large and are even greater than 1.0 for three criteria. This indicates that the weight change needed to make a change or rank reorder is not possible this is because a value over 1 for the normalized weight would indicate more than 100% change. Therefore, analysing all of the alternatives against the FIT best alternative yields the result that the FIT result is insensitive to a rank shuffle. Table 3.7 shows what will be necessary in order to obtain a change in FIT rank to FDI. The results from the sensitivity analysis can be better explained with the graphical representation given in Figure 3.2, which gives a graphical representation of the change in weights for the FDI criteria to be competitive with FIT. Due to the improbability of the reliability criteria to be change the scale of the chart is rather huge giving a false indication that the environment and profitability criteria are somewhat sensitive. However, upon analysis of the weight change needed to affect a rank shuffle, it can be seen that a 42% & 62% respective change in the criteria will be needed to affect it. The other criteria will require an improbable >100% weight change to affect a rank shuffle.

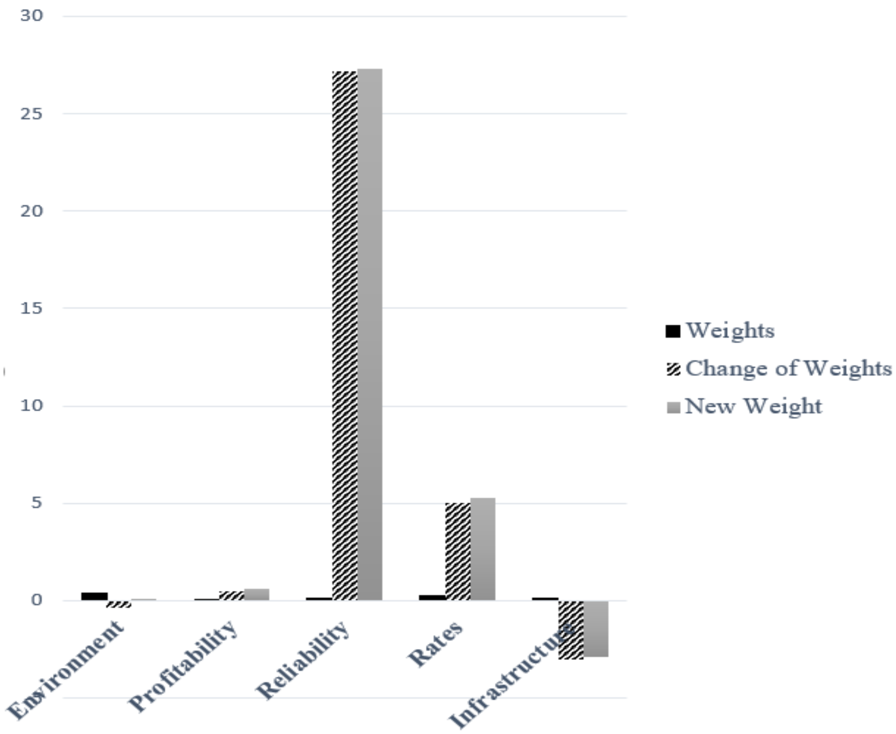


Figure 3. 2 Changes of Weights for FDI Alternative

Table 3. 5 FIT comparison to FDI for Environmental Criterion

Environment Alternative	**Overall Priority**	**Normalised Value**	**Difference**	**Value Difference**	**Change of Weight**
Symbol	Am,n	am,n,k1	Am-An	am.k1-an,k1	α_k^(m,n)
F.I.T	0.347718192	0.512992937			
F.D.I	0.226678627	0.159443773	0.12103957	-0.353549164	-0.3423557

Table 3. 6 The list of Weight Changes towards FIT

Changes of Weights Towards F.I.T					
Criteria	**Change of Particular Weight**				
Alternative	**Environment**	**Profitability**	**Reliability**	**Rates**	**Infrastructure**
F.D.I	-0.342355682	0.50507596	27.1527645	5.02001203	-3.01691229
R.D	-0.4260229	0.625207281	-1.0834428	-4.2906101	6.356539656
B.A.U	-0.346752927	1.344552013	-1.1015807	0.68953637	-0.90261813

3.3 Levelised Cost of Energy Results (LCOE)

The levelised cost of energy will be used to assess the viable performance of each form of energy that can be used in a DG energy scenario. The levelised cost of energy can ideally determine which type of power generation facility would be more profitable using either renewable or traditional sources of energy. The multi-criteria decision analysis support tool selected the use of FIT as the best alternative to promote the employment of DG in the electricity sector of Jamaica.

The focus of this study is primarily Industrial customers; who deem profitability of investing in a power generation source to be of primary concern. The LCOE will determine if the renewable energy focal point of the FIT can do so profitably over or competitively with the traditional sources of energy; if not the Industrial customers may not be interested to participate in its use.

The important fact within this study is without a feed-in tariff there is no preferential rates for renewable energy sources. The LCOE will be used to assess both sources of energy operating within the same deregulated market at the same market price. Table 3.8 illustrates the LCOE for the renewable options within the study to the base year of 2020 considering transmission cost, substation cost and distribution cost. These costs will be important if Industrial customers plan to export power to the grid and must be remunerated to the utility operator/transmission and distribution company. Table 3.8 uses the world bank developed Energy Sector Management Assistance Program which shows that select renewable technology are quite competitive at present electricity Tariff rates in Jamaica. The base energy cost for onshore wind technology is estimated at 7.94 USc/kWh and with the inclusion of Transmission, Substation and Distribution cost only amounts to 15.73 USc/kWh, which is well below the 39 USc/kWh reported in the ("Energy Transition Initiative Islands," 2015a).

This information leaflet gave the tariff rate in Jamaica reported by the Ministry of Science Energy and Technology. Table 3.9 depicts the LCOE for all the candidate technology eligible for use in DG based on the Jamaica's Generation expansion plan. While all the Technologies were below the benchmark tariff rate 39 USc/kWh it is notable that all the renewable technology shows not only profitable rates but also more competitive than traditional energy sources.

The most expensive renewable technology being utility scale solar P.V having a cost of energy of 25.40 USc/kWh with mini-hydro, biogas and landfill gas technologies having the cheapest energy cost. The traditional sources of energy though competitive with the average tariff rate are not as effective at accomplishing the least cost energy development plan set out by the OUR in their Generation Expansion plan. Figure 3.3 gives a graphical depiction of the projection of the LCOE comparing the movement in traditional sources of energy compared to renewable energy sources.

Table 3. 7 Summary of Rank Changes for FDI Alternative

Changes of Weights for F.D.I					
Criteria	**Environment**	**Profitability**	**Reliability**	**Rates**	**Infrastructure**
Weights	0.406634535	0.0839057	0.1492476	0.252647	0.107565411
Change of Weights	-0.342355682	0.505076	27.152765	5.020012	-3.016912293
New Weight	0.064278853	0.5889817	27.302012	5.272659	-2.909346882

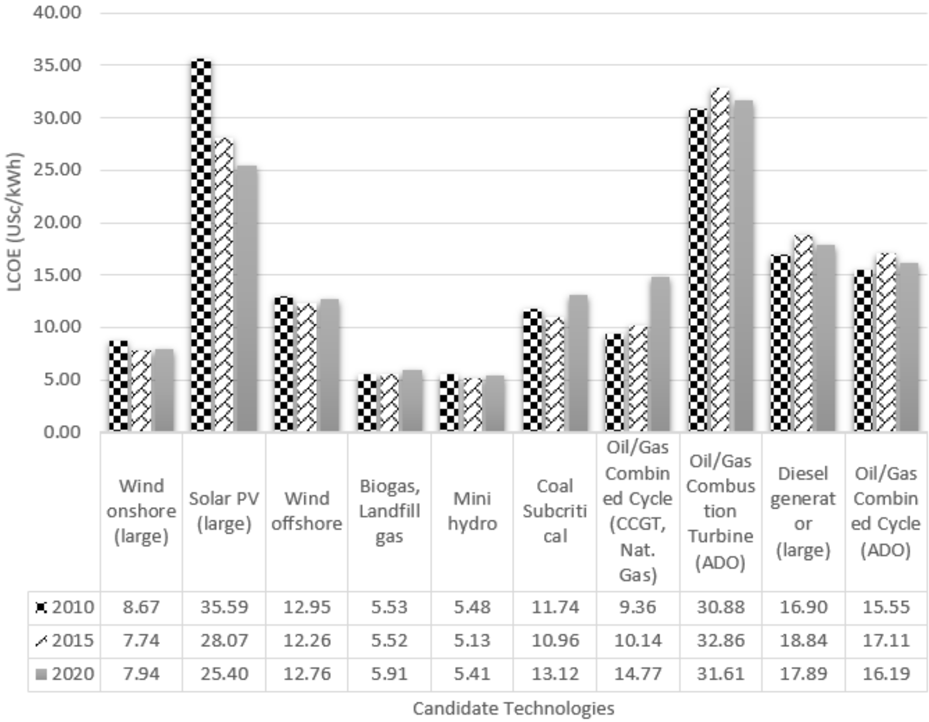
Table 3. 8 LCOE using Renewable Energy Sources to 2020

Cost comparison	Wind onshore (large), operating at 30% CF (USc/kwh)	Solar PV (large), operating at 15% CF (USc/kWh)	Wind offshore, operating at 30% CF (USc/kWh)	Biogas, Landfill gas, operating at 80% CF (USc/kWh)	Mini hydro, operating at 45% CF (USc/kWh)
Energy Cost	7.94	25.40	12.76	5.91	5.41
including environmental costs of:	0.00	0.00	0.00	0.00	0.00
Transmission Cost	3.44	134.24	3.44	25.21	44.78
Substation Cost	1.22	47.70	1.22	8.96	15.91
Distribution Cost	3.13	3.13	3.13	3.13	3.13
Total Delivered Energy Cost (USc/kWh)	15.73	210.47	20.55	43.21	69.22

Table 3. 9 LCOE of DG Candidate Technologies

Technology type	Levelised unit capital cost (Generation only)			Fixed O&M cost			Variable O&M cost (Generation only)			Fuel costs (Generation only)			Environmental costs (Generation only)			Levelised Unit Cost of Electricity		
	USc/kWh			USc/kWh			USc/kWh			USc/kWh			USc/kWh			(USc/kWh)		
	2010	2015	2020	2010	2015	2020	2010	2015	2020	2010	2015	2020	2010	2015	2020	2010	2015	2020
Wind onshore (large)	8.25	7.30	7.47	0.42	0.44	0.47										8.67	7.74	7.94
Solar PV (large)	34.09	26.52	23.73	1.50	1.55	1.68										35.59	28.07	25.40
Wind offshore	10.85	10.08	10.41	2.10	2.17	2.35										12.95	12.26	12.76
Biogas, Landfill gas	2.63	2.52	2.66	2.90	3.00	3.25										5.53	5.52	5.91
Mini hydro	5.12	4.76	5.00	0.36	0.37	0.41										5.48	5.13	5.41
Coal Subcritical	2.51	2.27	2.30	0.35	0.37	0.40	0.43	0.44	0.48	5.69	4.61	6.15	2.76	3.28	3.80	11.74	10.96	13.12

Oil/Gas Combined Cycle (CCGT, Nat. Gas)	1.63	1.50	1.52	0.26	0.27	0.29	0.31	0.32	0.35	6.23	6.91	11.3	0.93	1.13	1.34	9.36	10.14	14.77
Oil/Gas Combustion Turbine (ADO)	8.15	7.51	7.63	0.89	0.92	1.00	0.99	1.02	1.11	17.3	19.4	17.6	3.59	3.98	4.36	30.88	32.86	31.61
Diesel generator (large)	0.66	0.64	0.67	0.39	0.41	0.44	1.40	1.45	1.57	12.9	14.5	13.1	1.59	1.87	2.16	16.90	18.84	17.89
Oil/Gas Combined Cycle (ADO)	1.48	1.36	1.38	0.24	0.25	0.27	0.31	0.32	0.35	11.2	12.6	11.4	2.34	2.59	2.84	15.55	17.11	16.1



	Wind onshore (large)	Solar PV (large)	Wind offshore	Biogas, Landfill gas	Mini hydro	Coal Subcritical	Oil/Gas Combined Cycle (CCGT, Nat. Gas)	Oil/Gas Combustion Turbine (ADO)	Diesel generator (large)	Oil/Gas Combined Cycle (ADO)
2010	8.67	35.59	12.95	5.53	5.48	11.74	9.36	30.88	16.90	15.55
2015	7.74	28.07	12.26	5.52	5.13	10.96	10.14	32.86	18.84	17.11
2020	7.94	25.40	12.76	5.91	5.41	13.12	14.77	31.61	17.89	16.19

Figure 3. 3 Projected Cost of Candidate DG Technologies

Chapter 4. Result Context and Interpretation

In summary of the problem statements, Jamaica has charted a course for expansion of their electricity generation sector to employ the use of renewable energy while adopting a least cost development plan. Since 2012 when the request for proposal was submitted by the OUR, projects have been submitted to attain the 115 MW renewable energy penetration by 2015 however they have failed to accomplish this goal. Analysis of the studies done on the Jamaican Energy sector has indicated that not enough policies have been put in place to achieve the desired outcome (Barrett et al., 2013) (Makhijani et al., 2013) (*Generation Expansion Plan 2010*, 2010).

In fact, Jamaica has seemingly stumbled from technology to technology and policy to programs without clear definition of the path forward. This is evident from cases such as; Divestment of sugar industry to Chinese investors to encourage growth of Industry.

To date the biomass for energy rollout has not materialised and the sugar Industry has been struggling to make a profit. Riverton waste-to energy project failing to materialise (Makhijani et al., 2013), traditional energy projects such as the move to incorporate coal fired electricity generating technology and even natural gas use has been delayed by several years are further evidence of low success/commitment to plans.

4.1 Distributed Generation Analysis

The problem statement conveyed the dilemma surrounding distributed generation's ability to develop the electricity sector. There exist many misconceptions on the use of DG and how it affects system stability, reliability, safety and efficiency. The literature review was necessary in defending the use of DG despite the many technical constraints, which were posed and highlighted in the study (Koutroumpezis & Safigianni, 2010). Greatest among them were:

- Technical constraints existing at the feeder at which DG is installed such as thermal constraints from the current rating of the lines that existed at the location of installation. However simple engineering control would ensure that the line current rating I_{irated} is not exceeded; hence $I_i < I_{irated.}$
- Transformer capacity must be of such that the amount of generation connected less the stipulated minimum load must not exceed the transformer rated maximum voltage (Koutroumpezis & Safigianni, 2010). This limits the total power, able to be transferred through a substation transformer (HA et al., 2017).
- Short-circuit load constraints (SCL) must be maintained and allowed to remain below network design value (SCL_{rated}). The theoretical framework is that the SCL is highest at the medium voltage busbars

characteristically found at on the in-feeding substation (SCL_{max}); hence $SCL_{max} < SCL_{rated}$. Other studies have described this constraint in terms of a Short circuit ratio (SCR) which should be maintained at a minimal value of 10% (HA et al., 2017).

- Voltage variation limitations are specific in nature and includes the voltage profile/steps/angle, which have been exhaustively researched. The voltage of the load/bus and additionally some voltage value related to the impedance of the line connecting the DG will collectively be the generator voltage when DG are installed. This results in increased active power flow on the distribution network affecting the system power flow. Essentially the resistive element of the lines on the distribution network will be higher than the amount on other lines thus describing active power constraints. Conversely, the total reactive losses and demand that is a factor of the reactive power balance limit (RPBL) are also constraints still under investigation. However, operating or sizing DG within the technical confines of these restraints are ever available options.

Nevertheless, there have been developed alleviation of these constraints many of which summarized and discussed by HA et al. (2017). Researchers have suggested that by employing DG the transmission and distribution limitations effectively improve the electricity network due to the specialized grid strengthening/ engineering tools that will need to be deployed in order to accommodate them.

4.2 Summary of DG Benefits

Still focusing on the aspect of the study addressing the problem statement concerned with the benefits of DG to effect improvements to the electricity grid. The literature review detailed DG's capability to improve the overall technological obligation of the distribution company along with social and fiscal benefits to consumers, DG operators and the wider society. Expounding on the universe of benefits mentioned in chapter 1 the literature review explained benefits such as;

Demand/load Minimisation and Avoided Energy Costs are incurred due to the reduction in the annual quantity of electricity supplied over the grid by distribution utilities. The total quantity of electricity used by all customers are not reduced through DG in fact it may even increase but it reduces a customer's energy cost due to the pricing structure of utilities to charge different rate at peak hours compared to off peak. Customers energy cost are reduced by virtue of their consumption from the grid being shifted to a lower-priced hour (Woolf et al., 2014).

Generation demand reduction and Avoided Peak Supply Cost; which places importance on the DG to be able to reduce the distribution company's obligation to provide for peak demand. The scope and size of T&D projects to complement the growing size of a thriving economy may be reduced by DG. Economic growth is not always linear in relation to time and as such there are growth spurts, lulls and even recessions which must be forecasted and fulfilled by the distribution company (Woolf et al., 2013).

Avoided Environmental Compliance Tariffs; the objective of global leaders to position their economies to reflect a concerted effort to conserve the environment is a global trend that is projected to intensify rather than diminish. Global commitments by world leaders to honour their commitment to environmental accords like the "Paris Agreement" has seen many policies to impose tariff on polluters in many countries like Jamaica. Industrial customers are held to an emission tariff even though the "Paris Agreement" is non-binding however, government use this opportunity to compel industry to operate environmentally friendly and finance the budget through non-compliance tariffs (Davis, 2002). DG which employ renewable energy technology are better able to pass on this avoided tariff saving to utility customers.

Avoided Obligatory Support and Ancillary Services; In an effort to maintain the quality of power supply, ancillary services are required to maintain reliability of the electricity network and power quality. These services as defined by the Federal Energy Regulatory Commission in the U.S includes (U. F. E. R.

Commission, 1996):

i. Planning and Scheduling, system control and dispatch
ii. Generation Voltage control and reactive load supply
iii. Frequency correction, regulation and response services
iv. Power flow and energy imbalance services
v. Operating and Spinning Reserve services
vi. Auxiliary or Supplementary reserve services

Implementation of DG reduce the complexity of these services due to the use of smart grid devices that allows for better forecasting of load and demand patterns from pre-programmed responses to demand. These DG services may also include energy storage services that allows load following and frequency regulation benefits that are comparable to the ancillary services offered by from the utility (C. P. U. Commission, 2001).

Reduce Payment incentives and Anomalies; The use of DG reduces the need for utility operations that promote/encourage rate payment and utility debt recovery. Increased used of DG reduces arrearages due to non-payment and diminished need to commit resources for rate discounts. The likelihood of having bad debts which will have to be written-off is also significantly reduced.

Market Animation refers to the ability of a market to facilitate multiple suppliers of a good or service and describes the mobility of customers to move from one supplier to the next to being even an active participant in the market itself. DG allows the introduction of several power supplier and creates a competitive environment where many market suppliers facilitate competition and innovation, so consumers receive the best products or services at the most competitive prices.

4.3 AHP Multi-Criteria Decision Analysis

Entrepreneurs globally and those locally within the Industrial sector of Jamaica are under the constant threat of business ruination if they do not formulate plans, develop strategies and conceiving concepts to invoke success. In focusing on the problem statement regarding what is the best policy to invoke adoption of DG; one must not only consider benefits to the DG operator but also the benefits to the electricity sector of Jamaica. A complicated decision process is conceived that requires multi-level consideration to not just the interest of Industrial customers but policy makers that must consider the interest of the wider society. This complex decision-making process is made relatively simple by employing the Analytic Hierarchy Process. By firstly engaging in a comprehensive research of the criteria needed to choose the best technology for energy sector development this study accessed the criteria needed for policy selection. The criteria selected from the AHP tool indicated in Figure 4.1 the calculated weights of each criteria to deliver the goal of DG adoption. The environmentally friendly criteria having the majority weights of 0.41 indicates that the decision makers believe in the ability of renewable energy technology. This criterion based on its selection indicates the importance of environmental protection as an integral part of any plans for future development. The strength of decision-making AHP tool lies in its ability to simplify complex decisions, which may involve long-term, severe ramifications that involves multiple relevant criteria.

The tool should provide a solution to satisfy multiple factors involved within the decision. Within the context of this study, the policy tool should be environmentally friendly, effectively reduce electricity rates, allow for infrastructure development, be profitable for the investor/operator and effectively improve electricity reliability. As the nature of these criteria stand and the single goal that is to be achieved this objective seems unattainable. Case in point, as the nature of environmental technologies go they are normally more expensive than all other sources of energy hence are more expensive to employ.

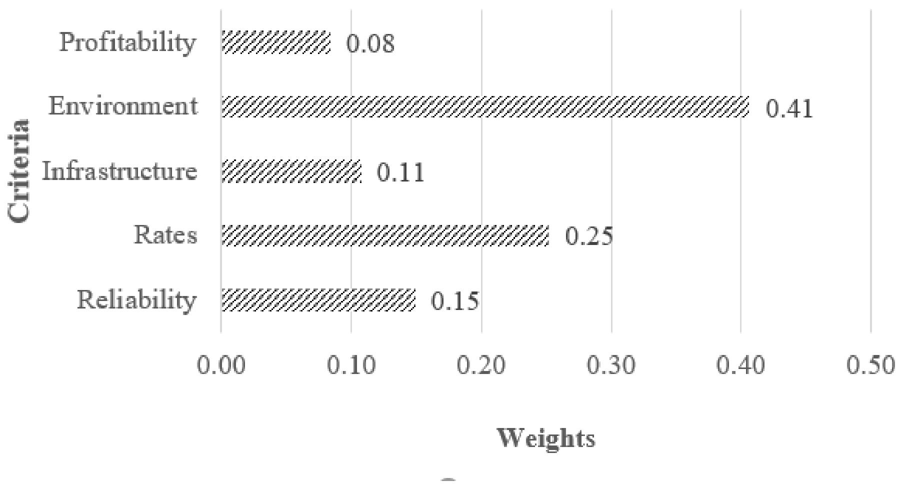


Figure 4. 1 AHP Overall Weightings of Criteria

So, based on the awareness of the respondents/experts who responded to the survey their strength of knowledge must be to the extent to fairly and without favour produce the results. The field of expertise from which each respondent is from will therefore invariably affect the results even though an unbiased comparison of all the criteria is required this is however a common human trait. The group of Respondents were classified into (6) six different fields of major expertise, which they were asked to classify themselves in based on their expertise. The major expertise was grouped as follows;

- Environmental Protection and Safety
- Petroleum Refining and Retail
- Business Development Specialist
- Engineering and Power Controls
- R&D and Academia Expert
- Government Ministry and Utilities Regulation

4.3.1 Respondent Descriptive Statistics

The survey respondents were selected from different organisation as mentioned in Chapter 2 from the private sector, Government and Non-Government Organisation. These organisations all have major role in the development of the electricity sector or possess strong social or technical influence on the economic and social well-being of the populous. Figure 4.2 gives a description of the respondent ages. Majority of the Respondents were within the age of 35-39 which accounts for a little over 38% of the sample. 10% of the sample had the maximum age range of 50-54 and the same percentage at the lowest age group of 25-29.

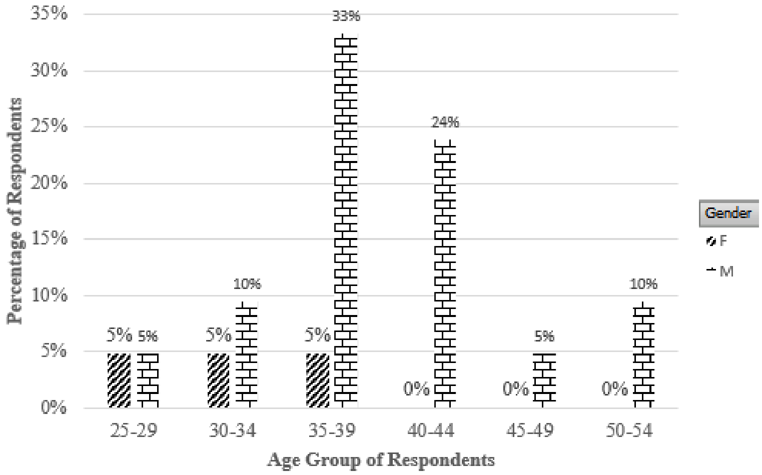
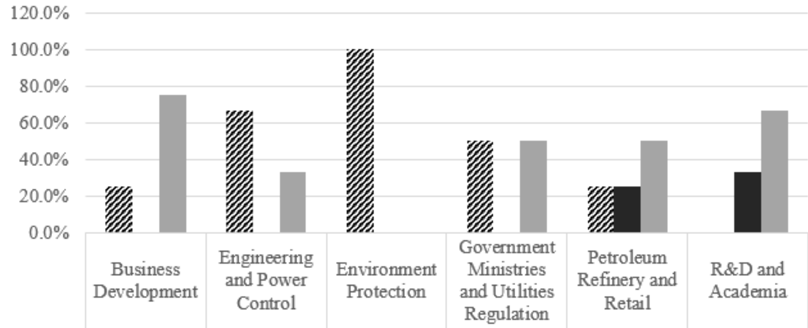


Figure 4. 2 Age and Gender Distribution of Respondents

Figure 4.3 shows the years of experience distribution of the expert groups; the business development group is the only group to have respondents across all years of experience. The qualification and experience distribution of the groups is presented in Figure 4.3 and 4.4. The lowest qualification held by the respondents within their field is a bachelor's degree and the highest is a doctorate within their professional posts. The figures in the appendix show the weights of the groups and reflects how the pairwise analysis by the different groups rank the criteria. The environmental group placed maximum weightage on the environmental criteria, giving it a weightage of 0.44 this was followed by reduction of rates (0.19) then reliability improvement of 0.16, Infrastructure development (0.11) and profitability (0.10)

The AHP method of result combination sufficiently deals with this anomaly in the GMM of combination of result. Analysis of the other participant groups indicate that for the petroleum refinery and retail group the criteria with the highest weight is in rates reduction.



	Business Development	Engineering and Power Control	Environment Protection	Government Ministries and Utilities Regulation	Petroleum Refinery and Retail	R&D and Academia
Bachelors	25.0%	66.7%	100.0%	50.0%	25.0%	0.0%
Doctorate	0.0%	0.0%	0.0%	0.0%	25.0%	33.3%
Masters	75.0%	33.3%	0.0%	50.0%	50.0%	66.7%

Figure 4. 3 Qualification Distribution of Expert Groups

The Business Development group comprising of professionals that are much more corporate oriented we see that reliability has a weightage of 0.38 while environment of 0.34. The Engineering and Power Control group placed the maximum weightage on Environment of 0.42 while reducing rates was next with weightage of 0.23. The Research & Development Academia group placed maximum weights on the environmental criteria gaining a weightage of 0.37 followed by improving reliability 0.22.

The government ministry and utilities regulation group placed maximum weights on infrastructure development at 0.30, which was closely contested by the environmental criteria again at 0.28 (Appendix a.e). Based on these results. It is evident that the importance of the environmental criteria is critical for any plans for the electricity sector development. The large support for these criteria even from professionals outside the discipline is a testament of its importance for the future development and sustainability of the electricity sector in Jamaica. The nature of how the different groups job characteristics impacts their criteria weight selection is evident with the criteria closest ranked with the environment criteria in each group. The environment criterion was ranked either above or second to the criterion which was characteristic to the nature or field of work of the group. The group with largest disparity in the weights given to the environmental criteria from all other groups was the petroleum refinery and retail group indicating their belief in disseminating DG is not impacted significantly by the use of fossil fuels. They also believed reducing rates was

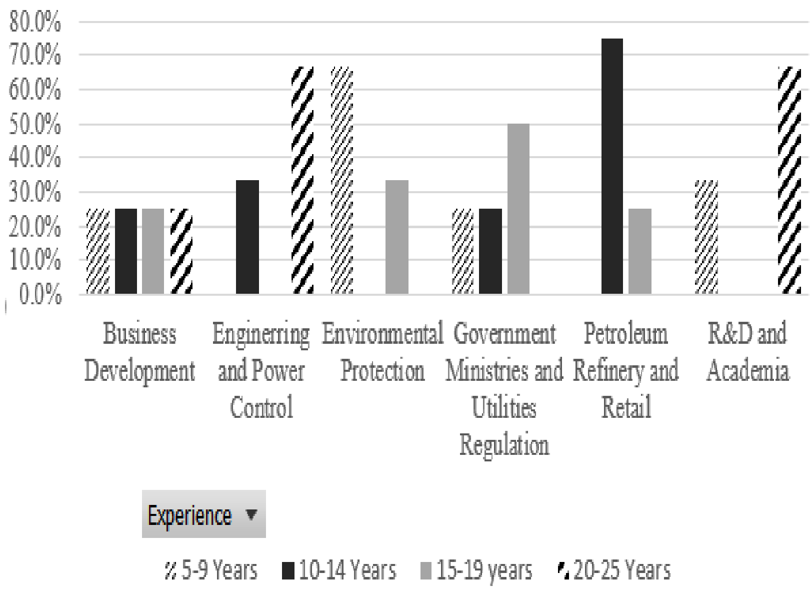


Figure 4. 4 Experience Distribution of Expert Groups

most significant in disseminating a DG program this based on their belief that fossil fuel technology will continue to be cheaper. The differences in the criteria weights between the groups show there exist a gap in how dissemination programs are approached. DG systems are able to use either renewable or traditional sources of energy and the priority given to renewable energy programs indicate Jamaica's renewable energy program is in the infancy stage. In this early stage of the renewable energy, results indicate there is no clear goal for the renewable energy program. The goal of the renewable energy program has therefore taken the same objective as the Generation improvement program; thus, explaining the reason the rates criteria is second in the dissemination of DG.

4.3.2 Alternative Selection and Sensitivity Analysis

The Alternative selection represent the final step in the AHP decision analysis and the most desirable step as it yields the decision that must be used to achieve the goal. The weights from the overall criteria selection will be used along with the weights for all the alternative with respect to each criterion (alternative criteria weight assessment) to select the best alternative. The alternative criteria weight assessment is a very important step; in just the same way as the criteria weights selection was produced using pairwise comparison of each criteria to the overall goal the same must be done at this level.

The pairwise comparison of each alternative must be done with respect to each criterion, in order to determine the weights of the alternatives to accomplish/fulfil that criteria objective. Table 3.3 in the results section presents the fulfilment of that step in the AHP analysis. The final step in achieving the overall weight of each alternative to accomplish the goal is achieved by multiplying the weights for each criterion in the alternative by the overall criteria weights of all the respondents and finding the summation of the weights multiplied for each alternative to achieve the overall alternative weights.

This produces the overall weights of the alternatives to accomplish the goal. The results illustrated in Figure 4.6 indicate that the respondents selected the Feed-in tariff policy to accomplish the adoption of DG within the electricity sector for Industrial customers. The policies described by Foreign Direct

Investment was the second most favoured however only marginally preferred

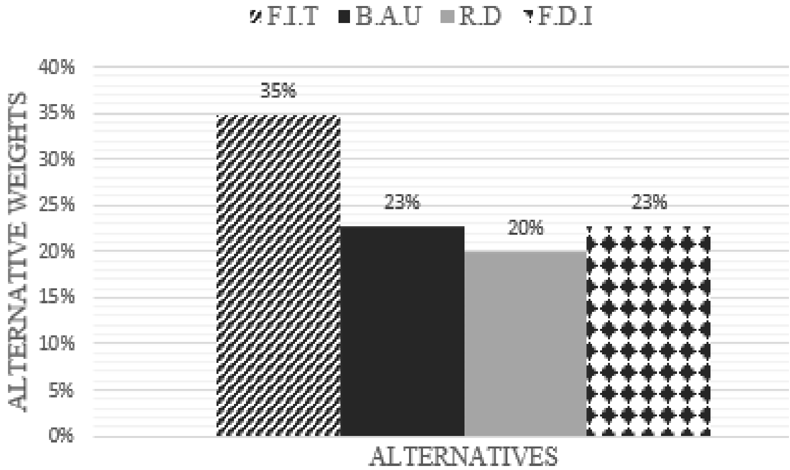


Figure 4. 5 Chart Showing Policy Alternative Selection by AHP

to the Business as usual policy followed by the Revenue decoupling alternative. The sensitivity analysis enables one to substantiate the robustness of the results by determining the implication of varying one criterion weight over the overall alternative selection. This authenticates the selection of the best alternative over all other alternatives. The sensitivity analysis functions on the premise of effecting a rank shuffle of all the alternatives by determining the limits that may affect the criteria weights to give new ranks to the alternatives.

The analysis determined that the changes in weights needed to create a shuffle in the original ranks are quite high to even improbable. This result affords the conclusion that the results stable and the chances of another alternative unseating the FIT alternative is unlikely. These results are given in table 3.6 and figure 3.2 in the results section.

4.4 LCOE Analysis

The LCOE analysis used in the context of this study was important in order to remove the remaining uncertainty perpetuated by the final problem statement. The problem statement was concerned with the decision's ability at invoking investor appeal and indicated that the policy decision is time sensitive. As such, the LCOE will provide a means to examine past events and forecasts future suppositions to determine the viability of the policy course of action. The decision by Industrial customers to participate in any investment opportunity relies on their profit-making potential.

The LCOE analysis affords a "birds eye view" of the overall cost which are involved and is as close to actual as history and estimates permits. Figure 3.3 which represent the LCOE comparison between renewable and non-renewable energy generation options can be used to compare and determine which technology is most appropriate for DG. The analysis shows how competitive both classes of technology are and by factoring in environmental costs of the traditional forms of energy the renewable technology is in fact more viable. The environmental cost is added to the traditional technologies as they significantly affect additional cost to society. These include harmful health effects cause by emission of harmful pollutants from the traditional sources of energy. The standard generation cost used to determine LCOE values for traditional technology were used along with damage values or carbon costs in USc/kWh for the most damaging negative impacts. In the Jamaican energy context, this allows a fresh insightful look at the viability of traditional energy technology to renewable technology. This study as was previously mentioned employed the Energy Sector Management Assistant Program (ESMAP) developed by the Model for Energy Technology Development (META) team at World Bank. This particular tool allows to use default values needed to calculate the LCOE while allowing for country specific values allowing the model to be completely custom designed for estimating Jamaican specific case. The model used included default values specific to Jamaica such as the discount rate employed, and the O&M fixed and variable costs used to add to the authenticity of the results.

That being said, the use of environmental costs as proportion of the cost of traditional energy is legitimately used because of the Jamaica regulatory situation. The carbon price used in this study is the moderate cost of $30 U.S/tonne which (Nicholson et al., 2011) in their study determined would need to be in excess of that amount before renewable energy technology could conceivably compete with traditional sources of energy. The air quality regulation in Jamaica is of such that it stipulates that operators of traditional energy source equipment that burn fossil fuel must provide the air-quality monitoring equipment to operate such facilities legally. The addition of this pricing to the cost of traditional energy is used in this study to simulate the procurement and maintenance of this technical very expensive equipment needed to measure emission from these traditional energy sources (Davis, 2002). Factoring all the costs for the different energy sources, the evidence reported in this study is overwhelmingly in support of renewable energy to be a viable alternative for Industrial customer in the Island of Jamaica. Table 3.9 shows the time dynamic varying LCOE for all candidate technologies from 2010 to 2020 supporting the use of FIT policy driven DG as being a viable alternative. The LCOE analysis also reveals that if Jamaica policy makers had instituted the renewable energy promoting policy from as far back as 2010 the avoided fuel cost that would have been realised from the switch would be very evident today. Table 3.8 goes further to include transmission and substation costs into the analysis to further reinforce the competitive attractiveness of renewable energy sources in the near future.

Chapter 5. Conclusion and Policy Implication

5.1 Conclusion

The phrase, “In times of rapid change, experience could be your worst enemy”, by Jean Paul Getty is relevant to what decisions are made today in developing a viable electricity/energy industry. The Global thrust to race to the discovery of the next new sustainable energy source has the blinding effect of causing one to fail to recognize when a pre-existing situation has advanced over time from being unfavorable to favorable. By virtue of the dynamic effects of the passage of time and the inter-relation between energy systems, the technology of DG presents the rare characteristic of crossing this threshold from unfavorable to favorable. Advancement of technology has made unique improvements affecting the use of DG and while technology has morphed simple distribution networks into complex ‘behemoths’ the technology to use DG has also discretely evolved. The universe of benefits to be derived from DG has somewhat overshadowed the technical issues which form deterrent for their use but with significant engineering controls DG can be viably employable. A great amount of research as well as the growing trend of adoption in the use of DG in growing markets in Europe, Asia Pacific and North America confirms the merits behind its use. Investor spending in these markets forecast the profitability expected as “the distributed generation market is projected to reach from USD 60.04 billion in 2017 to USD 103.38 billion by 2022" (Wire, 2017). The suitability of DG is therefore not limited due to technology as was the case 1880's and 1890's when "the war of current" between direct and alternating current raged, rendering the use of DG technology deceased in its wake.

The application of multi-criteria decision analysis to determine a course of action in a multi-factored conundrum with conflicting consequences was proven. The problem statement relating the expeditious resolution to these kind of situations is directly impacted by our AHP results. The capability of AHP to deliver a suitable result, which ideally satisfies all the criteria defined, is an excellent apparatus for decision makers. The ability for the tool to comprehensively analyze a problem and simultaneously generate a decision based on a combination of relevant information, expert knowledge, experience and preferences is very prodigious. The implication and application for its use presents real world benefits in many applications. The AHP method depends heavily on the simple subjective comparison analysis of experts to generate weights/priorities on the criteria/elements at different level in the hierarchy. The method ensures that these comparisons are consistent in order to remove the complications associated with the decision-making process. The consistent results ensure that the problem though sufficiently simplified through pairwise comparison will address the problem on an elementary basis deals with the most important issues individually. This independent operation of one element on the next does not completely divorce each criterion from the overall goal using the

AHP analysis. The method also places keen attention to the alternatives and recognizes the importance of not just the criteria to achieve the goal but also the alternatives dexterity to incorporate the criteria and achieve the goal. The selection of the preferred alternative is derived from this process and it evaluates other alternatives of the problem and allot weights or priority to each in achieving the goal. This method was applied in this study to evaluate the criteria and alternatives for dissemination of DG. The study evaluated four policy alternatives for dissemination of DG and determined that the environmental based alternative of feed-in tariff was most favorable for the dissemination of DG.

The importance of the environment criteria indicates the benefit to the environment that may be derived through the use of DG. The expert survey reveals that DG is required to reduce environmental damage and enhance supply reliability. The culture of the policy makers to design lowest cost generation expansion plan result in the rates criteria assigned a weight of 0.25 besting reliability at 0.14 and infrastructure development at 0.10. The feature of DG as a supplementary system to the grid explains why the profitability criterion is the lowest ranked as it will only be able to make a major contribution to profitability upon extensive application of DG into the grid.

Presently the Jamaica Government has applied little no dissemination programs for any form of renewable technology. In assessing the basic plans for generation expansion, the focus of the Governmental policies has been to stimulate traditional energy sources mainly due to their competitive advantage of being able to provide cheaper electricity rates as seen in the OUR report (2010). The thrust of the experts into a policy committed to environmental protection, while the OUR 2010 report more adept to boost traditional energy sources provides a clue into Jamaica's dissemination strategy. Aside from the fact that Jamaica has fell short of its 115 MW installed renewable energy targets by 2015 and since there is no policy change one can conclude they are poised to do the same in 2030. The results of the analysis lead to the assumption that the policy makers are intent on what may be viewed as a cost deferral introduction of renewable energy from being a Government burden to an investor risk. This obviously creates a slow dissemination of renewable energy and an increase in advance/latest technology fossil fuel energy.

This is evident from the close relation of the FDI and BAU alternatives to the dissemination of DG both acquiring a 23% priority amongst the alternatives and equally believed to be the second-best options to disseminate DG. This is due to their ability to deliver the first and second ranked criteria of environment and rate reduction both alternatives emphasize renewable energy penetration on investor appeal that would be encouraged by providing electricity at lower rates. The profitability criterion been assigned a weight of 8.0% is disparagingly small for what may be considered a very important criterion for sustainability. The supplemental characteristics of DG to the grid must change before the profitability can be realized. Government policies to create a local renewable energy technology market by using DG could facilitate creation of a local technology then profitability would be realized. Where a local technology market exists, opportunities would be created for local investors to seek out and create economically feasible projects. As these projects grow; wealth creation would be achieved and stimulate the pursuit of the local technology into global markets. The focus of the local renewable energy technology market would therefore have to be regulated around this local technology. This ensures that the renewable energy dissemination program seeks to promote the local technology in order to create an economically feasible and viable renewable energy program.

The feed-in tariff alternative was checked for its robustness/stability as indicated in our analysis in chapter 4. The varying of criteria weights against the alternative selected indicated that the selection could not be easily out ranked even with significant changes in the expert criteria selections. The other alternatives were not determined to be closely competitive in achieving the goal of DG dissemination. The policy maker using this method will be able to determine that based on the nature of the alternative as described in Chapter 2 market pull strategies such as feed-in tariff will proficiently initiate investment in renewable energy technology. Thirdly, the weights derived in this study can aid the policy maker to create policies that initiate programs for investment or simply to solve complex problems within the country. The policy maker is able to choose decisive/relevant factors (criteria) and assess their importance using

AHP in order to create many different policies. This allows for a useful accounting technique to asses before and after effects of renewable energy dissemination programs.

The LCOE analysis performed provides the real-world comparison that outside of a detailed financial assessment provides the evidence to support that the policy alternative will be beneficial to Industrial investors. The analysis performed was conducted such that the cost of energy for using the technology selected is calculated and is equivalent to the basic rate that must be charged for that facility to break even in the specified investment life. The Analysis detailed in Chapter 3 describes that the LCOE calculated is significantly lower than current market tariff indicating that a return on Investment can be achieved at current tariff rates before the total investment life. The ability of policy holders to develop a policy that effectively provides evidence of a positive return on investment to investors is highly meritorious. The merits of this study extend potential benefits to many participants who stand to gain directly and indirectly from this analysis. Directly the monetary value and expeditious assessment of policy implications from the LCOE analysis and the assurance and confidence that is gained from the easy empirical decision-making process employed.

5.2 Findings and Policy Implications

The principal findings within this study extend well beyond the goal of decision-making analysis and policy viability assessment. Though these are provisionally presented as face-value output of the study, one is able to analyse even deeper based on the key findings and results. Fundamentally, the study affords a profound knowledge of the use of DG in alleviating some of the frequent disturbances to transmission and distribution systems. The study highlights how DG once unfavourable due to the technical restraints behind its use has now morphed into a favourable alternative to help with grid stability, improve grid reliability positively affect energy security and is a profitable investment option. The use of multi-criteria decision analysis in the energy industry as navigated into new territory for application of its use. The literature review in this study revealed several studies where decision analysis has been used in determining the technology for best exploitation within the electricity sector of a country. The present study has shown where this analysis can be extended further into also determining the best policy for dissemination of said technology. The decision analysis methodology employed extends limitless capability for the user to produce results on a myriad of highly complex and complicated decisions. The weights derived from the criteria as indicated in the conclusion was able to provide information about the current stage of renewable energy dissemination program in Jamaica. The criteria selected, and their weights is able to provide policy makers with better insight in developing an effective dissemination program. Further studies of the same nature will also help policy makers to evaluate the dissemination programs implemented and identify ways in which to improve them.

From the disparity in the weightages given by the experts and the current business as usual idiosyncrasy, one is able to determine that a contrast exist between the indicated renewable goal and the employed policy directive. It is believed that the policy directive is not impellent enough to conceivably in the time desired effect the desired objective. To confirm these finding further studies is needed to determine what the barriers for renewable energy use are. As Jamaica has no local renewable energy technology, further studies can be done to determine the barriers for development of various renewable energy technology and determine which technology is best adept to be developed locally.

Another decisive limitation to this study is the inability to estimate the magnitude of different costs associated with selected policies. Essential to the use of a policy is the administrative cost or even the attainableness of implementation. Jamaica is at a precarious state of development in which significant development requires substantial investment which the government is not always at liberty to supply.

The alternative policies selected give a unique look on the policy used for not only technology dissemination but can be extended to technology innovation and diffusion. Through literature review we can link the findings from this study to other previous research on market pull and technology push policies. Based on the specific characteristics of these policies one is able to see their impact on financial as well as technological breakthroughs and how innovation and adoption can be enhanced or retarded. The study provides valuable information pertaining to the effect of market-pull and technology-push policies on renewable energy technology adoption. The Quantitative research done through the use of LCOE analysis affords preliminary financial documentation for venture capitalists financing prospecting and even for financiers' risk assessment.

The analysis has particular value with respect to the rate at which Jamaica has decided to institute its renewable sustainable growth plan. Having consistently missed renewable growth targets if a FIT is implemented the rate at which maximum renewable energy penetration will be increased. The faster Jamaica attains maximum renewable energy penetration the less of the country's GDP will be channelled into procuring highly priced fuel. The county will be able to realise real benefits from avoidable fuel cost greater than the rate now being experienced in the business as usual policy scenario. Earlier than projected maximum renewable energy penetration also has the added benefit of saving capital investment on traditional fossil fuel technology. This results in greater benefits to the country as these saving can invariably be channelled into other productivity focused investments.

The Literature review done describes the use of carbon pricing in affecting the competitiveness of traditional energy technology. Previous research determined that the favourability of traditional technology would not be affected by carbon pricing at $30 USD/tonne CO_2. The LCOE analysis has indicated that employing this minimal carbon pricing to mature traditional technology has rendered renewable energy technologies more competitive.

This study has enabled one to determine the discrete change of once unfavourable technology growing into one that is favourable due to the passage of time and improvement in indirectly related technology. This is advantageous in that through this study we see that research even into discarded/unfavourable technology should be promoted for not only academic posterity but to improve the quality of life. The major implications from the criteria selection and weightages is evident in their policy implications. The establishment of the environmental criteria as the major criteria evaluates the current dissemination program and identifies its frailty in disseminating a renewable energy program to best suit the need of Jamaica. It's inability to accomplish the modest goal of 115 MW of renewable energy by 2015 set by the OUR through their RFP in 2012 is evidence of its languor propensity. The policy that should be adopted in Jamaica is one that should allow for Jamaica to capitalise on the abundant renewable energy resources that it controls. The market pull strategy determined by AHP analysis will be sufficient to accomplish one of the key goals of the sustainable energy growth plan. The goal of increasing renewable energy penetration at the modest rate set by the OUR and even greater can be achieved. Additionally, increasing supply side stimulation facilitating multi participants in the renewable energy market. This will effectively set the foundation for a paradigm shift to propagate demand side stimulation by shifting government policy to a technology-push policy such as FDI/renewable portfolio standard (RPS) that promotes knowledge generation and cost reduction through learning by searching. The benefits of this type of policy will place Jamaica in greater control of their energy future as it promotes the creation of local renewable energy technology, that could be used to propel the country economically.

5.3 Limitations and Future Research

The Limitations for use of this research is significantly related to the customised characteristic of the analysis. The two very customised analysis of multi-criteria decision analysis using AHP and the LCOE are case specific to the target area being analysed. The results from the AHP analysis cannot be applied generally to some other location or country without changing the internal variables. The analysis does not offer a same case fits all situation, as conditional to the selected area of research the resources available for exploitation vary geographically. Government subsidies and allocation also vary due to location, natural and financial resources apportionment even political and social balance affect its suitability for use. The study is limited by its symptomatic investigative results that is; it provides information about remediation of current policy but not identification causative variables.

Another limitation was the availability of empirical studies performed on the Jamaica electricity sector that would enable a better assessment of the business as usual policy. The BAU policy had the highest rank in terms of the reduction of rates criteria, assigned a weightage of 38%. Effectively we realise that this is definitely in line with the Government set strategy of a least cost development plan for the electricity Generation sector. Empirical studies on the effect of policy stringency would allow greater assessment of the policy employed by the Government and that recommended by this study.

The results indicated how the inclusion of carbon pricing into the cost of the traditional energy technology was done to use it as a proxy to determine the effect of several costs on society. The health risk caused by the emission from traditional fossil fuel technology is a social cost that could not readily be determined hence the cost associated with healthcare could actually be greater than the tiny $30 USD/tonne carbon price estimated. The carbon price was also used as a proxy to determine the cost of very expensive stack emission monitoring equipment that must be fitted on new traditional technology. This is a requirement of the Jamaica Ambient Air quality regulation. Failure to comply may result in a revoking of any facilities license to operate until the adequate compliance is met. The result of this is a limitation in accurately determining the true levelised cost as the capital investment on this equipment are quite substantial as well as the O&M cost.

The finding, which supports the proliferation of market-pull policy, reduces the impact afforded through technology push policy. The latter has the specific advantage of directly promoting knowledge generation and the cost reduction benefit of learning-by-searching this was also a key finding in our literature review in the study by (Kim et al., 2017) and therefore miss the advantage of using the latter.

The threshold that once unfavourable technology has crossed into becoming favourable at the current level of technology advancement seems to be time dependent. This study has opened up the possibility to investigating the time dependence or lack thereof of unfavourable technology transcending to favourable prominence. This study highlights the need to determine if one can empirical determine when this phenomenon has occurred and how to recognise the signals of its occurrence. Further studies may also be carried out in order to determine to what extent has carbon pricing transformed renewable energy technology into competitive status with traditional energy, i.e. what minimum carbon price would make the most expensive renewable technology competitive with the cheapest traditional energy source.

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Appendix. Expert Group Criteria Weighting

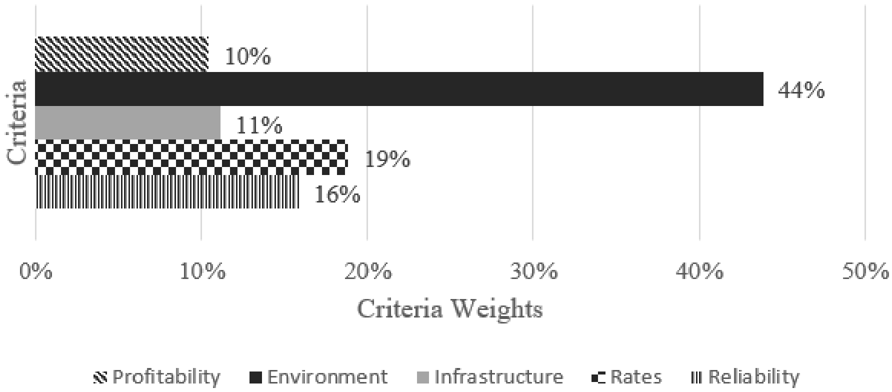

Figure a. a Environmental & Natural Resources Conservation Group

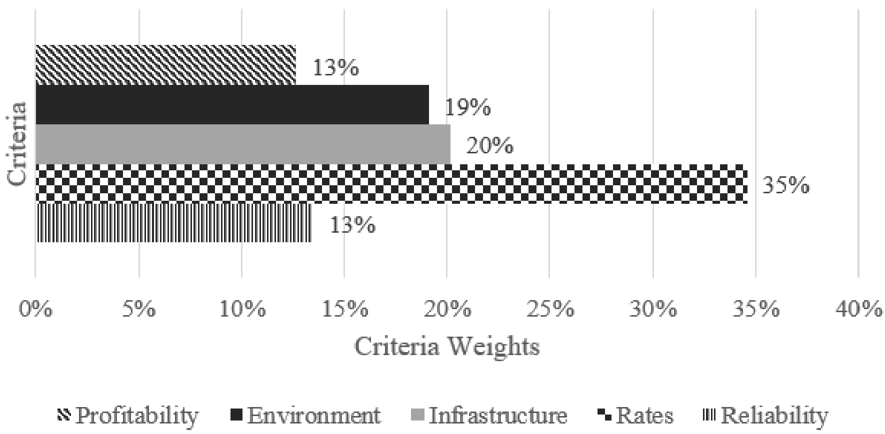

Figure a. b Petroleum Refinery and Retail Group

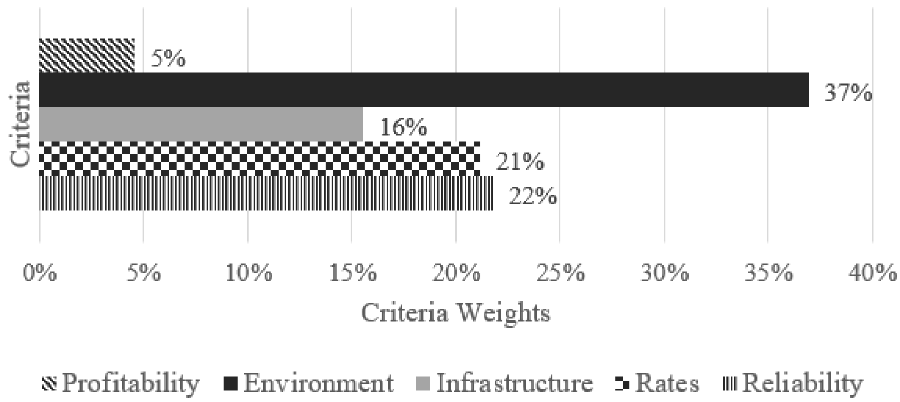

Figure a. c R& D and Academia Group

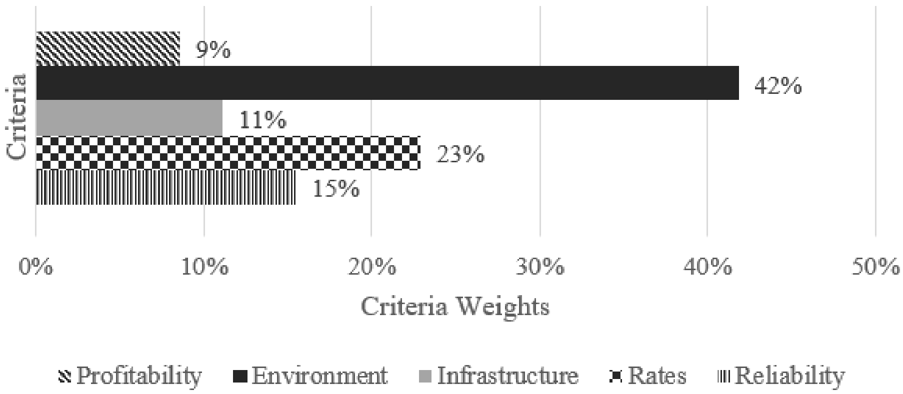

Figure a. d Engineering and System Controls Group

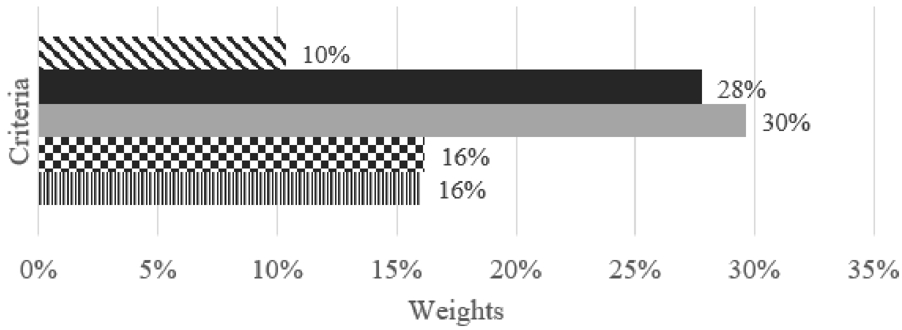

Figure a. e Government Ministry Group

초 록

독일, 영국, 미국 등의 선진국들은 전 세계적 추세에 맞춰 분산 발전 기술을 광범위하게 도입하고 있다. 분산 발전은 초창기 직류 배전 시스템에서 사용되던 기술이지만, 대규모 교류 송배전 기술이 등장하면서 점차 전력 공급에 분산 발전을 사용하지 않게 되었다. 그러나 분산발전은 부하에 가깝게 발전을 하는 특징을 가지고 있는 기술로, 대형 중앙 집중 식 그리드 네트워크에 비해 많은 장점을 제공한다. 최근 들어 여러 선행연구들을 통해 분산 발전 기술은 오늘날에도 유용하게 사용될 수 있다는 것이 밝혀졌다.

분산 발전은 주로 재생 에너지원을 사용한다. 지난 몇 년간 자메이카의 전력부문은 발전기의 노후화와 비효율성으로 인해 성장세가 정체되어왔다. 석유시장의 불안정성으로 인한 에너지 가격 급등도 성장세를 정체 시키는 데 한 몫 했다. 또한 자메이카는 풍부한 재생 에너지 자원을 보유하고 있지만 실제로는 미미한 양만이 사용되고 있다. 이런 상황에서 분산발전은 자메이카의 침체된 전력부문을 활성화 시키는 데에 있어서 매우 중요한 역할을 할 수있다.

본 연구의 주요 목적은 Jamaica Public Service (JPS)와 JPS의 고객들, 특히 국가의 공급에 전적으로 의존하는 산업 및 상업 소비자들이 최대의 이익을 얻을 수 있는 최선의 정책 도구를 파악하는 데 있다.

에너지 정책의 우선 순위에 대한 의견을 얻고 자메이카의 현 개발 프로그램을 평가하기 위한 기준 가중치를 결정하기 위해 먼저 전문가들을 대상으로 설문조사를 실시하였다. 그 뒤 계층 분석법(Analytic Hierarchy Process: AHP)을 사용하여 성공적인 에너지 개발에 있어서 중요한 기준이 무엇인지를 밝혀내었으며, 이 기준들을 통해 지속 가능한 최적의 정책 대안을 제시하였다. 최적의 정책 대안을 선택한 후 AHP 결과를 보완하기 위해 균등화 발전비용(Levelized Cost of Energy: LCOE)분석을 수행하여 생각할 수 있는 모든 자원에 대해 정책의 투자 매력과 잠재력을 평가했다.

전문가들은 선행연구를 토대로 위와 같은 정책을 수립하는데 중요한 정부, 학계 및 산업계 관계자들로 선정하였다.

전문가들은 분산발전의 보급에 필요한 요소로 1)친환경성, 2)요금 인하, 3)수익률, 4)인프라 개선, 5)신뢰도 개선을 선택하였다. 분석결과 친환경성 41%로 DG 프로그램을 보급하는 데 있어서 가장 중요하다고 나타났다. 현재 전력부문은 환경 친화적인 에너지 보급 정책이 취약한 것으로 평가되었다. 이로 인해 재생 가능한 에너지 원의 개발이 둔화되고있다. 위의 결과를 통해서 발전차액지원제도(Feed-in Tariff: FIT)가 다른 정책 대안보다 분산 발전의 보급에 있어서 더 적절한 정책대안임을 밝혔다.

또한 LCOE 분석 결과 재생 에너지를 사용하는 것이 기존의 에너지원과 비교했을 때에도 경쟁력 있는 투자 옵션이 될 수 있을 뿐만 아니라 미래에도 지속 가능하다는 점이 확인 되었다.

FIT의 도입은 현재까지 인프라나 경제성장에 의존해왔던 재생에너지에 대해서 적절한 시장 견인적 자극을 줄 수 있다. FIT를 통해 재생에너지의 도입이 늘어나고, 사용자들이 더 좋은 기술을 찾기 시작하게 되어 시장 경쟁이 활성화되면, 이는 기술 혁신으로 이어질 것이다. 현재의 정책은 시장 견인적, 기술 지향적 측면 모두에서 명확한 효과를 발휘하지 못하기 때문에 재생 에너지 기술(RET)을 촉진하지 못하고 있으며, 이를 통해서는 지속 가능한 에너지 공급이라는 정부의 목표를 달성할 수 없을 것으로 보인다.

키워드: 분산 발전, 다중 기준 결정 분석, 분석적 계층 구조 프로세스, 재생에너지 기술, 균등화 발전비용

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