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Renewable energy development in Trinidad and Tobago

Exploring scenarios for the deployment of solar photovoltaic systems

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Supervisor

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Neisha Maria Therese Manickchand

May 2011

Abstract

Countries around the world are employing renewable energy policies to increase renewable electricity in their electricity mix. Trinidad and Tobago (T&T), located in the Caribbean, has endogenous sources of oil and natural gas and has not yet capitalised on sources of renewable energy. The country's electricity is currently dominantly generated from natural gas however the natural gas reserves are expected to last 10 years. T&T is in the process of formulating a renewable energy policy but it currently lacks academic research on local renewable energy policy aspects and this thesis seeks to provide insight into policies to assist the deployment of solar photovoltaic (PV) systems in T&T. Solar PV technologies are declining in cost and are becoming more affordable thereby increasing the potential to make them competitive in the foreseeable future. The feed-in tariff (FIT) policy is one scheme used to encourage renewable electricity production and Trinidad and Tobago is considering applying the FIT policy to encourage renewable electricity generation. Other policies such as capacity building and the removal of energy subsidies can also be used to promote PV deployment in T&T. Three scenarios are constructed using these policies to explore possible pathways for PV deployment in T&T. These scenarios can be reviewed by policy makers when devising strategies to deploy photovoltaic systems in T&T.

Keywords: Renewable Energy, Solar Photovoltaic, Scenarios, Trinidad & Tobago

Executive Summary

Energy is an important facet of sustainable development as it influences environmental, social and economic aspects of development. The global demand for energy is projected to increase in the future and there is an urgent need to address the global challenges of climate change, energy security and sustainable development through the acceleration of advanced clean energy technologies (IEA 2010c). Renewable energy (RE) is growing and is receiving policy support from governments to increase energy security whilst addressing issues relating to the climate and the environment and the projected increase in the global energy demand.

Solar energy is one of many renewable energy resources. It is the most abundant energy resource on Earth where the energy that hits the Earth's surface in one hour is approximately the same as the amount which is consumed by all human activities in one year (IEA 2010c). Solar photovoltaic (PV) technologies have the potential to convert sunlight into electricity. It is estimated that by 2050, PV will provide approximately 11% of the global electricity production (IEA 2010c). Although investment costs of PV are relatively high, the costs are declining as a result of technological improvements and economies of volume and economies of scale. One scenario estimates that by 2020, PV will reach grid parity, that is, competitiveness with electricity grid retail prices (REN21 2010). However, grid parity may be reached in some selected electricity markets first which include countries with high solar radiation as well as high retail electricity prices.

The Republic of Trinidad and Tobago (T&T) is a twin island nation located in the southern part of Caribbean and it is the leading producer of oil and gas in the Caribbean. T&T has an economy that is heavily based on an energy sector driven by fossil fuel resources. Over the last 25 years, the country's economy has transformed from a predominantly oil-based economy to an oil and gas economy. These oil and gas resources are finite and calculations have estimated that the oil reserves have 15 years left while gas reserves have 10 years left at the current rates of extraction (BP 2010). 99% of the power generation in T&T comes from natural gas and with the 10 years left for natural gas, the country needs to identify and adopt alternative sources for electricity production.

Dawe (2008) suggested that Trinidad and Tobago should be developing and implementing policies to ensure that the country is self-sufficient and prosperous after the hydrocarbons have been fully extracted. There is however, limited academic research in the area of policy development for introducing renewable energy particularly solar photovoltaic power into T&T's local energy mix. Trinidad and Tobago is currently in the process of drafting a renewable energy policy. A renewable energy framework has already been established wherein policies were outlined and renewable energy technologies for deployment were suggested. Solar photovoltaic systems were one of the renewable energy technologies included in the framework as T&T has the technical potential to incorporate solar energy into the energy mix.

In light of the aforementioned, the aim of the thesis is to contribute to the body of knowledge for the development of renewable energy technologies in T&T. The objective of this work is to explore and describe scenarios for the deployment of solar photovoltaic power systems in T&T. The information generated can then be useful to policy makers as well as other researchers seeking to do research and implement actions in the field of renewable energy deployment especially PV in T&T.

As such, the following research question was used to guide the thesis research:

> How could solar photovoltaic systems be deployed in Trinidad and Tobago?

Primary and secondary data was collected to assist in answering the research question. Primary sources of information were obtained from stakeholders in the Ministry of Energy and Energy Affairs, the University of Trinidad and Tobago, and the Trinidad and Tobago Electricity Commission. The Valentin Software was a software tool used to obtain data and calculate the amount of electricity a PV system can feed into the grid under Trinidad and Tobago's climatic conditions. Secondary sources of information were obtained from books, reports, journals, articles, academic literature, publications, government documents, government websites, private company websites and other internet searches.

The literature review provided background information on a range of relevant topics. The energy sector of Trinidad and Tobago was reviewed since an understanding of the history and structure of the energy sector in Trinidad and Tobago provides insight into how renewable energy, particularly PV, fits into the energy sector to further develop it and by extension the economy. The thesis also reviews literature on the technological, economic, and policy aspects of PV. Experiences of some countries in PV development are included to portray how they deployed PV systems. Detailed information was provided on the policies which were used to develop scenarios. The policies that were reviewed were the feed-in tariff policy, capacity building, and the phase out of subsidies for conventional energy. Further information was gathered on the applications of PV deployment in the context of T&T.

The literature in the thesis was reviewed and three scenarios were developed to illustrate and explore possible pathways for PV deployment in T&T. Scenarios are descriptive narratives of plausible future events and as such were used as a method for guiding the exploration of pathways for the deployment of PV in T&T. The possible pathways for PV deployment in T&T are depicted through visual representations and narrative descriptions. The information outlined in each scenario could be reviewed by policy makers in the country to provide incite for when the country is considering strategies for PV deployment. This information can therefore be used by the Government, policy makers and other decision makers to review the pathways for PV deployment in T&T. This thesis was developed primarily for the Government of the Republic of Trinidad and Tobago and the relevant ministries and committees engaged in the development of the renewable energy policy for T&T. Other academics seeking to conduct research on solar PV in T&T are also part of the target audience.

Trinidad and Tobago can adopt a range of policies to encourage the deployment of solar photovoltaic systems including the feed-in tariff policy, capacity building, and removal of subsidies for conventional power generation. Three policy scenarios were constructed using these policies to represent possible pathways for PV deployment in T&T. In Scenario 1, the feed-in tariff (FIT) policy can be adopted to rapidly increase the installed capacity of PV in the country. Employing the FIT policy in T&T will encourage investors such as private homeowners to install PV panels on their rooftops and feed renewable electricity into the grid while receiving payments for each kWh fed into the grid. Scenario 2 displays another pathway for the deployment of PV in Trinidad and Tobago. The country can wait until grid parity is reached before scaling up or rapidly deploying PV but it will need to remove the subsidy so that the true cost of electricity production is revealed. Until grid parity is reached, the country can focus on capacity building where actors that are important to the deployment of PV will gain experience and knowledge in the field of PV technologies. Capacity building ensures that when grid parity is reached, stakeholders and actors in the field of PV deployment are experienced and familiar with the technology so that it can be effectively deployed. T&T can rapidly increase the installed capacity of PV when grid parity is reached since the technology is more affordable and the stakeholders are familiar and already experienced with the technology. Finally, Scenario 3 represents another pathway for PV deployment. In this scenario, the country can focus on capacity building until grid parity is reached but without removing the subsidy for electricity. Scenario 3 incorporates similar capacity building activities as described in Scenario 2 where stakeholders gain experience and knowledge with PV systems. However, if the country waits for grid parity to be reached, it may occur after 2050 at the current electricity rates. The country should be mindful of the fact that the natural gas reserves are expected to last another 10 years. As such, unless new reserves are discovered by 2021, there may be no local natural gas to provide electricity and the country would have to import the natural gas. The author advises that Scenario 3 should be avoided and PV deployment in T&T can occur by incorporating a combination of Scenarios 1 and 2.

After reviewing the scenarios, the author devised a range of recommendations issuing from the research. One includes the fact that in order to incorporate grid-connected PV into the electricity mix in T&T, the legislation needs to be amended. The legislation to enable open access is not available which means that the Government should amend the electricity legislation and open up the opportunity for electricity production so that power can be generated from grid-connected PV. If the country wants to take aggressive steps to deploy RE in the country, one of the ways that it can do this is to design and implement an attractive FIT which supports the growth of renewable electricity. However, this option requires changes in the structure of the electricity sector and the governing legislation as soon as possible. Capacity building can be initiated at the preparatory phase of deploying PV. The Government could focus on building the capacity for PV while waiting for costs of PV technologies to decrease. As such, the Government can provide training and education in the field of RE development and ensure that employment opportunities are accessible to the local population. Energy subsidies provide benefits that are mainly short term in nature so it is important to reduce or remove them to address the challenges that they impose. If these subsidies are removed or reduced, they can encourage energy efficiency, energy conservation and furthermore increase the attractiveness of renewable energy. Removing the subsidies enables PV to be more attractive and have a fair and competitive chance for deployment. Finally, T&T should try to achieve grid parity before the natural gas reserves deplete so that renewable electricity deployment is attractive.

There is limited research on renewable energy in T&T therefore suggestions for further research include researching other types of renewable energy technologies that can be deployed in the country. One topic in particular that can be researched is the use of solar water heating for homes in T&T.

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Abbreviations

bcm : billion cubic metres

EIA: Energy Information Administration

ESI : Energy Sustainability Index

FIT : Feed-in tariff

IEA : International Energy Agency

kW : Kilowatt

kWh : Kilowatt Hour

kWh_p : Kilowatt Hour Peak

LNG : Liquefied Natural Gas

MT : Metric tonnes

MW : Megawatt

MWh : Megawatt hour

POWERGEN : Power Generation Company of Trinidad and Tobago

PV : Photovoltaic

RE : Renewable Energy

REC : Renewable Energy Credit

RIC : Regulated Industries Commission

tbd : Thousand Barrels Daily

tmb : Thousand Million Barrels

tcm: Trillion Cubic Metres

T&T: Trinidad and Tobago

TT$: Trinidad and Tobago dollar

T&TEC: Trinidad and Tobago Electricity Commission

UNDP : United Nations Development Programme

US$: United States dollar

USA : United States of America

WEC : World Energy Council

1 Introduction

1.1 Energy for a sustainable future

International Context

Energy is a topic of importance for sustainable development as it influences environmental, social and economic aspects of development of which include employment, education, health, and access to water (UNDP 2011a). The global demand for energy is projected to increase in the future. The world primary energy consumption grew by 45% over the last two decades and it is expected to grow by 39% over the next 20 years (BP 2011). The two main driving forces behind the increase in energy demand are population and income growth.

According to the International Energy Agency (IEA) (2010e), the world's energy future faces uncertainty amidst the global economic crisis of 2008-2009 which placed energy markets around the world in a difficult position. Therefore, the future global energy scenario will be influenced by the pace at which the global economy recovers from the crisis. The onus rests on governments and how they respond to the challenges of energy security and climate change as this will influence the energy future of the world in the long term (IEA 2010e). The global energy outlook to 2035 depends on government policy actions and how those actions influence technology, the price of energy services and end-user behavior (IEA 2010e).

There is an urgent need to address the global challenges of climate change, energy security and sustainable development through the acceleration of advanced clean energy technologies (IEA 2010c). Over the last few years there have been global commitments and plans to address climate change as well as phase out fossil-energy subsidies. If these plans are implemented, they would have a real impact on energy demand and related carbon dioxide (CO_2) emissions (IEA 2010e). One such plan includes using policies to increase the share of renewable energy sources in the energy supply.

Renewable energy sources are expected to become more competitive as the technology matures and fossil-fuel prices increase but government support is required. According to the IEA (2010e), this support can be encouraged by acknowledging the long-term economic energy security and environmental benefits of renewables. In 2009, renewable sources of energy delivered 18% of the global electricity supply (IEA 2010e). Renewable energy sources according to the IEA (2010d) will have to play a central role in moving the world onto a more secure, reliable, and sustainable energy path. Renewable energy (RE) is growing and is receiving policy support from governments. Many countries are increasing renewable energy in their energy mix to increase energy security whilst addressing issues relating to the climate and the environment.

Governments are setting policy targets for renewable electricity where recently, many targets are set to be 15-25 percent by 2020 (REN21 2010). The best scope for increasing the use of renewables lies in the power sector (IEA 2010e). The world's demand for electricity is expected to grow more strongly than any other final form of energy. Additionally, electricity generation is also experiencing a shift toward low-carbon technologies because of higher fossil-fuel prices and policies to reduce CO_2 emissions and increase energy security (IEA 2010e). According to Bhandari and Stadler (2009), exploiting renewable energy sources is a good solution to generate electricity especially with the scarcity of fossil fuels and their negative environmental impacts.

At present, renewable energy provides 19% of the global final energy consumption and the main areas that it replaces conventional fuels include, power generation, hot water and space heating, transport fuels, and rural energy services. The renewable energy generating capacity is increasing. In 2009, 1230 GW of generating capacity was derived from renewable power which accounts for more than 25 % of the total generating capacity globally. Many technologies contribute to renewable power generation. Of all the renewable energy technologies, PV increased the fastest at a rate of 60% annually between 2004 – 2009 (REN21 2010).

Solar energy is the most abundant energy resource on Earth where the energy that hits the Earth's surface in one hour is approximately the same as the amount which is consumed by all human activities in one year (IEA 2010c). Solar photovoltaic (PV) power is a reliable technology with potential for long-term growth. Solar PV currently provides approximately 0.1% of the total global electricity generation but it is estimated that by 2050, PV will provide approximately 11% of global electricity production (IEA 2010c). Solar PV generates electricity in more than 100 countries and it is currently the fastest growing power-generation technology in the world (REN21 2010). The cost of solar PV modules are declining and the efficiency of the modules are expected to increase (REN21 2010).One scenario estimates that by 2020, PV will reach grid parity, that is, competitiveness with electricity grid retail prices (REN21 2010). However, grid parity may be reached in some selected electricity markets first which include countries with high solar radiation as well as high retail electricity prices.

Over the last 15 years, the adoption of policies to promote renewable energy has increased (REN21 2010). More than 85 countries had some type of policy target by 2009 where many national targets were for shares of electricity production. At least 83 countries have some type of policy to promote renewable power generation (REN21 2010). The most common policy is the feed-in tariff, which has been implemented in a growing number of countries recently, and has been proven to be the best support mechanism to rapidly increase the share of renewable energy production and use (Mendonça, Jacobs, and Sovacool 2010). From 1978 to early 2010, 78 countries have adopted feed-in policies to deploy renewable energy (REN 21 2010).

Trinidad and Tobago Context

The Republic of Trinidad and Tobago (T&T) is a twin island nation located in the southern part of Caribbean (Appendix 1). Trinidad and Tobago covers an area of 5,128 km^2 and has a population of 1.3 million (CSO 2010). T&T is found at latitude 10^0 North, longitude 61^o West so the country is located near the South American continent, northeast of Venezuela's coastline (Dawe 2008). The country is classified as a high income country with an unemployment rate of approximately 5% according to the World Bank (2011). The country is also ranked high on the UNDP Human Development Index (HDI) where it is placed 59th out of a total of 169 countries (UNDP 2010).

T&T is the leading producer of oil and gas in the Caribbean. Over the last 25 years, the country's economy has transformed from a predominantly oil-based economy to an oil and gas economy. According to the statistics from the Central Bank of Trinidad and Tobago (2010), the energy sector accounted for 35.8% of the GDP in 2009 and 49.1% in 2008. T&T therefore has an economy that is heavily based on an energy sector driven by fossil fuel resources (Sharma and Aiyejina 2010). These oil and gas resources are finite and the country needs to consider alternatives to sustain itself in the future when these energy sources have been exploited (Dawe 2008). Calculations have estimated that the oil reserves have 15 years left while gas reserves have 10 years left at the current rates of extraction (BP 2010). 99% of the power generation in T&T comes from natural gas which is a non-renewable source of energy and with the 10 years left for natural gas, the country needs to identify and adopt alternative sources for electricity production.

T&T's CO_2 emissions per capita have been increasing. In 1971 T&T had 8.15 tonnes of CO_2 per capita (IEA 2010a) but it has increased over the years as the country's CO_2 emissions per capita in 2008 was 28.37 tonnes of CO_2 per capita. Jamaica, another country in the Caribbean, had lower CO_2 emissions recorded in 2008 where the emissions were 4.44 tonnes CO_2 per capita (IEA 2010a). Other countries such as the United States of America and the United Arab Emirates had 18.38 tonnes of CO_2 per capita and 32.77 tonnes of CO_2 per capita respectively (IEA 2008). Among the world's countries, T&T's ranking of CO_2 emissions per capita increased from 69th in 1971 to 3rd in 2008 (Thomas, 2009).

The World Energy Council (WEC) developed an Energy Sustainability Country Index (ESCI) which assesses three core dimensions of energy sustainability in addition to three broader dimensions of political, societal and economic strength in many countries. Under each of the dimensions, indicators are assessed and scores are provided and calculations determine the ranking of the countries (WEC 2010). Energy sustainability was defined by the World Energy Council as having three core dimensions; energy security, social equity, and environmental impact mitigation (WEC 2010). T&T was ranked number 85 in the energy sustainability country index ranking in the year 2010 (WEC 2010) out of 91 other countries. Other net energy exporting countries such as Saudi Arabia and Nigeria obtained higher sustainability rankings of 68 and 46 respectively. In this index, the higher the country ranking, the greater the energy sustainability of the country. Further details concerning the ESCI are provided in Section 2.4.

Trinidad and Tobago is currently in the process of drafting a renewable energy policy and a renewable energy framework has already been established. Up to this date, the renewable energy policy is a draft at this stage and it has not been approved by Cabinet as yet. The main objective of the policy is to examine strategies and make recommendations for introducing renewable energy (RE) into the local energy mix (MEEA 2011). The Minister of Energy and Energy Affairs of T&T stated that renewable energy and energy efficiency were key elements for the country's long term energy security which could also reduce greenhouse gas emissions, diversify the economy, as well as create new business and employment opportunities (Matroo 2011). According to the draft national climate change policy for T&T, "Enhancing the use of renewable energy… will augment power generation and demand and provide greater energy security for the future" (GORTT 2009).

Dawe (2008) suggested that Trinidad and Tobago should be developing and implementing policies to ensure that the country is self-sufficient and prosperous after the hydrocarbons have been fully extracted. There is however, limited academic research conducted in the area of developing strategies for introducing renewable energy particularly solar photovoltaic power into T&T's local energy mix. Currently, the country is devising strategies to maximise renewable energy resources as well as to promote sustainable development to achieve a low carbon economy.

The renewable energy policy framework identified a range of renewable energy technologies and strategies to be considered. The framework sets an installed capacity target of 60 MW of renewable electricity to be attained by 2020 but it states that the bulk of this is expected to come from wind energy. Solar photovoltaic power is mentioned in the framework as one of the applications to be incorporated into the residential, commercial and other institutional sectors. According to Dawe (2008), solar energy is one of the alternatives that T&T can adopt since the country is close to the equator and has sun throughout the year. The framework suggests activities which can be used to encourage renewable energy but there is limited literature available on the details of these activities applied to Trinidad and Tobago. Feed-in tariffs were identified as one of the activities but there is currently no research in the area of feed-in tariffs applied to T&T. Thus, the thesis reviews the FIT scheme and applies the policy in the context of T&T.

Solar PV technology is on a steep learning curve and the factors which will reduce costs include technological improvements, mass production, economies of scale, and improved operation (Ramadhan and Naseeb 2010). Trinidad and Tobago has favourable climatic conditions for PV and it is possible to implement the technology as the efficiencies are increasing and the costs are declining. However, the major barrier to RE deployment in the country is the relatively cheap costs of hydrocarbon-generated electricity. The affordability of conventional fossil fuel based energy does not promote the use of renewable energy in the country.

One of the barriers identified by the Government of Trinidad and Tobago is the lack of local education, awareness, training and overall capacity building in the field of RE deployment in T&T. According to the MEEA (2011), capacity in the RE field needs to take place through training and skills development.

1.2 Problem Statement

T&T is commencing actions to establish a foundation for growth in the renewable energy sector and the country is pursuing a framework to facilitate renewable energy development. However, the country lacks literature on renewable energy policy development in the local context. The Government of Trinidad and Tobago recognises the lack of local education, awareness, training and overall capacity building in the field of RE deployment in T&T. There is a lack of academic research into renewable energy policy in Trinidad and Tobago and by extension, policy information addressing solar photovoltaic development in the country. Stakeholders and relevant actors in the energy sector in T&T also have little experience and familiarity with photovoltaic systems and using policies to deploy such a technology.

T&T identified strategies to deploy renewable energy but the country needs to assess the strategies which other countries have adopted to increase renewable energy technologies. There is limited academic research on alternative power sources and strategies or policies that the country could adopt to generate renewable sources of electricity. If the country is to deploy renewable sources of electricity, there needs to be a strategy or policy which encourages generation of renewable electricity since the current tariffs for electricity generated by natural gas is cheap. The citizens of T&T need incentives or policies that persuade them to deploy renewable energy technologies particularly solar PV. The lack of familiarity with RE and PV technologies means that the country also needs to build capacity so that stakeholders are informed and experienced with the technologies.

A renewable energy policy is in the process of formulation but even after the policy is constructed, there is a need to put policy plans into action. This thesis provides recommendations for PV deployment based on experiences of other countries, as well as based on the existing structure of the country's capacity to implement plans for renewable energy deployment.

1.3 Research Focus

The particular renewable energy technology explored in this thesis is solar photovoltaic (PV) systems. Although there are a range of renewable energy technologies that can be applied to T&T, this thesis focuses on PV which is being used to provide encouragement for the development of other types of renewable energy technologies which can possibly be deployed in T&T. There are several reasons supporting the case for PV deployment in T&T. Firstly, T&T has the technical capacity whereby the climate is suitable for PV development. Additionally, the cost of PV is declining making it a competitive alternative energy source in the future. Finally, PV can diversify the electricity mix as well as reduce the need for gas thereby increasing the lifetime of the gas reserves in the country.

This thesis provides an illustration of a specific type of renewable energy technology in the context of policy making which is lacking in the country as it seeks to illustrate how PV deployment can be achieved. In order to cast light on PV deployment strategies and specifically with regard to T&T, this work reviews policies. One such policy, the FIT policy, is a successful policy used to deploy PV and as such is reviewed in this thesis. The concept of capacity building is also reviewed since the country lacks experience with PV technologies. The phase out of subsidies for conventional energy is the final policy reviewed in the thesis. The literature gathered, is used to develop scenarios for PV deployment in T&T as these can yield pathways that the country can assess to deploy PV.

1.3.1 Aim and Objective

The aim of the thesis is to contribute to the body of knowledge for the deployment of renewable energy technologies in T&T.

The objective of this work is to explore and describe scenarios for the deployment of solar photovoltaic power systems in T&T. The information generated can then be useful to policy makers as well as other researchers seeking to do research in the field of renewable energy deployment especially PV in T&T.

As such, the following research question was used to guide the thesis research:

> How could solar photovoltaic systems be deployed in Trinidad and Tobago?

1.3.2 Scope and Limitations

Renewable energy and energy efficiency are areas identified by the Government of Trinidad and Tobago which need to be addressed. They are both important for achieving sustainability but this thesis focuses on renewable energy. Research on energy efficiency is outside the scope of the research because more time would be needed to research this aspect. Energy efficiency is however, one of the aspects that the country can research and develop which will assist in improving the country's environmental sustainability.

There are many renewable energy technologies that can be researched and implemented but this thesis is looking into the applicability of solar PV as one of the technologies that can be deployed in the country as it was incorporated into T&T's renewable energy policy framework. A limited amount of academic research has been conducted in the field of PV and policy development in the country. Therefore, this work contributes to the body of knowledge that the country can incorporate or even build upon.

Although there are specific renewable energy technologies that can be implemented in T&T, analysing them will go beyond the scope of the study therefore the thesis is focusing on solar photovoltaic systems. The renewable energy policy framework suggests a range of measures to incorporate renewable energy in the country and the feed-in tariff was one such measure. This thesis reviews FIT which is one of the measures that the country is considering and applies it in one of the scenarios to illustrate how it can be used as a strategy for the deployment of PV in T&T.

This thesis contributes to an understanding of the feed-in tariff (FIT) policy. Therefore, a calculation is not performed since it is anticipated that the country will calculate a suitable tariff for T&T in the near future. This thesis reviews the experience of feed-in tariffs which is one of the strategies used to promote renewable electricity. Illustrating how to deploy PV with this strategy can provide guidance on how to deploy other RE technologies in T&T. The FIT experiences in Germany and Spain are reviewed because the lessons learned are valuable and should be considered if the FIT scheme is implemented for T&T.

The Government of Trinidad and Tobago recognised the lack of awareness and experience with renewable energy technologies which includes PV technologies. As such, the thesis reviews the concept of capacity building and the activities which are involved in building capacity for PV deployment, and the phase out of subsidies for conventional energy.

The thesis includes the topic of phasing out subsidies for conventional energy because subsidies can be a financial burden on government budgets. Although subsidies provide benefits, these benefits are usually short term in nature. Having artificially low energy prices can result in lower energy conservation measures and higher carbon emissions. Subsidies are considered unsustainable because they disproportionately benefit wealthier persons and damage the climate.

A range of limitations were encountered during the thesis process. The timeframe for this thesis only enabled for the research to explore the use of PV for electricity diversification in Trinidad and Tobago and not go into depth about other potential sources of renewable energy in the country. As such, the research is limited to Trinidad and Tobago and it focuses on reviewing feed-in tariffs, capacity building experiences for PV deployment, and phasing out of subsidies for conventional energy, which are then applied to T&T by constructing scenarios. In addition to the time, there is limited information related to renewable energy policy in the context of T&T. Also, there is not a wealth of information on solar PV in T&T as it is a technology that is currently being applied in remote areas and in telecommunication systems. Furthermore, contacting various actors in the field of energy or relevant sectors was difficult as many did not answer their phones or respond to emails and living in Europe did not permit interaction at their places of work. The thesis writing was conducted while the Government was producing the Renewable Energy Policy and stating plans to promote projects related to PV deployment. As such, not all the projects related to PV may be documented to the date of the thesis submission.

1.3.3 Methodology

In order to address the research question, this study was conducted in a series of phases:

1.3.3.1 Phase 1- Review and definition of topic

The background research into the topic commenced in January 2011 by writing a research paper for the course on Applied Research in Preventative Environmental Approaches (ARPEA). This paper was written to develop insights into Trinidad and Tobago's energy sector and review the prospects for renewable energy. Contacts were made with stakeholders in the renewable energy field in the Caribbean and T&T pertaining to renewable energy policy development in the region. A field visit was conducted in Trinidad and Tobago to obtain literature from the national library and obtain research for the ARPEA paper. The visit also provided an opportunity to attend the National Energy Policy Consultation which was part of the process for the development of a new energy policy for T&T. The consultation on Renewable Energy was attended on January 26, 2011, to observe stakeholder presentations and listen to public feedback. The consultation provided further information and understanding of the direction the Government was taking with regard to renewable energy development. Phase 1 for the thesis enabled brainstorming to identify relevant actor groups and identify sources of literature.

1.3.3.2 Phase 2- Data collection

After conducting research with the ARPEA paper, the final thesis topic was defined. Information was collected from primary and secondary sources. Primary sources of data were obtained from stakeholders in the renewable energy sector in T&T through email, skype, or phone calls over the thesis period from January 2011- May 2011. Primary sources of information were used to clarify information or provide relevant information that was not published on renewable energy, PV and electricity in the country. Contacts were made with relevant actors in the energy sector for the provision of data needed for the thesis. Stakeholders were mainly contacted in the Ministry of Energy and Energy Affairs, the University of Trinidad and Tobago, and the Trinidad and Tobago Electricity Commission. The Valentin Software was a software tool used to obtain data and calculate the amount of electricity a PV system can produce under Trinidad and Tobago's climatic conditions.

Secondary sources of information were obtained from books, reports, journals, articles, academic literature, publications, government documents, government websites, private company websites and other internet searches. The literature review provided background information on a range of relevant topics. The energy sector of Trinidad and Tobago was reviewed since an understanding of the history and structure of the energy sector in Trinidad and Tobago provides insight into how renewable energy, particularly PV, fits into the energy sector to further develop it and by extension the economy. The thesis also reviews literature on the technological, economic, and policy aspects of PV. Experiences of some countries in PV development are included to portray how they deployed PV systems. Detailed information was provided on the policies which were used to develop scenarios. The policies that were reviewed were the feed-in tariff policy, capacity building, and the phase out of subsidies for conventional energy. Further information was gathered on the applications of PV deployment in the context of T&T.

1.3.3.3 Phase 3- Development of Scenarios

Scenarios were used as a method for guiding the exploration of pathways for the deployment of PV. The literature in the thesis was reviewed and scenarios were developed to illustrate the possible pathways for PV deployment in T&T. The pathways for how PV can be deployed in T&T were depicted through visual representation and a narrative description. Three scenarios were developed as guides to the deployment of PV in T&T. The information outlined in each scenario could be reviewed by policy makers in the country to provide incite for when the country is considering options for PV deployment. This information can be used by the Government, policy makers and other decision makers to review the pathways for PV deployment in T&T.

1.3.4 Target Audience

This thesis is being developed primarily for the Government of the Republic of Trinidad and Tobago and the relevant ministries and committees engaged in the development of the renewable energy policy for T&T. The thesis will, by extension, provide relevant information for policy makers and other decision makers when focusing on the deployment of PV for the country.

Other academics seeking to conduct research on solar PV in T&T are also part of the target audience. Energy rich countries seeking to deploy renewable energy technologies particularly PV systems can also benefit from this body of research. This thesis can also be used to assist in policy development for the generation of electricity from other possible renewable energy sources such as wind and biomass which the country is considering to deploy.

1.3.5 Outline of the study

The thesis is structured in the following way:

Chapter 1: Provides the context for understanding the topic, why it is being researched and how the research is conducted.

Chapter 2: Literature review on Trinidad and Tobago's energy sector. The information provides a justification for the deployment of renewable energy in the country. An understanding of the history and development of the energy sector in Trinidad and Tobago provides insight into how renewable energy particularly PV, fits into the energy sector to further develop it and by extension the economy.

Chapter 3: Reviews literature on the technological, economic and policy aspects of PV as well as experiences of some countries with increasing the deployment of grid-connected PV systems.

Chaper 4: Provides information on the status and capacity for PV technology in T&T. It also describes scenarios for PV deployment in T&T by applying research from the thesis.

Chapter 5: Concludes and provides recommendations for PV deployment in T&T.

2 Review of Trinidad and Tobago's energy sector

This section reviews the energy sector of Trinidad and Tobago and explores areas where renewable energy, and by extension PV, can be deployed.

2.1 A brief history of the energy sector

The history of T&T's energy sector illustrates the absence of renewable energy technology since the country's infrastructure was ingrained in the hydrocarbon industry for several decades. The country's energy sector is divided into three main components: the upstream, midstream and downstream sectors. The upstream sector refers to the exploration and production of oil and gas (Renwick 2009). The midstream and downstream sectors in Trinidad and Tobago are linked where the former sector involves the refining of oil and gas, and the latter refers to the selling and distribution of the refined products (Renwick 2009).

Trinidad and Tobago has oil and natural gas resources. The oil and gas fields exist mainly on the southern end of the island of Trinidad (Appendix 2) as well as offshore on the southeast and southwest shelves (Marcelle-De Silva and Jagai, 2001; MEEI, 2006; Renwick, 2007; Dawe 2008). Oil production in T&T has occurred for over 100 years (Dawe 2008). The first successful oil well in T&T was drilled in 1866. In 1911, the country shipped its first export cargo of crude oil and since then crude oil production increased over the years but peak oil production occurred in the year 1978 (MEEIa 1998). In 1917, a refinery was built which manufactured products such as liquefied petroleum gas (LPG), gasoline, kerosene, gas oil and fuel oil for local consumption and for export to regional and international markets. Oil exports were the dominant external revenue earner for T&T until 1999 (Dawe 2008).

Trinidad and Tobago's economy transitioned in 1999 with the exportation of liquefied natural gas (LNG) (Dawe 2008). Natural gas became the major revenue earner from this period onward (Dawe 2008). The first major natural gas discovery occurred in 1968 (MEEIa 1998). The discovery of gas led to major developments in the energy industry (MEEIa 1998). Since 1953, natural gas was used to produce electricity for the country (Martin 2009).

Natural gas is an important feedstock for the manufacture of fertilizers such as ammonia and urea, and chemicals like methanol. There are currently 11 ammonia plants that include two ammonia complexes which have a total annual capacity of 5.2 million metric tonnes (MT) (MEEA 2009). The methanol industry began since 1984 and it has a production capability close to 6 million MT of methanol annually making it one of the largest producers of methanol in the world and it is the largest supplier of methanol to North America and a significant supplier to the European Market (MEEA 2009).

2.2 Supply

2.2.1 Primary energy mix

In 2008, natural gas accounted for 90% of the total primary energy supply in T&T (IEA 2010b). Oil, on the other hand, accounted for approximately 9.9% of the total primary energy supply (IEA 2010b). Electricity production in T&T is mainly from natural gas (IEA 2010b).

2.2.2 Reserves

Trinidad and Tobago has hydrocarbon resources that are greater than its domestic requirements. This enables the country to export the hydrocarbon resources and obtain monetary benefits. A review of the scale of the reserves was conducted to provide an understanding of how many years may be left for the country to export and obtain revenues from the conventional fuels.

A review of proved natural gas reserves for the country revealed that it has approximately 10 years of natural gas remaining. Table 2-1 illustrates proven natural gas reserves of Trinidad and Tobago and compares it to other countries to illustrate the scale of the country's reserves. Venezuela is geographically close to T&T and Venezuela's gas reserves are almost 13 times larger than the reserves in T&T. T&T has less than 1% share in the global total of natural gas reserves. The Russian Federation has the highest proved natural gas reserves from the statistics that were reviewed. The trend for the gas reserves in Trinidad and Tobago is declining, while production is showing an increasing trend (BP 2010).

Table 2-1 Comparison of natural gas reserves in Trinidad and Tobago, Venezuela and the Russian Federation

	T&T	Venezuela	Russian Federation
At end 1999 (tcm)	0.61	4.15	42.44
At end 2008 (tcm)	0.44	4.98	43.30
At end 2009 (tcm)	0.44	5.67	44.38
Share of global total (%)	0.2	3.0	23.7
R/P ratio (years)	**10.7**	>100	84.1
Tcm: Trillion cubic metres			
R/P- reserves-to-production (reserves are divided by the production, resulting in the length of time those remaining reserves would last if production were to continue at that rate)			

Source : BP 2010

In addition to the gas reserves, Trinidad and Tobago has oil reserves which are expected to last another 15 years approximately. Table 2-2 summarises the proven oil reserves for the country and provides a comparison with other countries. The countries illustrated in Table 2-2 have greater oil reserves than T&T. Venezuela is close to T&T geographically and statistics on Saudi Arabia provide an understanding of the small scale of T&T's oil reserves in relation to the global context.

Table 2-2 Comparison of oil reserves in Trinidad and Tobago, Venezuela and Saudi Arabia

	T&T	Venezuela	Saudi Arabia
At end 1999 (tmb)	0.8	76.8	262.8
At end 2008 (tmb)	0.8	172.3	264.1
At end 2009 (tmb)	0.8	172.3	264.6
Share of global total (%)	0.1	12.9	19.8
R/P ratio (years)	**15.1**	>100	74.6
Tmb- thousand million barrels			
R/P- reserves-to-production (reserves are divided by the production, resulting in the length of time those remaining reserves would last if production were to continue at that rate)			

Source: BP 2010

The R/P ratio provides estimates as to the number of years that oil and gas reserves are expected to last but there are limitations to such statistics because exploration for new fields in the countries reviewed can lead to discoveries of new oil and gas fields.

2.2.3 Energy production

From 1999 to 2010, natural gas production in T&T generally increased and according to the United States Energy Information Administration (EIA) (2009), domestic consumption is also increasing. Natural gas production in T&T involves four main producers, Petrotrin, EOGR (EOG resources), BGTT (BG Trinidad and Tobago) and BPTT (BP Trinidad and Tobago) (GSTT 2010). Out of the four aforementioned producers, BPTT produces the largest share of the gas production (GSTT 2010). In 2008, T&T produced 39.3 bcm (billion cubic metres) of natural gas and countries such as the United States of America (USA) and Venezuela produced 574.4 bcm and 29.2 bcm respectively (BP 2010). Figure 2-1 illustrates the trend of natural gas production in T&T from 1999 to 2008.

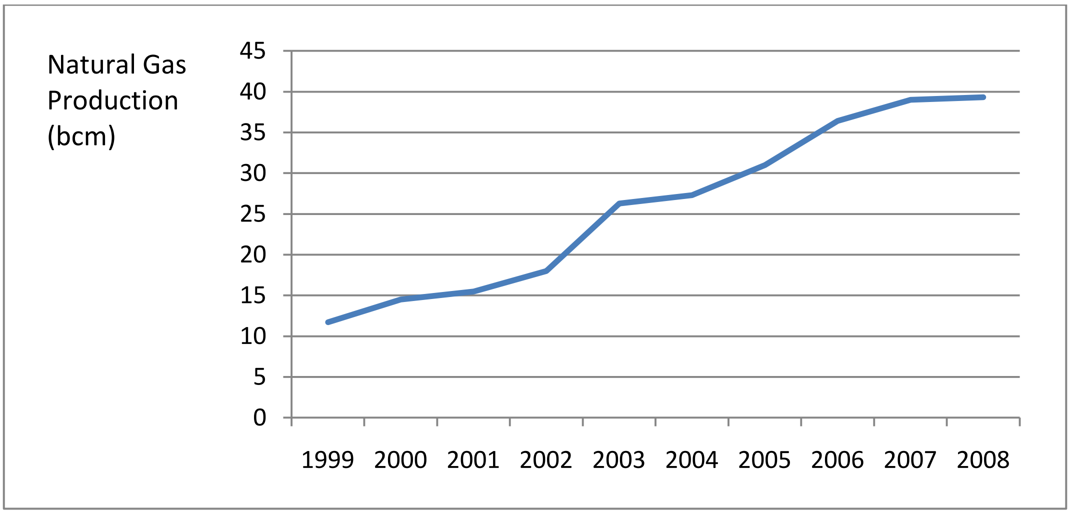

Figure 2-1 Natural Gas production in Trinidad and Tobago

Source: BP 2010

The trends in oil production and consumption in T&T are different from those for natural gas. Research shows that oil production is slowly declining while consumption is showing an increasing trend (EIA 2009). In 2008, T&T produced 149 thousand barrels daily (tbd) and countries such as the United States of America and Venezuela produced 6,734 tbd and 2,558 tbd respectively. According to GSTT (2010), the main producers of oil in T&T over the period 1999 to 2010, were BGTT, NGC (National Gas Company), Trinmar, Repsol, Petrotrin, EOG, BHP (bhp billiton) and BP. Figure 2-2 illustrates the trend of oil production in T&T from 1999 to 2008.

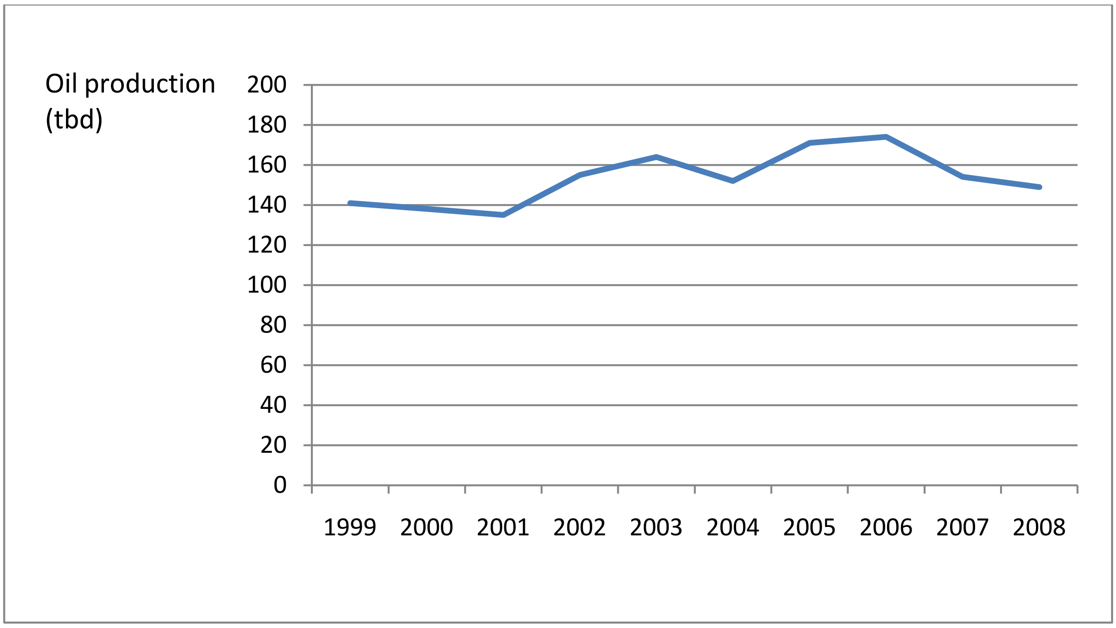

Figure 2-2 Oil production in Trinidad and Tobago

Source: BP 2010

2.3 End Use

2.3.1 Domestic End use

The largest end user of energy in T&T is the downstream industrial sector. This sector is mainly dependent on gas where the petrochemicals industry accounts for approximately 75% of the domestic gas demand.

There are many uses for natural gas in T&T. Natural gas is dominantly used to be converted to liquefied natural gas (LNG). More than 50% of the natural gas is converted to LNG. Figure 2-3 illustrates the uses of natural gas.

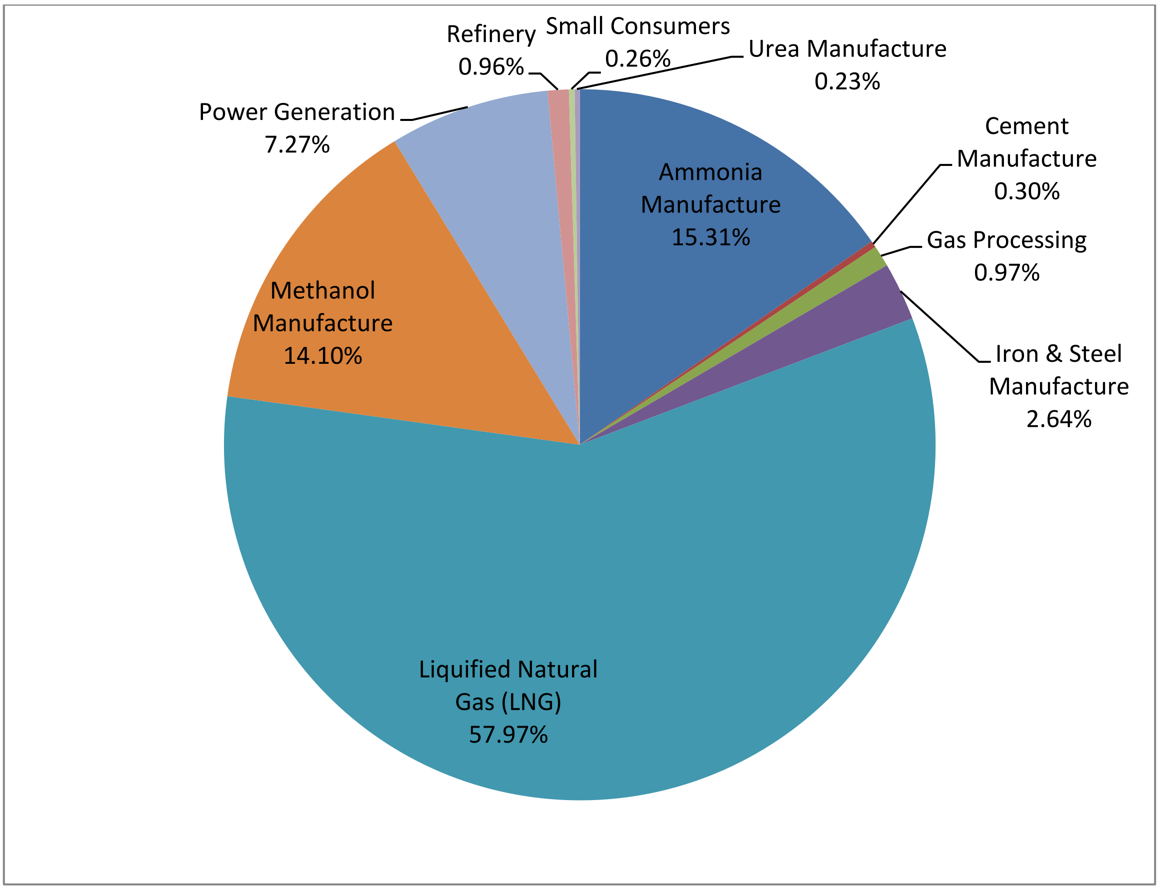

Figure 2-3 Natural gas usage by sector

Source: MEEI 2010

2.3.2 Energy exports

Energy commodities account for approximately 80% of T&T's exports and the bulk of the country's foreign exchange earnings. The energy exports include oil, liquefied natural gas (LNG), methanol, ammonia, urea and other petro-products. (ECTT2011).

Natural gas is exported from T&T in the form of LNG. T&T is one of the largest exporters of LNG in the world. In 2009, T&T exported 19.74 bcm of natural gas, all of which was in the form of LNG (BP 2010). The largest exporter of LNG in 2009 was Qatar which exported 49.44 bcm. The main importer of LNG from T&T is the USA (BP 2010). Figure 2-4 illustrates the countries that imported LNG from T&T in 2009.

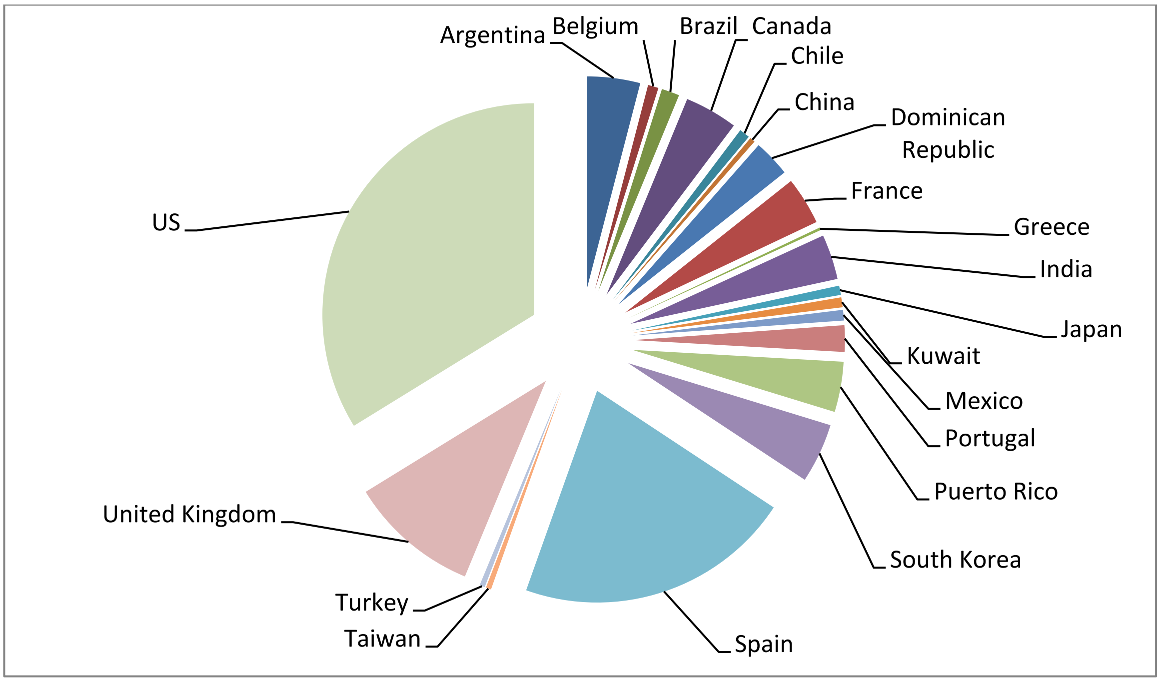

Figure 2-4 Countries that import liquefied natural gas from T&T

Source: BP 2010

2.4 Energy Sustainability in T&T

There are several aspects of T&T's energy sector that provide justification for alternative energy deployment. The World Energy Council (WEC) Energy Sustainability Index (ESI) provides information on a range of indicators that illustrates T&T's position amongst other countries regarding energy sustainability. Table 2-3 compares indicators under the Energy Security dimension of the index as well as the Social Equity and Environmental Impact Mitigation dimensions of the index that the WEC assessed.

Energy sustainability was defined by the World Energy Council as having three core dimensions; energy security, social equity, and environmental impact mitigation (WEC 2010). Each of the aforementioned dimensions is defined to provide the context of the concept of energy sustainability. One of the dimensions, energy security, is concerned with the reliability of the energy infrastructure, the ability of the energy companies to meet current as well as future demand, the ability to maintain revenues from external sales markets, and the effective management of primary energy supply from domestic and external sources. Energy security applies to both net energy importers and exporters and it is the latter that is applicable to the country of T&T. Social equity, another dimension, relates to the affordability and accessibility of the energy supply in the population. Finally, the last dimension is environmental impact mitigation which incorporates the use of renewable and low-carbon sources of energy, and the achievement of supply- and demand-side to energy efficiencies (WEC 2010).

The World Energy Council (WEC) conducted an assessment of the energy profile of WEC member countries which led to the development of an Energy Sustainability Country Index.

The index reviews a total of 22 indicators for each country which were ranked and an overall ranking was achieved which ranked T&T as number 85 out of 91 countries.

Regarding the index, there are two categories: energy performance and contextual performance. The energy performance has a higher ranking and it contains the three core dimensions which were mentioned before; energy security, social equity and environmental impact mitigation. Figure 2-5 illustrates the structure of the ESI and the corresponding weightings allotted for each dimension.

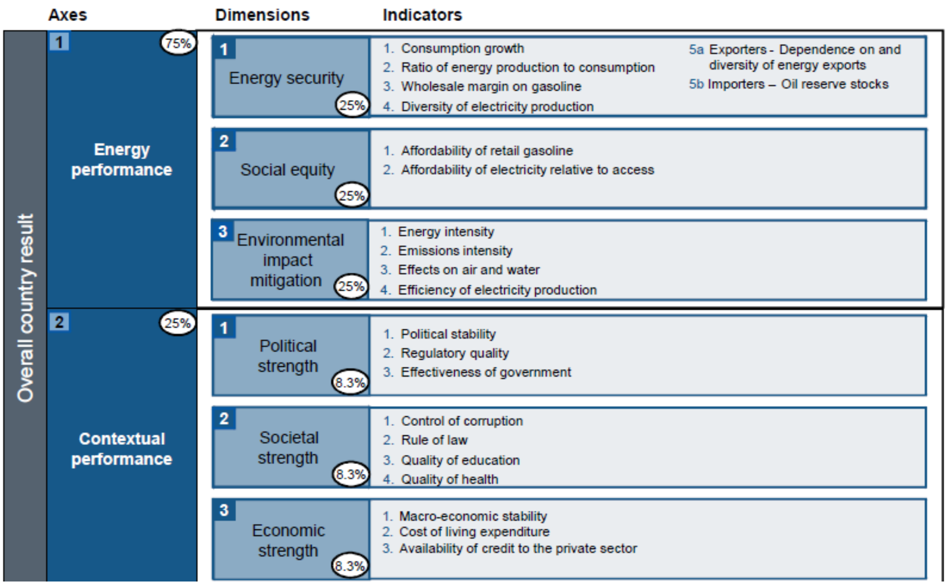

Figure 2-5 Index structure and weighting

Source: WEC 2010

Table 2-3 provides the energy sustainability indicators obtained from the WEC for T&T. The indicators in Table 2-3 range from 0 to 10 where the former represents a lower sustainability and the latter represents a higher sustainability. This table summarises the rankings for various indicators and compares them with other countries which provides an understanding of the overall energy performance.

Table 2-3 Comparison of Energy Sustainability Indicators of selected countries

Axes	Dimension	Indicators	Country (oil & gas producing, countries)		
Energy Performance	Energy Security		Trinidad	Norway	Nigeria
		Consumption growth	0.11	6.38	5.94
		Ratio of energy production to consumption	8.66	9.77	10.00
		Wholesale margin on gasoline	2.32	5.34	4.17
		Diversity of electricity production	**1.63**	2.39	5.43

		Exporters- dependence on and diversity of energy exports	3.05	8.21	3.42
	Social equity	Affordability of retail gasoline	-	4.49	7.25
		Affordability of electricity relative to access	4.24	6.96	1.74
	Environmental Impact Mitigation	Energy intensity	0.0	3.84	9.34
		Emissions intensity	0.0	7.58	6.37
		Effects on air & water	3.66	10.00	0.00
		Efficiency of electricity production	1.38	9.66	5.29
Contextual Performance	Political Strength	NA	5.16 (Average indicator scores)	9.16	0.65
	Societal Strength	NA	3.5 (Average indicator scores)	9.22	0.51
	Economic Strength	NA	5.94 (Average indicator scores)	6.09	3.86
NA- Not Applicable					

Source: WEC 2010

Energy in the country is subsidised which results in the low cost of diesel fuel as well as low electricity prices (MEEA 2011).The cost of energy in the country is affordable and relatively cheap because it is subsidised by the Government. According to Iwaro and Mwasha (2010), energy subsidies are any type of government action aimed at the energy sector which can lower the cost of energy production or lower the price paid by energy consumers. The energy subsidies in T&T are mainly targeted to gasoline and diesel oil (Iwaro and Mwasha 2010). Gasoline and diesel oil are mainly used for domestic use, industrial use, transportation and electric use (Iwaro and Mwasha (2010). The gas subsidy that the Government paid in the year 2010 was TT $2.7 billion (US 0.42 billion) which was to keep down the price of transportation fuel (Taitt 2010). The fuel subsidy in 2008 was 0.8% of the country's GDP (IMF 2008). Electricity in Trinidad and Tobago is highly subsidised (A. Sharaf, personal communication, 20 April, 2011).

T&T's carbon dioxide emissions are increasing and forecasts illustrate that the country's CO_2 emissions will continue to increase. In 2003, T&T had approximately 17 million metric tonnes of CO_2 emissions and it is projected to increase over 40 million metric tonnes by 2012 (Boodlal, Furlonge and Williams 2008). Each sector in the country contributes to different levels of CO_2 emissions. The petrochemical sector is the dominant contributor of CO_2

emissions (Figure 2-6) followed by the power generation sector and the transport sector respectively (Boodlal *et al.* 2008).

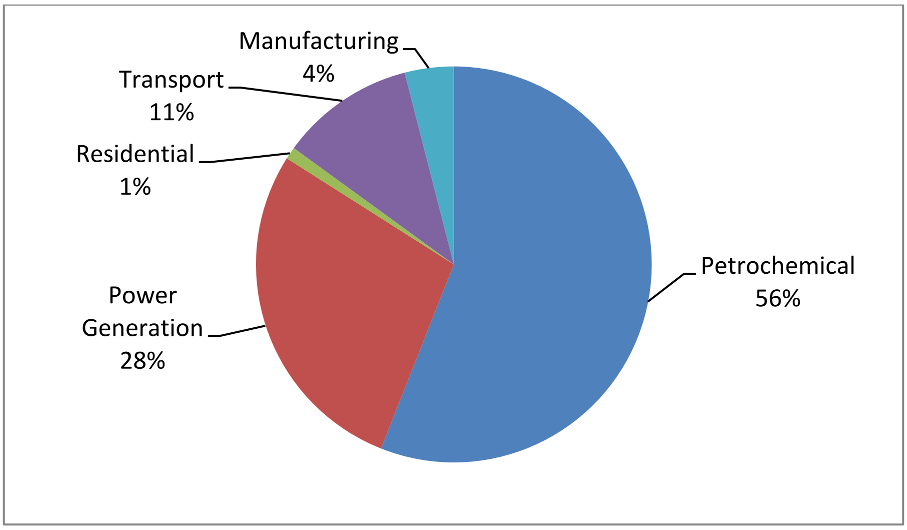

Figure 2-6 T&T's CO_2 emissions by sector

Source: Boodlal et al. 2008

2.5 Electricity sector in T&T

A brief review of the history of the electricity sector in the country revealed that electricity in T&T was introduced in the 1800's for the operation of tramway services in the transportation sector. In 1895, electricity was installed into buildings and street lights in T&T.

2.5.1 Electricity Production & Consumption

The dominant fuel used for electricity generation in T&T is natural gas. The Energy Sustainability Country Index illustrated that T&T has a low diversity of electricity production (highlighted in Table 2-3) since the country is highly reliant on natural gas to provide electricity for the industrial, commercial and residential sectors in the country. According to the IEA (2008), more than 99% of T&T's electricity is derived from natural gas. In 2008, T&T produced a total of 7,892 GWh of electricity (IEA 2010b). T&T meets all of its domestic electricity needs locally and therefore does not import or export electricity (EIU 2010). 97% of the population has access to electricity, the majority of which are connected to the grid, and the remaining areas are in remote locations which are not economical to electrify (I. Thompson, personal communication, January 14, 2011).

Electricity is used in three main sectors of the economy; the industrial, residential, and commercial and public service sectors. Currently, electricity is not utilised for transportation in the country. Out of the three sectors that use electricity, industry consumes the most. Figure 2-7 illustrates the share of electricity consumed by each sector. The total electricity consumed by the country in 2010 was 7.72 TWh (IEA 2010b). In 2008, out of the total electricity supplied to consumers, 95.8% was consumed therefore, 4.2 % of the electricity supplied was lost (IEA 2008).

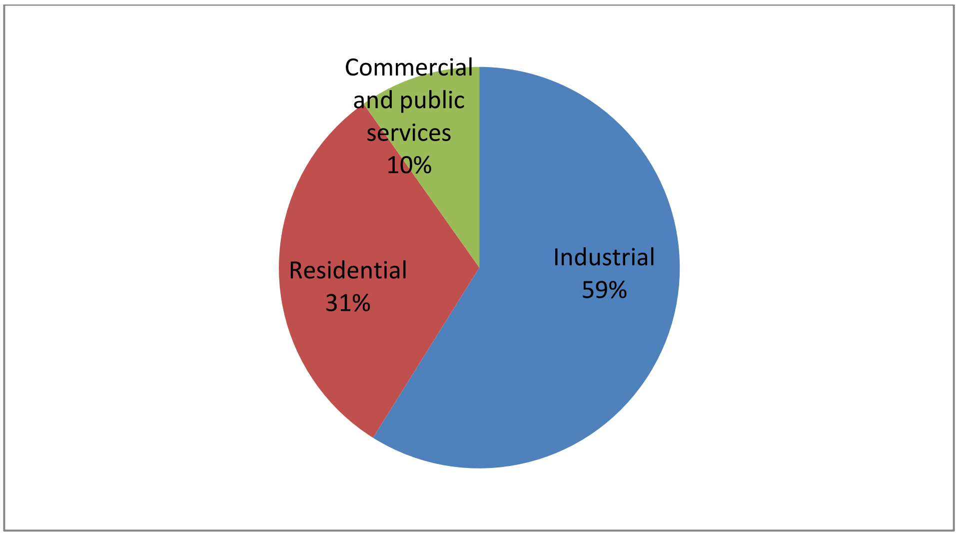

Figure 2-7 Percentage of electricity consumed by the industrial, residential and commercial and public services sectors

Source: IEA 2008

The demand for electricity in T&T is steadily growing (Sharma and Aiyejina 2010). Figure 2-8 illustrates that over a 12 year period, the demand for electricity increased gradually in the residential and commercial sectors and increased at a faster rate for the industrial sector. The residential demand increased over the last decade because the Government started a housing construction programme in 2002 to construct thousands of new houses a year over a 7 year period (EIU 2011).

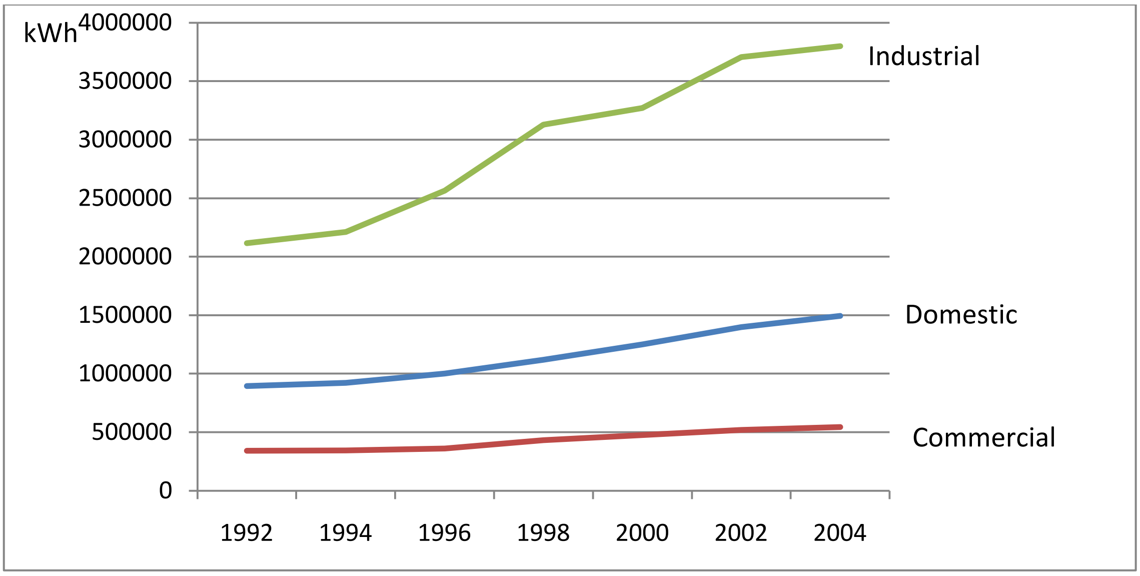

Figure 2-8 Trend in energy demand in T&T 1992-2004

Source: CSO 2007

On an average day, the demand for electricity over a 24 hour period in T&T has two peaks. The first peak is the day-time peak of up to 8 hours duration which ends after 4:00 p.m. (16:00). The second peak is a higher night-time peak of 3 hours duration which commences at 7:00 p.m. (19:00). The day-time peak is primarily driven by industrial activities and the night-time peak is mainly due to lighting loads and residential demands (T&TEC 2004).

The country currently has sufficient electricity and distribution capacity but there are intentions to upgrade the facilities so that the rising demand can be accounted for especially in the industrial sector (EIU 2011). Recent forecasts predict that the demand for electricity will double within the next decade and if plans to increase industrial activity come to fruition, it is possible that peak demand will exceed 2,500MW by the year 2016 (Martin 2009). According to Martin (2009), the growth of the industrial sector depends on the continuous supply of electricity in adequate quantities as well as in a safe, reliable, efficient and cost-effective approach.

2.5.2 Electricity cost

The rate structure for residential customers uses a three-tiered system where the tiers are defined on the basis of electricity usage which is measured in kilowatt-hours (kWh) over a two-month billing cycle. In Tier 1, residential customers pay TT 26 cents per kWh for consumption of up to 400 kWh. In Tier 2, they pay TT 26 cents per kWh for the first 400 kWh and 32 cents TT for each kWh beyond 400 kWh and up to 1,000 kWh. In Tier 3, customers pay the same as Tier 1 and Tier 2 but if they consume above 1,000 kWh they pay TT 37 cents per kWh for electricity (T&TEC 2011). The average price a residential customer pays for electricity is TT 32 cents per kWh which is approximately US 5 cents per kWh. A summary of the electricity tariffs for residential customers is provided in Table 2-4.

Electricity tariffs in T&T are reviewed annually and within the review period (2006-2011), the annual tariff adjustments have not always increased. The tariffs that were adjusted for residential customers decreased in 2008 for Tier 1. In Tier 2 and Tier 3 the tariffs were increased. Table 2-4 illustrates recent tariff reviews from 2006-2009 for the three tiers.

Table 2-4 Residential Electricity Tariffs (TT$) 2006-2009

Year	≤400 kWh	401-1,000 kWh	>1,000 kWh
2006	$0.27	$0.31	$0.34
2007	$0.27	$0.31	$0.35
2008	$0.25	$0.31	$0.36
2009	$0.26	$0.32	$0.37

Source: RIC 2009

The country has a low electricity tariff based on single cycle power generation utilising cheap natural gas (R. Maurice, personal communication, April 6, 2011). Trinidad and Tobago has one of the lowest electricity tariffs in the Caribbean. Figure 2-9 depicts the average tariff among domestic consumers in the Caribbean per 100kW in 2010.

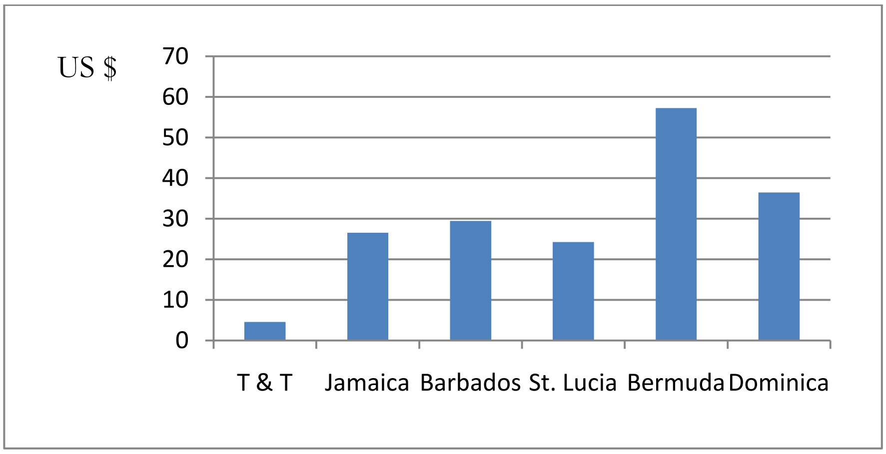

Figure 2-9 Comparison of domestic electricity tariffs per 100kWh

Source: CARILEC 2010

2.5.3 Utility ownership & legislation

2.5.3.1 Trinidad and Tobago Electricity Commission

The Trinidad and Tobago Electricity Commission (T&TEC) began operations in 1946 and its operations entailed the generation, transmission and distribution of electricity for the country (T&TEC 2011). In 1994, T&TEC established POWERGEN and although it divested 49% of its equity to other companies, it retains the remaining 51% of the equity (T&TEC 2011).

T&TEC is owned by the Government of T&T and it is the sole electric utility for the country. Its detailed responsibilities entail the design, construction, operation and maintenance of the electrical transmission and distribution network in T&T (MEEA 2009).

2.5.3.2 Power Producers & Installed capacity

The main independent power producers of T&T are the Power Generation Company of Trinidad and Tobago (POWERGEN) and Trinity Power Limited. POWERGEN is owned by Amoco Trinidad Power Resources Corporation, MaruEnergy Trinidad LLC and T&TEC (MEEA 2009). POWERGEN was established in 1994 and it operates three power generation plants; the Point Lisas plant which has a capacity of 838 MW, the Port-of-Spain plant which has a capacity of 270 MW and finally, the Penal plant which has a capacity of 236 MW (MEEA 2009). Trinity Power Limited is owned by a United States consortium which started operations in 1999 (MEEA 2009). The country will also have in the future another power station which will be able to produce 64 MW of power from natural gas but diesel will be used in case it is needed (MEEA 2009).

2.5.3.3 Regulated Industries Commission (RIC)

The Regulated Industries Commission (RIC) is a statutory body which regulates the cost of utility services in Trinidad and Tobago. The electricity service providers that fall under the purview of the RIC include T&TEC, POWERGEN and Trinity Power Limited. The job of the RIC is also to ensure that these service providers earn sufficient return to finance the necessary investments (RIC 2008).

The RIC was established under the Regulated Industries Commission Act, No. 26 of 1998, and it came into effect in 2000. In addition to regulating the electricity services, it regulates the water services in the country as well. The RIC has many functions but the main ones include establishing the principles upon which tariffs are based, and also monitoring the rates charged to ensure there is compliance (RIC 2008). The Regulated Industries Commission determines the price limits every 5 years and the Trinidad and Tobago Electricity Commission has the option to modify the rates within the limits (T&TEC 2004). The current 5-year regulation period is from June 01, 2006 to May 31, 2011 (RIC 2009).

The RIC attempts to balance the interests of both the Trinidad and Tobago Electricity Commission and its customers by annually reviewing and adjusting the overall cap on the total annual revenue that T&TEC can recover (RIC 2009). This is performed by adjusting the tariffs during the regulatory control period. T&TEC is therefore required to make a case for the tariff adjustments by defining their objectives and providing a rationale for the tariffs which are to be implemented (RIC 2009). T&TEC performs this activity by submitting their annual proposed tariffs to the RIC at least two months before the beginning of the next annual control period (RIC 2009). The RIC measures the performance of T&TEC against defined performance targets and other specific directives and this determines the approval or rejection of T&TEC's proposed price adjustment. In addition to this, T&TEC must inform customers of the new tariffs at least two weeks prior to implementation (RIC 2009). T&TEC is also directed by the RIC to establish a Low-Income Assistance Programme so that a rate increase does not burden low-income earners of the country.

2.5.3.4 Legislation

The Trinidad and Tobago Electricity Commission Act is an Act which was created to establish an Electricity Commission for T&T. This Act enables the Electricity Commission to supply electrical energy and perform other related purposes (GORTT 2007). The Act states that the right to supply electricity in any part of T&T to the public or any member thereof, either directly or indirectly, is vested in the Trinidad and Tobago Electricity Commission (GORTT 2007). The Act also states that the Electricity Commission of T&T 'may enter into a license agreement with an approved generator of electricity permitting an approved generator of electricity the non-exclusive right to supply electricity' (GORTT 2007). There are terms and conditions associated with this right. Firstly, a period is specified during which the right can be exercised and secondly, the approved generator of the electricity must pay the Electricity Commission of T&T a fee for the aforementioned right (GORTT 2007).

2.6 The policy framework for renewable energy in T&T

Trinidad and Tobago is currently in the process of developing a renewable energy policy. The country put forward a 'Framework for development of a renewable energy policy for Trinidad and Tobago' in early 2011. This framework outlines proposals for renewable energy development in T&T.

The Government is currently laying the groundwork to enable RE technologies to integrate into the national grid (M. Narayane, personal communication, March 26, 2011). This means that the Electrical Wiring Code Renewable Energy Sub-committee is amending the Trinidad and Tobago Electrical Wiring Code to enable the interconnection of renewable energy power systems with the T&TEC grid (M. Narayane, personal communication, March 26, 2011). This ensures that there is compatibility with RE power generation systems and the national grid.

The policy framework states that the country is considering setting a target of 60MW of installed capacity from renewable energy by the year 2020. The policy framework also identified wind and solar energy as applicable renewable sources but it states that wind is the technology of choice for bulk electricity generation with a target of 5% of present peak demand (or 60MW) by 2020. Wind is currently the option of choice because it is the most competitive in the local scenario at the moment.

The Government of Trinidad and Tobago has identified several mechanisms for the deployment of renewable electricity. Four instruments are being considered in the framework for renewable energy in Trinidad and Tobago: open access, feed-in tariffs, net metering and renewable portfolio standards. No feed-in tariff was set to date as the policy is still being finalised but there are collaborations occurring at various levels (R. Maurice, personal communication, April 6, 2011). The RIC would be the lead agency on determining the feed-in tariff (R. Maurice, personal communication, April 6, 2011).

2.7 Drivers and Barriers to renewable energy deployment in T&T

There are many drivers and barriers to renewable energy deployment in T&T. Some of the positive aspects that arise from using renewable energy technologies are that power generation from renewable sources of energy has the potential to reduce greenhouse gas (GHG) emissions and create employment opportunities (Sharma and Aiyejina 2010). Some of the drivers for RE in T&T include increased energy security whereby renewable energy is not subject to the fluctuations in the availability and price of fossil fuels, and Trinidad and Tobago can extend its natural gas reserves by reducing the demand for conventional electricity production from natural gas. The reduced domestic demand for conventional fossil fuels enables the country to export more products associated with these conventional fuels (MEEA 2011). Finally, the technologies for renewable power are becoming more affordable and are attracting investments which contribute to the development of the local economy (Sharma and Aiyejina 2010).

There are also barriers to renewable energy deployment in T&T. RE technologies are expensive and fossil fuels in T&T are cheap which creates a further barrier for deployment of RE in T&T. Energy in the country is subsidised which results in the low cost of diesel fuel as well as low commercial and electricity prices (MEEA 2011). The RE framework for T&T identified that the country lacks a legislative agenda to encourage renewable energy development in the country (MEEA 2001). There currently is no legislation supporting interconnection from potential RE power producers to the national electrical grid and there are no guidelines to set feed-in tariffs for such RE producers (MEEA 2011). Additionally, the lack of private financing towards renewable energy systems in the country makes deployment of RE a difficult task as RE systems have higher initial capital costs than the conventional energy sources (MEEA 2011). Therefore, the Government would have to intervene and provide incentives for RE deployment in the country (Sharma and Aiyejina 2010). Finally, the lack of local education, awareness, training and overall capacity building in the field of RE, are all barriers to RE deployment in T&T. Sharma and Aiyejina (2010) noted that a pilot project using solar water heating on host homes in T&T failed because of improper installations. This therefore demonstrated that technicians and installers need to be properly educated and trained to oversee the installation of RE technologies. According to the MEEA (2011), capacity in the RE field needs to take place through training and skills development.

3 Solar Photovoltaic deployment

This section reviews the technological, economic and policy aspects of solar photovoltaic (PV) systems. Solar photovoltaic technologies have the potential to convert sunlight into electricity. The costs of the technology are declining and becoming more affordable however, policies are used to assist in the deployment of PV. The policies reviewed in this section are feed-in tariffs, capacity building and removal of energy subsidies.

3.1 Technology

In a photovoltaic device, the smallest unit is the PV cell which can be categorised as either wafer-based crystalline or thin film cells (IEA 2010d). The crystalline cells can be further differentiated as being either single crystal or multicrystalline (also known as polycrystalline). The former has efficiencies ranging from 15% to 18%, whilst multicrystalline cells have an average conversion efficiency of approximately 14% (IEA 2010d). Although the multicrystalline cells have a lower efficiency, they are becoming more popular since they are less expensive to produce. The other type of PV cells, thin film cells, generally cost less to produce than crystalline cells but have an efficiency ranging between 7% to 13% (IEA 2010d). The PV technologies can also be categorised or grouped into first-, second-, and third- generation PV. First generation (1G) PV refers to single-junction solar cells based on silicon wafers which include single crystal and multi-crystalline silicon (Bagnall and Boreland 2008). PV production is dominated by 1G technology which accounts for approximately 90% of PV production. Bagnall and Boreland (2008) describe the efficiency level of 1G to be about 20% and such devices are supposed to be reliable and durable but half the cost is attributed to the silicon wafer. Second generation (2G) technologies are single-junction devices that use less material while maintaining the efficiencies of first generation PV. 3G or third generation PV incorporates the use of new technologies to produce high-efficiency devices (Bagnall and Boreland 2008).

The main components of a photovoltaic power system are the PV cells (which are interconnected to form a PV module), the mounting structure for the module, and the inverter (IEA 2010d). The inverter is essential for grid-connected systems and it is also required for most off-grid systems. There are different mounting options for PV. The panels can either be roof mounted or free standing/ground mounted. Other components of a photovoltaic power system include the storage battery and charge controller which are used for off-grid stand-alone systems (IEA 2010d). Batteries can be incorporated into grid-connected PV to form a hybrid PV/battery generation system which can be more stable and reliable (IEA 2010d).

There are 4 main applications for PV which include off-grid domestic systems, off-grid non-domestic systems, grid-connected centralised systems, and finally, grid-connected distributed PV systems (IEA 2010d). Off-grid domestic systems enable households to produce electricity without being connected to the utility electricity network. This network or grid is also absent for off-grid non-domestic systems which provide power for different applications including telecommunication and navigational aids. Grid-connected centralised systems function like centralised power stations whereby they can function independently and supply bulk power. These systems are also normally ground mounted (IEA 2010d). Finally, grid-connected distributed PV systems provide power directly to the electricity grid or to a grid-connected customer.

A typical grid-connected small-scale PV system consists of the PV modules and the balance of system (BOS) components (Shum and Watanabe 2008). The BOS of a PV system is made up of all the systems or engineering parts of the PV system, excluding the PV modules or cells (Shum and Watanabe 2008). Thus, the BOS of a PV system consists of inverters, charge controllers, cables, electronic components and system installation among other things (Bhandari and Stadler 2009). Grid-connected PV, also referred to as grid-tied photovoltaic systems, involves connecting to a power grid and selling the excess electricity back to the utility. In grid-connected PV, an inverter is used to convert electricity from direct current, produced by the PV array, to alternating current which is then supplied to the electricity grid (Foroudastan and Dees 2006). This system can be on or integrated into the customer's premises often on the demand side of the electricity meter, on public and commercial buildings (IEA 2010d). Many solar PV systems are grid-connected (Foroudastan and Dees 2006). Grid-connected PV is a relevant application of solar PV in feed-in tariff schemes.

The lifetime of PV modules is guaranteed to be approximately 20 years (IEA 2010d). PV has the ability to operate for long periods unattended and it also requires low maintenance (Bhandari and Stadler 2009). PV has the ability of generating electricity during the day when the demand for electricity and the price is also high.

3.2 Economics of PV

3.2.1 PV system costs

The investment costs of PV are relatively high but the costs are declining as a result of technological improvements and economies of volume and scale (IEA 2010c). REN21 (2010) also states that grid-connected solar PV has been experiencing declines in the cost of the systems over the years. The prices of PV systems vary and depend on a range of facets including size of the system, location, technology, and connection to an electricity grid (IEA 2010d). According to IEA (2010d), the cost for the lowest price off-grid system is, on average, double the cost for the lowest price grid-connected system because off-grid systems require storage batteries and other necessary equipment which add to the cost of the systems.

The costs of PV systems are decreasing but the costs are still high which is hindering market competitiveness. As a result, PV systems require subsidies and support strategies for its deployment in the market (Bhandari and Stadler 2009).

3.2.2 Experience curve

The general understanding of the experience curve concept is that cost reductions are correlated with the level of experience with a technology. Experience curves describe how cost declines with cumulative production in the context of accumulated experience in producing and employing a technology (Bhandari and Stadler 2009). To understand this concept further, Bhandari and Stadler (2009) state that the cost reductions in the experience curve refer to total costs and changes in production, products, and input prices. Production in this case refers to process innovations, learning effects, and scaling effects. Products include product innovations and product redesign (Bhandari and Stadler 2009). While production may be done at a local level in another country, PV module production learning is transferred among countries (Shum and Watanabe 2008).

Research and development and learning by doing are mechanisms used to reduce uncertainty with a new technology which also improves performance and costs of the technology (Shum and Watanabe 2008). The PV experience curve analysis reveals that there should be a significant increase in global cumulative PV installations which will significantly reduce the prices of PV modules as a result (Bhandari and Stadler 2009). It was demonstrated that with every doubling of cumulative production of PV, there was a 36% reduction in PV costs (Shum and Watanabe 2008). If PV investment occurs at a faster rate, the prices of the PV systems will also decrease at a faster rate which will enable grid parity to occur sooner (Bhandari and Stadler 2009).

3.2.3 Grid parity

Grid parity refers to the point at which the cost of producing electricity from alternative means such as renewable technologies is cost competitive with electricity production from conventional sources of power generation at or near the point of final consumption. Grid parity occurs at the point in time when the cost of purchasing a kWh of electricity from solar PV becomes equal to the cost of generating a kWh of electricity from the grid (Bhandari and Stadler 2009). Therefore, in the context of PV, grid parity is the point in time when the electricity from grid-connected PV is able to compete with the electricity generated from conventional fuels (Bhandari and Stadler 2009).

Grid parity can be achieved by reducing the cost of PV power generation to grid electricity rates (Asano and Saga 2008). Deploying PV at a faster rate today, will lead to a rapid price decrease in PV systems which means that grid parity would occur sooner (Bhandari and Stadler 2009). The cost of PV was thought to be the most expensive renewable energy source but according to Mendonça *et al.* (2010), it is expected to reach grid parity within the next decade. Other researchers documented that grid parity will be achieved between 2010 and 2015 (Asano and Saga 2008). Rüther and Zilles (2011), state that grid parity would be reached in 2013 in many countries worldwide. Grid-connected PV is expected to reach competitiveness in many countries around the world but especially in countries that are sunny (Rüther and Zilles 2011).

The specific cost of producing 1kWh of electricity from PV varies with regard to a range of factors including the amount of solar irradiation, financial aspects, type of installation, and the PV technology. The IEA has set cost reduction goals (Table 3-1) regardless of the variation in the aforementioned factors using information from a range of sources (Larsen and Petersen 2010). The cost targets are based on solar cell modules rated power in Watt-peak (Wp). Watt-peak is the rated module power that is measured under standard test conditions (1,000 W/m^2 light intensity, AM 1.5G spectrum, and 25°C) (Larsen and Petersen 2010). Table 3-1 illustrates that as the prices of PV systems decrease over time, the electricity generation costs from PV will also decease. PV electricity production costs primarily depend on the yield of the system and the investment cost for the PV system. Grid parity occurs when these PV electricity production costs (in US dollars per kWh) are lower than the retail price at the point of end use for households. PV electricity generation costs are expected to be in the range of US 16 cents per kWh to US 32 cents per kWh in 2020. Places that receive irradiation of approximately 1,500 kWh/kW$_p$/year are expected to have PV generation costs of US 21 cents per kWh.

Table 3-1 Cost reduction goals for PV

<table>
<tr><td colspan="2" rowspan="2">Cost targets for the residential sector
Typical system price (2008 US$/kWh$_p$)</td><td>2008</td><td>2020</td><td>2030</td><td>2050</td></tr>
<tr><td>6,000</td><td>2,700</td><td>1,800</td><td>1,200</td></tr>
<tr><td rowspan="3">Typical electricity generation costs (2008 US$/kWh)[1]</td><td>2,000 kWh/kW$_p$[2]</td><td>0.36</td><td>0.16</td><td>0.10</td><td>0.07</td></tr>
<tr><td>1,500 kWh/kW$_p$[2]</td><td>0.48</td><td>0.21</td><td>0.14</td><td>0.09</td></tr>
<tr><td>1,000 kWh/kW$_p$[2]</td><td>0.72</td><td>0.32</td><td>0.21</td><td>0.14</td></tr>
<tr><td colspan="6">[1]Assumptions: interest rate 10%, technical lifetime 25 years (2008), 30 years (2020), 35 years (2030), and 40 years (2050); operations and maintenance costs 1%
[2]Capacity factor; the amount of electricity generated by a PV system per W$_p$ per year; a typical range is 1,000-2,000 kWh/kW$_p$</td></tr>
</table>

Source: Larsen and Petersen 2010

3.3 Global Market status & trends

Photovoltaics were mainly used in applications for powering satellites and remote locations but with the growing concerns of the environmental impact of non-renewable energy sources and the economic volatility from the reliance of oil and gas, photovoltaics are observing a different trend (Bagnall, D.M. and Boreland M. 2008). Phovoltaics are not only providing an energy source that is pleasing to environmentalists, it is also of interest to the financial sector that sees a business case for investment. It is a billion dollar industry that is growing rapidly and increasing in economic importance (Bagnall, D.M. and Boreland M. 2008).

Solar PV generates electricity in more than 100 countries and it is one of the fastest growing power-generation technologies in the world (REN21 2010). Solar PV, especially grid-connected solar PV is growing and it is expected to continue this trend in the coming years (REN21 2010). McCormick (2008) also noted that there is an increase in the rate at which solar photovoltaic systems connected to the grid are occurring. In the early 1900s, off grid PV systems had a higher capacity than grid-connected PV but currently grid-connected PV is increasing and represents a larger share of the cumulative installed PV (Figure 3-1). Grid-connected PV capacity increased at an average annual rate of 60 percent between 2004 and 2009 (REN21 2010).

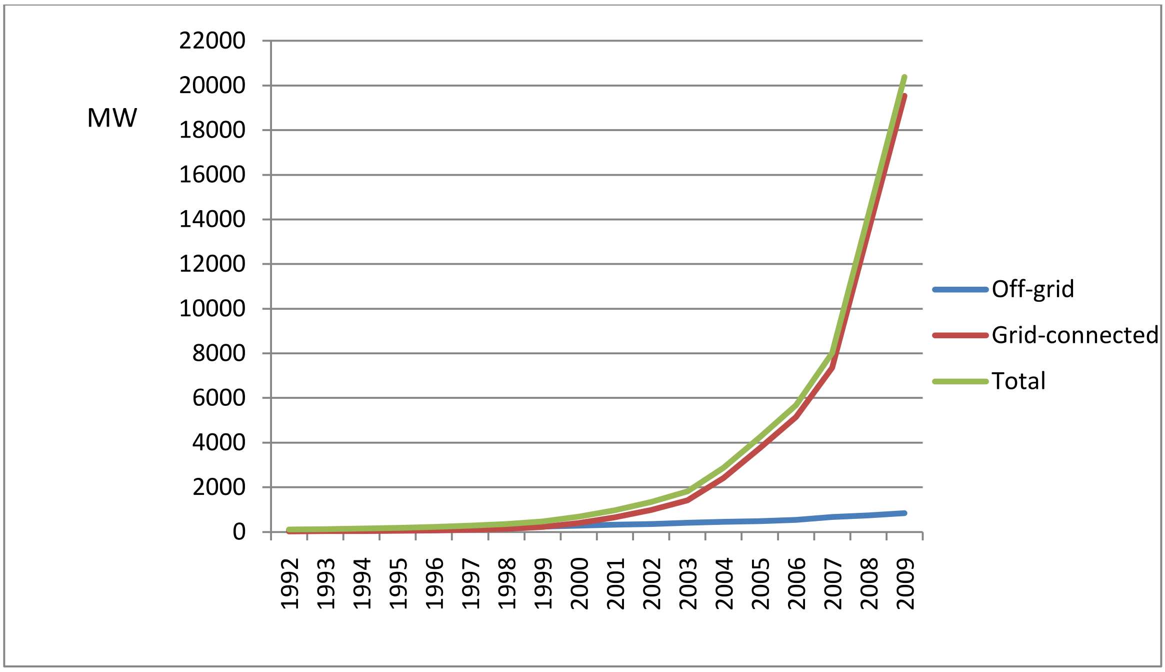

Figure 3-1 Cumulative installed capacity of PV

Source: IEA 2010d

The cumulative installed power from PV increased over the years and some countries accounted for higher PV installed capacities than others. In 1995, the United States of America (USA) had a higher installed PV capacity compared to other countries including Germany but in 2009, Germany's cumulative installed PV power was 9.8 GW whilst USA had approximately 1.6 GW of installed PV power (IEA 2010d). In 2009, Germany accounted for the highest share of the solar PV capacity (Figure 3-2).

Solar PV additions reached 7 GW in 2009 where Germany was the leader having 3.8 GW added in this year. Other large markets included the United States, Italy and Japan (REN21 2010). Solar PV capacity is increasing and with 7GW of grid-tied capacity added in 2009, the capacity increased by 53% bringing the total capacity to approximately 21 GW (REN21 2010). Analysts expect more growth of solar PV capacity in the coming years (REN21 2010).

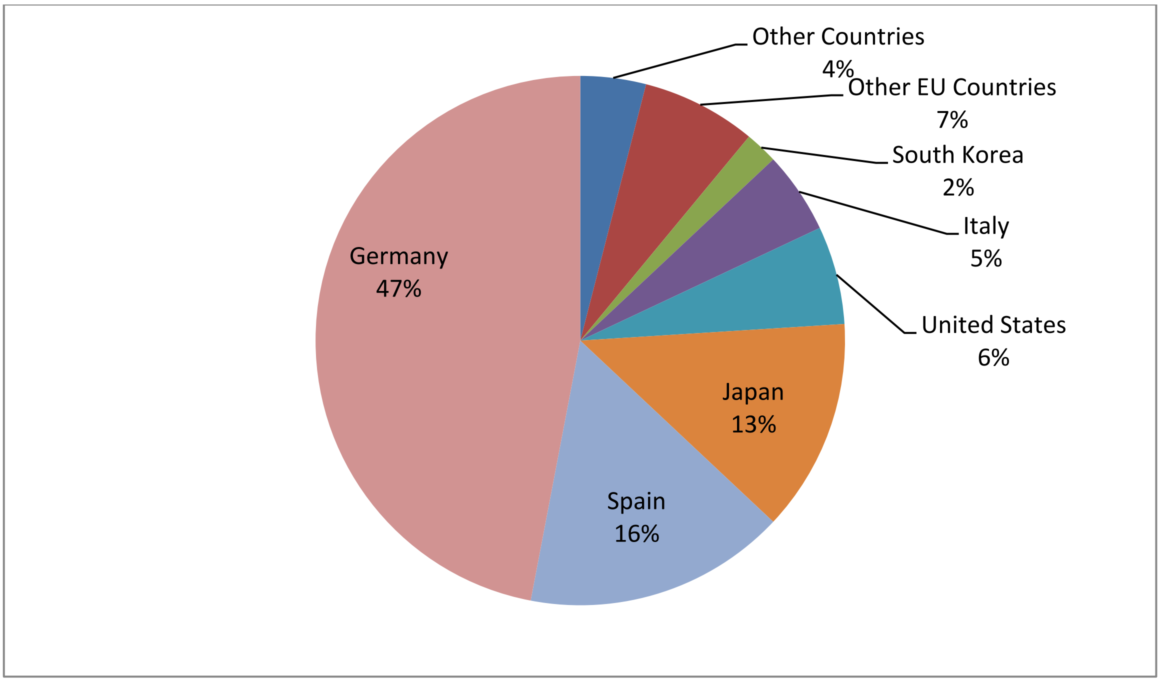

Figure 3-2 Share of cumulative installed capacity of PV by country (2009)

Source: REN21 2010

3.4 PV policies

According to the Oxford Dictionary (2011), a policy is a course or principle of action adopted or proposed by an organisation or individual. Policies were used in the past and are currently being used to encourage the deployment of PV and some are described in this section. Historically, the promotion of renewable energy technologies occurred mainly through government subsidies to reduce the initial capital investment (Moner-Girona 2009). One feature of successful dissemination strategies for PV is the creation of financial incentives which are used to improve the economic performance of PV systems (IEA 2002). Financial incentives include subsidies and attractive financing offers. Subsidy-based market strategies in the late 1990s, particularly in countries such as Japan and Germany stimulated the PV industry which is now a billion dollar industry that is continuing to grow (Bagnall and Boreland 2008). Capital subsidies and tax credits have been instrumental in supporting solar PV markets (REN21 2010). Capital subsidies are used to reduce the initial cost of the PV system whilst tax credits enable some of the expenses associated with PV installation to be deducted from taxable income streams (IEA 2010d). Having sustainable building requirements is another initiative used to promote PV whereby new building developments can be mandated to incorporate PV when constructing the building (IEA 2010d).

Other policies which also encourage PV deployment include renewable portfolio standard (RPS), net metering, net billing, and feed-in tariff policies. Renewable portfolio standard is a scheme which mandates that a minimum portion of the electricity supply from the grid is obtained from PV electricity supplies (IEA 2010d). As a result, retail electricity suppliers are required to obtain a specified minimum percentage of their electricity from renewable energy and this is done by obtaining renewable energy credits (RECs) (IEA 2002). The retail electricity suppliers can obtain their RECs by purchasing renewable electricity from a separate generator of renewable electricity or they can obtain the RECs by purchasing them directly which facilitates trading of the RECs (IEA 2002). Net metering is a scheme which enables producers of electricity from solar photovoltaic power systems to receive the retail value for the electricity fed into the grid. The amount of electricity fed into the grid is recorded by a bi-directional electricity meter and calculated over the billing period (IEA 2010d). Net billing tracks electricity taken from and fed into the grid, and provides a given price for the electricity which is fed into the grid (IEA 2010d). In a feed-in tariff scheme, the electric utility company is mandated to purchase the electricity produced from the renewable energy source at a specified price for a specific time period. The prices offered for the generation of electricity from renewable energy sources are supposed to be attractive for the producers of renewable energy (Couture *et al* 2010). According to Couture and Gagnon (2009), experience from around the world illustrates that FITs are the most effective policy to encourage the rapid and sustained deployment of renewable energy. Feed-in tariffs are explained further in Section 3.4.1.

Capacity building is another policy that can promote PV deployment. Capacity building for PV involves performing a range of activities which include education, awareness, training of the range of stakeholders involved in dealing with PV technology. Public and private institutions are involved in the capacity building such as banks, government agencies and domestic homeowners. Section 3.4.2 further discusses capacity building.

The other policy reviewed is the removal or phase out of subsidies for conventional energy (Section 3.4.3). Subsidies for conventional fossil-based electricity production hinder the deployment of PV since the market prices of conventional energy sources do not reflect total costs. This can therefore undermine the real competitiveness of renewable energy sources.

3.4.1 Feed-in tariff (FIT)

The feed-in tariff is a policy for promoting renewable electricity production. The Feed-in tariff (FIT) is a popular mechanism in promoting strong growth in grid-connected PV (IEA 2010d). The FIT sets 'a fixed price for purchases of renewable power, usually paying producers a premium rate over the retail rate for each unit of electricity, or kilowatt-hour (kWh), fed into the grid' (Mendonça *et al.* 2010). The concept behind the feed-in tariff scheme is that a utility is obligated to purchase electricity that is generated by renewable energy producers at a tariff that is determined by public authorities and is guaranteed for a specific period. The power company is generally required to purchase electricity that is produced by eligible producers for a long period of time (Mendonça *et al.* 2010).

The feed-in tariff scheme obliges electric utility companies or transmission operators to connect all renewable power providers to the grid and the utility is required to cover the interconnection costs (Mendonça *et al.* 2010). Electricity producers can include private households as well as large utilities. The tariff is given for every kWh of electricity that is produced and this tariff can be differentiated for example with regard to the type of technology used, the size of the installation and the quality of the resource.

Many countries have adopted the FIT to promote renewable power generation and it is the most commonly used policy to achieve such a goal. By the year 2010, approximately 50 countries and 25 states/provinces have adopted FITs to deploy renewable power generation where at least 83 countries in total have used some form of policy to promote power generation from renewable sources (REN21 2010). Countries in Europe such as Germany, Denmark and Spain have set up successful FIT schemes with attractive prices being given to renewable energy producers. In other European countries such as Portugal, Austria and Belgium, FITs were introduced but the prices were less attractive (Couture *et al* 2010). It is expected that as more and more countries implement well-designed FIT schemes, the costs of renewable electricity will fall below the price of conventionally produced electricity (Mendonça *et al.* 2010).

The concept of the FIT was utilised for several decades as it was first implemented in the United States of America. Figure 3-2 illustrates some of the countries that have adopted FITs and it shows that USA was the first country to have such a scheme which was in 1978 (Couture *et al.* 2010). The first national feed-in tariff legislation in Europe occurred in Germany and details are provided further in Section 3.4.1.2

Table 3-2 List of selected countries enacting the FIT policy

Year of Adoption	Countries
1978	United States
1990	Germany
1991	Switzerland
1992	Italy
1993	Denmark; India
1994	Spain; Greece
2001	France
2005	China; Turkey; Ecuador; Ireland
2010	United Kingdom

Source: REN21 (2010)

3.4.1.1 FIT design elements

There are many elements to consider when designing a FIT and some of them are presented in this section. Mendonça (2007) and Mendonça *et al.* (2010), have written extensive research related to the feed-in tariff scheme. One of the first elements to consider when designing a FIT, is to ensure that investors of renewable electricity are guaranteed access to the national grid (Mendonça 2007). Ensuring priority grid access is an important activity in the FIT scheme. Producers of renewable electricity such as PV electricity should be given precedence to be connected to the grid. Thus, grid operators should immediately connect renewable electricity to the grid to prevent delay by the grid operator (Mendonça *et al.* 2010).

The idea of designing FITs is to balance investment security for producers whilst avoiding windfall profits for them (Mendonça *et al.* 2010). It is recommended that countries which are commencing the adoption of FITs, keep the FIT design simple at the start (Mendonça *et al.* 2010). This section therefore provides information on elements for designing a basic feed-in tariff.

When setting the tariff, it should be high enough to ensure that costs are covered and development of PV is encouraged. A high or attractive tariff provides a reasonable return on investment (Mendonça 2007). If the tariff is too low, it will not encourage investment but if the tariff is too high, it leads to unnecessary profits and poses higher costs for the final consumer (Mendonça *et al.* 2010). To derive a suitable tariff for a country, other countries with similar resource conditions could be studied and used as a reference point (Mendonça *et al.* 2010).

Tariff payments can be further differentiated based on technology used, project size, and other factors. If one renewable energy technology has higher generation costs than another, higher tariffs can be stipulated for the former (Mendonça *et al.* 2010). With regard to size-differentiated tariffs, it is advised to categorise the sizes based on the installed capacity. For example, Mendonça *et al.* (2010) suggest establishing groups from 0kW-30kW; 30kW-100kW; 100kW-2MW; and so forth. With respect to PV, the size of the system can be used to differentiate tariffs. For an average private household, a typical rooftop installation has a capacity of 3-30kW whereas an industrial building may have a larger rooftop installation with an installed capacity of approximately 100kW (Mendonça *et al.* 2010).

Determining the contract duration period is another important element to pay attention to when designing a feed-in tariff (Couture *et al.* 2010). A FIT should be created for a long-term period, for example 20 years (Mendonça 2007). A long contract period provides security and an incentive to investors considering investing in renewable technologies such as PV (Couture *et al.* 2010). It is also easier to obtain financing by specifying a period of time since banks and other investors are assured a guaranteed rate of return over the period (Mendonça 2007). Some countries set tariff payments for a period of 10-20 years but Mendonça *et al.* (2010) states that 15-20 years is a more common and successful approach. As technologies change, the producer is given the opportunity after the period to adopt newer and more efficient technologies.

Financing and funding for the FIT is another important element when designing a FIT. Some countries have used ratepayer funding which spreads the costs of electricity amongst consumers (Couture *et al.* 2010). This is another basic feature of the FIT where the additional costs are distributed amongst all electricity consumers (Mendonça *et al.* 2010). There can be a differentiation however for low-income families and energy intensive industries (Couture *et al.* 2010). The World Future Council (WFC) (2009) suggested creating a special fund such as a Renewable Energy Policy Fund that can assist with the increases in electricity costs for households. The fund can receive finances from national revenue sources, which reduces dependence on international donours (WFC 2009). Funds can be also be obtained from other potential funding sources.

Grid-connection costs can contribute to approximately 26.4 % of the total investment costs (Mendonça *et al.* 2010). As such, Mendonça *et al.* (2010) recommend using one approach where costs are shared between the investor and the grid operator where the investor pays for the new electricity line to the next grid connection point, and the grid operator pays for potential reinforcement of existing grid infrastructure. The grid operator costs can then be transferred to the final consumer. Another approach can be attributing connection costs to the grid operator especially if the connection charges are costly for the investors themselves (Mendonça *et al.* 2010).

3.4.1.2 Country Case Studies

Many countries have implemented different PV promotion programmes such as subsidies and feed-in tariffs but some of these countries have been more successful at increasing PV capacity. Figure 3-2 illustrates the countries with the highest existing capacity of solar PV which include Germany, Spain and Japan. Germany became the primary driver of PV installations and has played a major role in advancing PV and reducing their costs. This section reviews PV development in selected countries and especially the role of the feed-in tariff scheme in deploying PV in Germany and Spain. The FIT scheme was successful in deploying PV in these countries but building capacity also helps to deploy PV.

Germany

Germany has been quite successful in increasing the share of renewable electricity over the years mainly because of effective public policy wherein the feed-in system was most influential. The support for renewable energy started in 1974 when the Government promoted energy research (Wüstenhagen and Bilharz 2006). The key element to the development of renewable energy in Germany was attributed to the system of feed-in tariffs introduced with the feed-in law (StrEG) of 1991, which was updated in the renewable energy law (EEG) of 2000 and the EEG amendment of 2004) (Wüstenhagen and Bilharz 2006). Germany had the highest existing capacity of solar PV (grid-connected) at the end of 2009. The existing capacity of grid-connected solar PV in 2006 was 2.8 GW and in 2009 it increased to 9.8 GW (REN21 2010). Figure 3-2 illustrated that Germany accounted for 47% of the existing global solar PV capacity by the end of 2009 (REN21 2010).

Grid-connected PV in Germany mainly started with a few pilot projects where one involved the installation of a 4 kW_p PV system on the roof of a house in 1983 (Erge *et al.* 2001). Grid-connected PV was commercially viable for the first time when the 100,000 roof-programme was initiated. This programme provided attractive debt finance for solar energy in the country (Erge *et al.* 2001). The 'German 1000 Roofs Measurement and Analysis Programme' encouraged grid-connected PV which led to more than 2000 grid-connected PV systems (about $5MW_p$) installed on roofs of private houses. The main goals of this programme included gaining installation know-how, stimulating the users to save electricity and adapt to solar generation, and harmonising the use of roofs for electricity generation with construction and architectural aspects (Erge *et al.* 2001).

In 1998, the number of PV installations was decreasing and one reason for this was because the Government announced a new initiative to promote grid-connected PV known as the German '100,000-Roofs-Solar-Programme'. Prospective owners of PV systems postponed their investments while they waited for the improved conditions of the new programme which commenced in 1999. This new programme supported the installation of PV systems of a size of $1kW_p$ and over through subsidies and low interest rate loans for owners of PV (Huang and Wu 2007). The conditions included a 10-year, interest free loan which was to be repaid in 9 annual installments with no repayment needed in the final year. At the end of 1999, nearly 4000 systems with a total capacity of $10MW_p$ were installed (Erge *et al.* 2001).

The first national feed-in tariff legislation in Europe was adopted in Germany. This was adopted in 1990 and was known as the 'Electricity Feed-in Law' after translating the German word *Stromeinspeisungsgesetz* (StrEG) (Couture *et al.* 2010). This law involved the electricity being fed into the grid and in 1991 the utilities in the country were required to buy electricity from non-utility RE producers at a fixed percentage of the retail electricity price. There was a purchase obligation imposed and it ranged from 65-90% which depended on what type of technology was used and the size of the project (Couture *et al.* 2010). In order to encourage solar PV, a different approach was used whereby utilities of some German municipalities based FIT prices on the actual costs of RE generation as opposed to an avoided cost (value-based) approach to tariff calculation, or where the prices were tied to the prevailing retail price (Couture *et al.* 2010).

In the year 2000, Germany enacted the Renewable Energy Sources Act (EEG) which led to a few developments. One of these developments led to the decoupling of FIT prices from electricity prices at the national level. Another development enabled utilities and not just non-utilities to participate in the scheme. Additionally, RE sources were given priority access to the grid and tariffs were based on the costs of generation (Couture *et al.* 2010). Figure 3-3 illustrates that from the year 2000, the annual installed capacity of PV increased significantly with the FIT scheme.

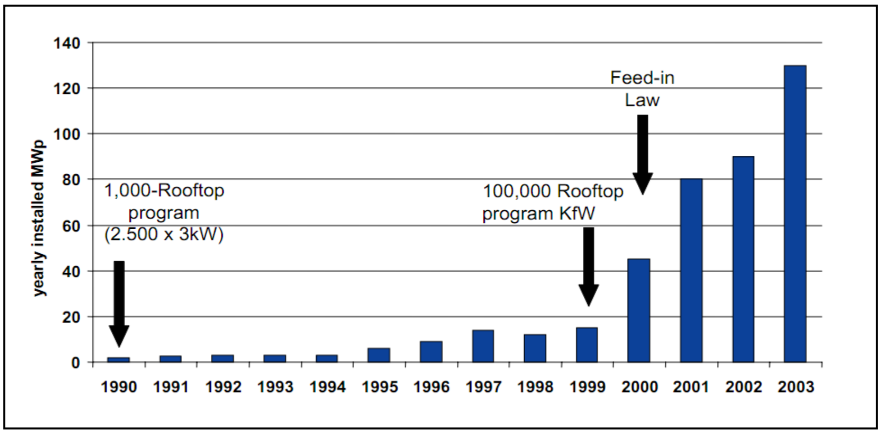

Figure 3-3 Yearly installed capacity of PV in Germany 1990-2003

Source: EPIA 2004

After 2000, amendments were made to the FIT in 2004 and in 2009. In 2004, further differentiations were made to the tariff payments with regard to the technology, location and size of the schemes (Mendonça *et al.* 2010). As the share of renewable energy in the electricity mix increased, amendments were continuously made to control costs and avoid windfall profits. In 2009, amendments were continued but the design encouraged a larger share of renewable energy in the electricity mix (Mendonça *et al.* 2010).

Germany has had a considerable amount of experience with the development of the FIT and it has observed sustained support and growth in the PV sector because of the FIT scheme. The FIT led to an overall increase in the share of renewable energy in the electricity mix (Mendonça *et al.* 2010).

Spain

Spain has experienced a significant growth rate of PV in the country which is attributed to political commitment and continuity of support schemes and the specific design elements of the support scheme itself: the feed-in tariff (González 2008). Spain introduced the feed-in tariff scheme in 1998 but made amendments afterward in 2004 and 2007.

The *Royal Decree on Special Regime* (RD 2818/1998) had two options, where one was based on a fixed FIT and the other was a technology specific feed-in premium on top of the electricity market price. The former option was comparable to the scheme in Germany whilst the latter option involved the premium being paid independent of the market price (Klessmann, Nabe, and Burges 2008). The tariff for PV that was less than 5kW in size was approximately 36 Euro cents/kWh under the fixed premium option for the period 1999 to 2003 (González 2008).

Royal Decree 436/2004 (RD 436/2004) employed a percentage-based design where the premium amount could exceed 100% of the retail price (Couture *et al* 2010). In 2004, electricity market prices increased which led to high revenues for wind power projects

(Klessmann *et al.* 2008). With the rising electricity prices there was an increase in the share of renewable electricity sold under RD 436/2004 and windfall profits occurred. The windfall profits as well as the consumer costs of renewable electricity were rising more than expected because the level of fixed tariffs and premiums increased slightly but also mainly because of the premium option where electricity prices formed a direct component of the overall remuneration for renewable electricity (Held, Ragwitz, Huber, Resch, Faber, and Vertin 2007).

Royal Decree 436/2004 was succeeded by another decree. In the year 2007, caps were placed where there was a minimum and maximum tariff price irrespective of the market price (Klessmann *et al.* 2008). Spain's *Royal Decree 661/2007* (RD 661/2007) introduced upper and lower boundaries for the tariffs where producers of wind electricity were given a minimum tariff independent of the market price and also limited the maximum value of the market price plus the premium.

The Royal Decree 1578/2008 was mainly targeted at solar PV systems where new tariffs and caps were applied. PV systems that were registered before September 2008 were given a FIT range between Euro cents 23/kWh and 44/kWh depending on the size of the system (Couture *et al.* 2010). There was an installation cap of 371MW which was adjusted upwards to 500MW as of 2009 and the tariff was reduced to Euro cents 32/kWh for ground systems and Euro cents 34/kWh for rooftop systems. This tariff that was especially adjusted for PV technologies involved a cap on the amount of solar PV that could be installed in a given year enabling 267 MW to be shared between small (<20kW) and large (>20kW) rooftop systems. The other 133MW was to be shared for large ground-mounted systems (Couture *et al.* 2010).

Generation from solar PV in Spain increased from approximately 1GWh in 1995 to 427GWh in 2007 (González 2008). After 2008, the PV market in Spain declined because the cap on subsidies was exceeded (REN21 2010). In 2009, however, Spain had the 2nd largest solar PV installation capacity as illustrated in Figure 3-2. According to Mendonça *et al.* (2010), having capacity caps in a FIT design can limit the total amount of newly installed capacity and in Spain, PV increased but for a short time because the cap was reached. Once the cap is reached, the market collapses and it generally takes some time before new capacity is installed. Instead of using capacity caps, it is recommended that the design options should use tariff degression where the tariffs decline annually based on expected cost reductions of PV systems (Mendonça *et al.* 2010).

3.4.1.3 Benefits & Challenges of FIT

The FIT policy has many benefits and challenges that need to be considered if a country is considering implementing the policy. There a range of benefits offered by the FIT policy. A few include offering a secure and stable market for investors seeking to deploy RE, stimulating growth of the local industry and providing jobs, impacting RE generation and capacity, and enhancing market access for investors and participants (Couture *et al.* 2010). The FIT scheme stimulates technological development and according to Mendonça *et al.* (2010) FITs often 'jump-start a robust manufacturing sector for renewable energy technologies'. A manufacturing sector therefore supplies jobs for people in the country.

Despite the benefits, there are challenges that are encountered with the policy which include the fact that FITs do not directly deal with the high initial costs of RE technologies, may distort wholesale electricity market prices, lead to near-term upward pressure on electricity prices, and may exclude lower-income individuals from participating in the scheme (Couture *et al.* 2010). It can also be challenging to set accurate tariffs and keep them cost-efficient over time (Mendonça *et al.* 2010). Additionally, in developing countries, there can be a lack of support from donors for feed-in tariffs (Mendonça *et al.* 2010).

3.4.2 Capacity building

Capacity building, also known as capacity development, is the process whereby individuals, organisations and societies obtain, strengthen and maintain their capabilities to set and achieve specific goals over time (UNDP 2011b). IEA (2003) noted that there is a strong link between capacity building and the effective implementation of a project. The process for capacity building is a long-term process that goes beyond developing individual skills and training activities (UNDP 2009). It also addresses institutional change, leadership, empowerment and public participation amongst a range of stakeholders (UNDP 2009). Capacity building seeks to strengthen the political, social, economic, policy, legal and regulatory systems which organisations and individuals function (UNDP 2011).

Capacity building in the context of PV deployment is an activity which seeks to prepare and strengthen the institutional infrastructure of a country in order to contribute to the successful implementation of PV projects (IEA 2003). The institutional infrastructure incorporates political, legal, educational, research or scientific institutions and other interest groups (IEA 2003). If a country is designing a policy to deploy PV, capacity building assists to strengthen the outcome of the policy by reinforcing knowledge and decision making amongst relevant stakeholders. It therefore enhances the abilities of stakeholders involved to understand and employ PV systems.

The UNDP (2011b) identified four elements that have the greatest influence on capacity building: institutional arrangements, accountability, environmental leadership, and knowledge and information. Institutional arrangements involve development planning and decision making, as well as political, legal and policy processes. This ensures, for example, that organisations design efficient policies that are beneficial to the local society (UNDP 2009). Institutional arrangements seek to strengthen regulation, authority and enforcement especially with regard to environmental agencies and related ministries (UNDP 2011b). Accountability ensures that there is collaboration amongst institutions especially between public and private organisations and other actors that are impacted by their actions (UNDP 2011b). UNDP (2009), recognised that accountability can be strengthened by encouraging participation from stakeholders and increasing transparency especially government transparency. The third element which influences capacity building, environmental leadership, is the ability of individuals and organisations to make changes as well as motivate actions from stakeholders (UNDP 2011b). Finally, knowledge and information ensures that stakeholders are provided scientific and technical information through education and training to make decisions and take initiatives (UNDP 2011b). Knowledge can be obtained through acquiring education, training and learning or experience (UNDP 2009).

Capacity building with regard to PV involves a range of activities. Activities which can be used to build capacity for the deployment of PV include training government officials, training entrepreneurs and installers of PV, and informing society and customers of PV systems. Training government officials enables them to know how to implement and manage PV projects; training entrepreneurs and technicians helps them to increase the commercial viability of PV operations; and constructing public awareness campaigns provides consumers with knowledge and understanding of PV systems (IEA 2003). Improving technical performance entails improving the technical reliability through a series of methods including the promotion of research and development of the technology (IEA 2002).

Capacity building ensures that the persons responsible for operating and maintaining PV systems such as private homeowners are informed about the systems. Marketing and information generation provide technical information so the potential customer understands how and where a PV system can be installed, and it also provides information on the cost of the system and the conditions for installing a PV system (IEA 2002). Pilot projects demonstrate the use of the technology as well as the commercial and economic potential of PV (Martinot 2001). The pilot projects enable stakeholders (policy makers, consumers, utility companies, government agencies, and private enterprises) to gain familiarity with the technology (Martinot 2001).

Capacity building activities such as business training workshops can increase the commercial capabilities of small PV companies. Training for the PV companies are related to financing, accounting and developing business plans so that they can obtain loans from banks and create a sustainable market for PV systems (IEA 2003). Installers and end-users also benefit from capacity building activities such as training programmes. Addressing public awareness focuses on the social aspects related to PV development where the state of the public's knowledge and awareness is sensitised to aspects of PV deployment including job creation possibilities (IEA 2002). If schools or other public institutions are using PV systems, there should be regular re-training of staff on operation and maintenance issues (IEA 2003). Capacity building therefore helps to strengthen individual competence of decision-makers and specialised staff, and increase the importance of PV in academic education and vocational training.

3.4.2.1 Country Case Studies

Indonesia

One project in Indonesia researched using grid-connected PV to investigate the economic viability of grid-connected PV systems but the project also served to increase public awareness and build technical and institutional capacity (ADB 2005). The project potentially serves as a teaching tool for engineers and manufacturers on PV systems. It also encourages institutional creation and collaboration among stakeholders such as the electricity utility, project developers, financial institutions, and government bodies which include the energy and finance ministries (ADB 2005). The ADB (2005) recognised that lack of awareness of renewable energy advantages does not only occur at the consumer level but at almost all levels where decision makers are involved. The benefits of PV are often overlooked because of the lack of familiarity with the technology and the high investment costs.

China

In China, a project was developed to increase the use of PV technologies and capacity building activities were initiated at the preparatory phase of the project. These activities included increasing public awareness as well as increasing commercial capabilities of the PV companies. A public information campaign involved publishing brochures, providing lectures, and broadcasting information through radio programmes so that consumers were more informed about PV technologies (IEA 2003). To increase the commercial capabilities of PV companies, business training workshops and business consultant services were conducted. Another capacity building activity involved providing training workshops for government officials on project implementation and management which included project monitoring and evaluation (IEA 2003). Providing PV quality assurance was another activity included in the capacity building which entailed establishing PV testing and certification centres and initiating PV system standards. Quality assurance also included improving quality control procedures of PV technology suppliers (IEA 2003).

3.4.3 Phase out of subsidies for conventional energy

Many countries around the world use energy subsidies and the subsidies vary in importance and type of fuel (Iwaro and Mwasha 2010). More than half of the world's states subsidise energy in some form and it was recorded that in 2006, global energy subsidies were US $220 billion per year which is approximately 0.7% of the world GDP (Dansie, Lanteigne, and Overland 2010).

According to Iwaro and Mwasha (2010), energy consumption subsidies are 'government measures that result in an end user price that is below the price that would prevail in a truly competitive market including all the costs of supply'. Governments use energy subsidies to promote economic development and benefit the lower income members of a population (Dansie *et al.* 2010). Subsidy reduction is not easy especially on people in the low-income bracket. Therefore, 'improvements in the design and implementation of social safety nets can help to rationalise energy prices while protecting the poor' (WB 2008).

Russia is one country that subsidises energy. Russia is the third largest energy consumer in the world and it also has the world's largest natural gas reserves and the eighth largest oil reserves (Dansie *et al.* 2010). Russia has the largest energy subsidies which amount to approximately US $40 billion per year (Iwaro and Mwasha 2010). The subsidies are mainly targeted at natural gas. The rest of the subsidy is targeted at electricity which includes the under pricing of gas delivered to power stations (Iwaro and Mwasha 2010).

India is another country which provides subsidies even though it imports most of its energy. India is currently the sixth largest consumer of energy in the world where in 2006, it accounted for 3.6% of the world's energy consumption (Dansie *et al.* 2010). India imports most of its energy and is therefore at risk of external supply disruptions. Approximately one-third of the world's population that does not have access to electricity lives in India (Dansie *et al.* 2010). Energy subsidies have been used in India for many years as a popular mechanism to win favour in the next round of elections (Dansie *et al.* 2010). India has subsidies in excess of US $10 billion per year (Iwaro and Mwasha 2010). Subsidies are 2 to 7.5 times as large as public spending on health in India (Iwaro and Mwasha 2010).

3.4.3.1 Benefits and challenges of subsidies

Subsidies primarily encourage economic development and intend to benefit the poorer members of the population (Dansie *et al.* 2010). The energy subsidies aim to stimulate economic development which can then speed up industrialisation. Providing subsidies for the less wealthier members in the population can specifically target the forms of energy used or can provide employment opportunities that arise from accelerated development in the country (Dansie *et al.* 2010). Subsidies provide benefits but they are usually short term in nature (Iwaro and Mwasha 2010).

There are many disadvantages with the provision of energy subsidies. Subsidies can be a burden on government budgets especially if the prices for energy are high on the world markets (Dansie *et al.* 2010). Having subsidies is not sustainable as it is expensive and damages the climate (IMF 2008). Subsidies also disproportionately benefit wealthier persons (Iwaro and Mwasha 2010). The market prices of conventional energy sources do not reflect total costs that can undermine the real competitiveness of renewable energy sources (MEEIb

1998). Having artificially low energy prices generally results in lower energy conservation measures and higher CO_2 emissions (Dansie *et al.* 2010).

Subsidies provide benefits that are mainly short term in nature so it is important to reduce or remove them to address the challenges that they impose (Dansie *et al.* 2010). If subsidies are removed or reduced, they can encourage energy efficiency, energy conservation and furthermore increase the attractiveness of renewable energy. Removing electricity subsidies can benefit decentralised PV electricity production since it can enable grid parity to be achieved earlier when the electricity subsidies are removed. Removing energy subsidies also means that more resources will then be available to directly assist the poor and invest in cleaner power (Iwaro and Mwasha 2010).

4 PV deployment in T&T

This section reviews the feasibility and the status of PV in T&T. In addition to this, three possible scenarios whereby PV deployment in T&T can occur are explored, illustrated and discussed.

4.1 Technical potential of PV

4.1.1 Caribbean

Trinidad and Tobago is located in the Caribbean region and it was documented that in the Caribbean, the duration of sunshine on a monthly basis between 1971-1990 was approximately 231.67 hours on average (MEEIa 1998). The number of hours of sunshine is one of the ways in which to estimate the solar potential of a location. Other ways of determining the solar potential include calculating the light intensity which is measured in LUX, and calculating the energy content of solar radiation which is measured in kWh/m^2 /day or kWh/m^2/year. The latter calculation is the most useful for determining the potential for PV electricity. According to Saunders, Simon and Jahoor (1996), the average solar illumination in T&T is over 2,000 lux on a bright day and 500 lux on a dull day.

During the dry season in the Caribbean, each square metre of surface area receives approximately 7 kilowatt hours (kWh) of solar energy (Headley 1995). The Caribbean is situated in an ideal location where there is little seasonal variation and according to Haraksingh (2001), the Caribbean region lies in a strategic position with regard to the high insolation levels year round but it has not yet capitalised or exploited the abundance of such a resource.

Some of the islands in the Caribbean have recorded data on monthly insolation levels on the horizontal plane (kWh/m^2/day). The average daily solar irradiance on a horizontal plane in the Caribbean varies from 4 – 6.5 kWh m^2 as illustrated in Figure 4-1 (Moseley and Headley 1999). Barbados is an island located in the most easterly part of the Caribbean island chain with an area of approximately 461 km^2. Barbados has experience with solar technology applications. The population of the country is about 260,000 and at the end of 1997, the number of solar water heater installations were 30,700 (Moseley and Headley 1999). In the early 1970s, the Government of Barbados adopted the policy of offering tax incentives for solar hot water systems (SHWS) which enabled the number of systems in the country to grow. Barbados is located approximately 13^o N latitude and 59 ^{o}W longitude which is close to Trinidad in relation to the other Caribbean islands.

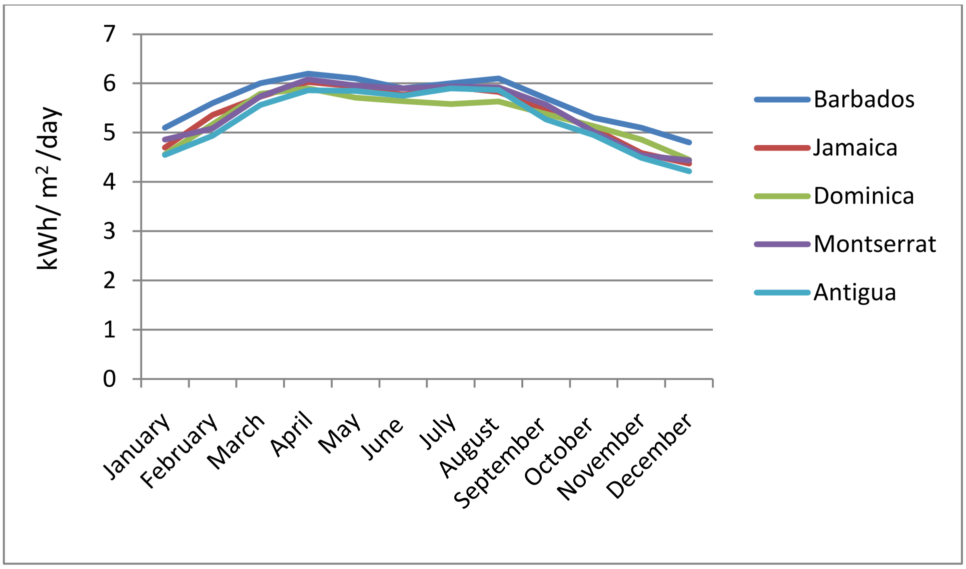

Figure 4-1 Average monthly insolation on the horizontal plane (kWh/m² / day) at sites in the Caribbean

Source: Moseley and Headley 1999

4.1.2 Trinidad and Tobago

In addition to research that was conducted on other islands in the Caribbean, further information was gathered using software to complement research conducted on insolation in the Caribbean. The Valentin Software was used to perform calculations and estimate the amount of electricity that can be fed into the grid for PV of different sizes under T&T's solar conditions. An investor can also utilise the software to calculate the annual feed-in payment that can be received with the feed-in tariff scheme. Calculations with the software revealed that with polycrystalline silicon modules, an investor of grid-connected PV can possibly feed into the grid a range from 147 kWh per year to 12,769 kWh year with the size of PV ranging from 0.1kW$_p$ to 10kW$_p$ on a 15^0 angle roof that is south facing (Valentin Software 2011). From the calculation, a 1kW$_p$ has the potential to feed into the grid 1,321 kWh/year (Valentin Software 2011). In Germany, a 1kW$_p$ has the potential to feed into the grid 865 kWh/year (Valentin Software 2011) which is less than the figure for Trinidad and Tobago.

The Valentin Software, is a useful tool to calculate the return an investor would receive if the FIT payment was set at a price higher than the current electricity price. When the Government determines a suitable tariff in the FIT scheme, homeowners should be encouraged to use the software or similar software to the Valentin Software to calculate the returns received using PV of different sizes.

The average cost of installing solar PV, to supply all electricity needs in an average two bedroom home in T&T, can range from TT $500,000 to $800,000. The payback period is estimated to be between 15–20 years taking the current electricity rates into consideration (G. Sooklal, personal communication, January 14, 2011). The cost of PV systems is expected to be lower with the Government incentives.

4.2 Status of PV in T&T

Trinidad and Tobago has some practical experience with solar technology applications. The main solar energy applications studied at the University of the West Indies in Trinidad and Tobago were in the area of solar dryers and solar cookers (Haraksingh 2001). The University of the West Indies in T&T has been involved in researching and testing the use of solar stills, solar cookers and solar crop driers which are mainly used by local entrepreneurs and the farming community (MEEIa 1998). Haraksingh (2001) noted that less than 1% of the houses in T&T utilised solar water heating technology and there were a few small PV installations in remote areas.

PV applications are used in T&T for a range of purposes but none are currently grid-connected. Solar powered applications have also been used by the Telecommunication Services of Trinidad and Tobago (TSTT) as well as the Trinidad and Tobago Electricity Commission (T&TEC). According to Boon (2011), there are approximately 40 PV systems being used in the telecommunications industry and the sizes of the systems range from 500W–2kW. PV is also used offshore, on oil and gas platforms and there are over 50 systems which range from 60W–3 kW in size (Boon 2011). PV is also used for navigational aids and telemetry in T&T (Boon 2011). Some demonstration off-grid PV projects were initiated in 2004 by T&TEC in parts of T&T which include Chickland, Freeport, Cumaca, Valencia, Paria and Blanchisseuse (MEEA 2011). The demonstration projects with off-grid PV illustrated that it is cost-effective to install PV for certain remote locations in the country (MEEA 2011).

The Trinidad and Tobago Electricity commission (T&TEC) partnered with solar companies in the country to install PV systems for some households that do not have electricity. It is not economical to install transmission lines to those areas which were very distant to the grid (I. Thompson, personal communication, January 14, 2011). There are approximately 150 PV systems installed on residential rooftops which are in rural areas and the systems range from 60W–5.1 kW in size (Boon 2011).

The Government of Trinidad and Tobago established a Renewable Energy Committee in 2009 and one of the assignments for the Committee included the development of a renewable energy policy. In January 2011, a 'Framework for development of a renewable energy policy for Trinidad and Tobago' was released. In this framework, a few projects regarding PV were proposed. The Government is currently looking at the possibility of using small scale to middle scale PV systems for residential, commercial, and small industrial applications. The size of the systems range from approximately 2 kW to 150 kW (A. Sharaf, personal communication, 20 April, 2011). The incentives being used to promote PV systems include tax rebates for the importers of renewable energy technologies and reduced import duties on equipment (MEEA 2011). According to Seepersad-Bachan (2011), the Government launched a pilot programme that will consider using 'solar energy generation devices either in the form of grid-tied or stand-alone energy devices in 9 schools in T&T in addition to other renewable energy technologies such as solar stills. The United Nations Association of Trinidad and Tobago is responsible for this pilot project which serves 'to create an awareness and practical knowledge of alternative energy' (Seepersad-Bachan 2011). The Government is also considering the possibility of manufacturing photovoltaic panels (Seepersad-Bachan 2011). The country is seeking to utilise the available supply of energy and obtaining the silica resources from Guyana which is geographically close to T&T.

The renewable policy framework in T&T included the feed-in tariff scheme as one of the initiatives it will use to promote PV deployment. Some of the instruments considered in the framework for renewable energy in Trinidad and Tobago besides feed-in tariffs include net metering and renewable portfolio standards (MEEA 2011). The country currently does not have guidelines for potential independent RE producers to feed electricity into the power grid. According to MEEA (2011), for the country to incorporate grid-connected PV, there is a need to first address technical and legislative issues before grid-connected PV can occur.

4.3 Scenarios for PV deployment in T&T

4.3.1 Scenarios

According to Fahey and Randall (1998), scenarios are 'descriptive narratives of plausible alternative projections of a specific part of the future'. Another author describes scenarios as 'a means to represent a future reality in order to shed light on current action in view of possible and desirable futures' (Godet 2011). Scenarios can be used in formulating energy policy by imparting knowledge and information to an audience. This provides learning, understanding and decision making when formulating the policy.

Scenario analysis applies quantification or qualitative methods to help decision makers prepare for the future (Chen, Yu, Hsu, Hsu, & Sung 2009). Characteristics of a storyline scenario, apart from being qualitative, include capturing future worlds in stories, ideas and visions without using a fixed set of assumptions or having no data (Vliet *et al.* 2010). Quantitative knowledge for constructing scenarios is not necessarily required (Vliet, Kok, Veldkamp 2010).

Scenarios can vary in the time scale that they are used to address a certain issue and the choice of the time scale depends on the subject of study and the aim of the scenario developed (Strupeit and Peck 2008). Scenarios describe a set of plausible future events, their causes and consequences (Chen *et al.* 2009). Scenario analysis involves exploration which can be adopted to highlight future possibilities (Chen *et al.* 2009). They can also help decision makers face uncertainty by supplying them with various possibilities for future development (Chen *et al.* 2009).

There are limitations to using scenarios. One limitation includes that scenarios can be affected by changes in technologies and the business environment (Chen *et al.* 2009). As such, the three scenarios created can be different with changes in the future especially if there are policy changes.

Three scenarios for the deployment of PV in T&T are constructed based on the literature review conducted. The scenarios particularly take into consideration the research from Section 3.2.3. The scenarios provide suggestions on the rate at which PV can occur in T&T. Each scenario incorporates different characteristics which provide different outcomes which are discussed. The discussion illustrates the pros and cons of each scenario which can be reviewed by decision makers in the country to consider the prospects for PV deployment in T&T.

4.3.2 Scenario 1- Rapid PV deployment with FIT policy

Scenario 1 focuses on the FIT scheme that was successfully used to deploy solar photovoltaic systems in Germany and Spain. This Scenario provides a rapid pathway for the development of PV in the country. The main goal in Scenario 1 is to achieve a rapid rate of PV deployment in T&T. The Feed-in tariff scheme will be the policy used to achieve this goal. It is assumed that an attractive FIT rate is provided for investors to generate electricity from PV. The attractive tariff will seek to deploy PV at a fast rate. Trinidad and Tobago can adopt the FIT policy to increase the installed capacity of PV in the country. The advantage of using this scheme is that it encourages investors such as private homeowners to install PV panels on their rooftops and feed renewable electricity into the grid while receiving payments for each kWh fed into the grid. This approach could be seen as similar to the development which occurred in Germany from 2000 onwards (Figure 3-3) where the annual installed capacity of PV increased significantly.

Figure 4-2 illustrates schematically the development of the cumulative installed PV capacity until 2020. It is anticipated that by about 2020, grid parity is reached. After the point when grid parity is reached, there will no longer be a need for the FIT policy to encourage PV deployment because the cost of PV will be competitive with the retail cost of conventional electricity. This scenario is under the assumption that subsidies of electricity prices will be gradually phased out by 2020.

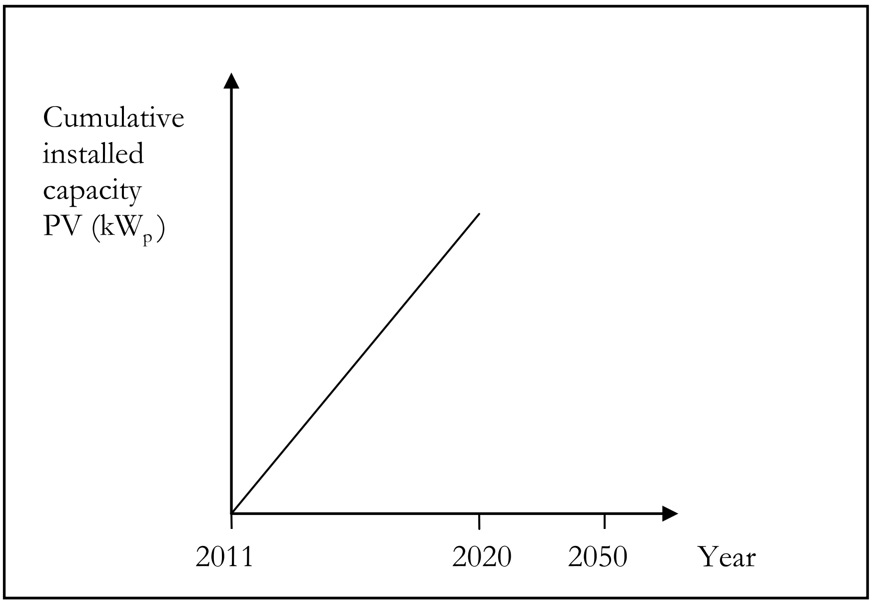

Figure 4-2 Scenario 1- Rapid PV deployment with feed-in tariff policy

Source: Authors design

There are positive and negative aspects with Scenario 1. Scenario 1 is beneficial as it deploys PV at a rapid rate. This however, comes at a price to the electricity consumers. The main disadvantage of this scenario is that the cost of electricity for customers will become more expensive. This is due to the extra costs incurred for the generation of PV electricity as the FIT scheme may re-allocate these costs amongst all electricity consumers.

4.3.3 Scenario 2 – Reaching grid parity in 2020 with Capacity building policy (Subsidy removed)

Scenario 2 (Figure 4-3) incorporates a different approach to encourage PV deployment. The main goal of this scenario is to wait until grid parity is reached before scaling up or rapidly deploying PV. If the country removes the energy subsidy so that the true cost of electricity is revealed, grid parity may be reached in 2020 in the same way that it is expected for other countries. Until grid parity occurs, the country will focus on capacity building where actors that are important to the deployment of PV will gain experience in the field of PV technologies.

Capacity building in Scenario 2 also encourages the Government and stakeholders to build the capacity of the public in understanding and gaining experience with PV. Other activities can be part of capacity building which lead to a gradual increase in PV until grid parity occurs. Once grid parity is reached, T&T can rapidly increase the installed capacity of PV since the technology is more affordable and the stakeholders are familiar and already experienced with the technology. This scenario takes into consideration the costs associated with the solar technology. The pathway that Scenario 2 takes is similar to that in Germany from 1990 to 1999 (Figure 3-3) where the Government introduced the rooftop program so that the country could gain the installation know-how and build capacity before rapidly increasing the installed capacity of PV.

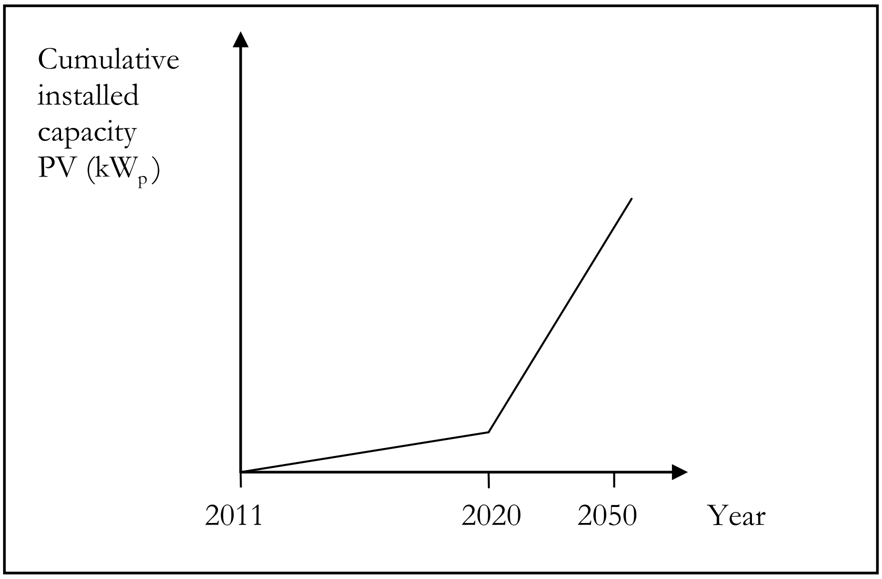

Figure 4-3 Scenario 2- Reaching grid parity in 2020 with capacity building policy (subsidy removed)

Source: Authors design

According to Sharma and Aiyejina (2010), the Government can provide training and education in the field of RE development and ensure that employment opportunities are accessible to the local population. The Government of Trinidad and Tobago can try to educate people about the importance of using PV (A. Sharaf, personal communication, 20 April, 2011). The stakeholders that would be targeted in the capacity building program include T&TEC, select staff in the Ministry of Energy and Energy Affairs, the RIC, commercial providers of PV, installers and engineers, policy makers, banks and financial institutions, and the general public. The activities that will be part of capacity building include pilot projects with households or government buildings, radio and television broadcasting, brochures, workshops and training programmes.

In Scenario 2, the Government of T&T can start promoting PV research which is what Germany commenced since 1974. This will be the basis for learning about the technologies and policies applicable for the country. The Roofs-Solar-Programme that Germany initiated was a way to gain installation know-how and stimulate the users to save electricity and adapt to solar generation. T&T can commence their PV deployment with a strategy like this until grid parity occurs and then the country can seek to rapidly increase the installed capacity of PV at a relatively low cost. Grid parity can be reached in T&T if the energy subsidy is removed thereby increasing the electricity tariffs.

When grid parity occurs, other policies can be implemented to feed renewable electricity into the grid. Such policies include net metering and net billing which can be used to encourage PV investors to feed the electricity into the grid.

The benefit of adopting the policies in this scenario is that the population and relevant stakeholders are familiar and experienced with the PV technology so that when grid parity is reached, the yearly installed capacity of PV can be scaled up. The disadvantage with this scenario is that the subsidy is removed and as a result the cost of electricity is more expensive for consumers. Another disadvantage is that it takes a longer time for PV to significantly increase.

4.3.4 Scenario 3 – Reaching grid parity after 2050 with Capacity building policy (Subsidy not removed)

Scenario 3 (Figure 4-4) has a different set of characteristics from Scenarios 1 and 2. In Scenario 3, the Government is focusing on capacity building like that in Scenario 2 but the energy subsidy is not removed. As such, grid parity may occur after 2050 or later with the current electricity tariffs. Grid parity occurs when the PV electricity production costs (in US$/kWh) are lower than the retail price at the point of end use for households. The average price a residential customer pays for electricity in Trinidad and Tobago is TT 32 cents per kWh which is approximately US 5 cents per kWh. The cost reduction goals illustrated in Table 3-1 depict that PV electricity generation costs are expected to be in the range of US 7 cents per kWh to US 14 cents per kWh by 2050. Therefore, if the subsidy for electricity in T&T is not removed, grid parity can occur after 2050.

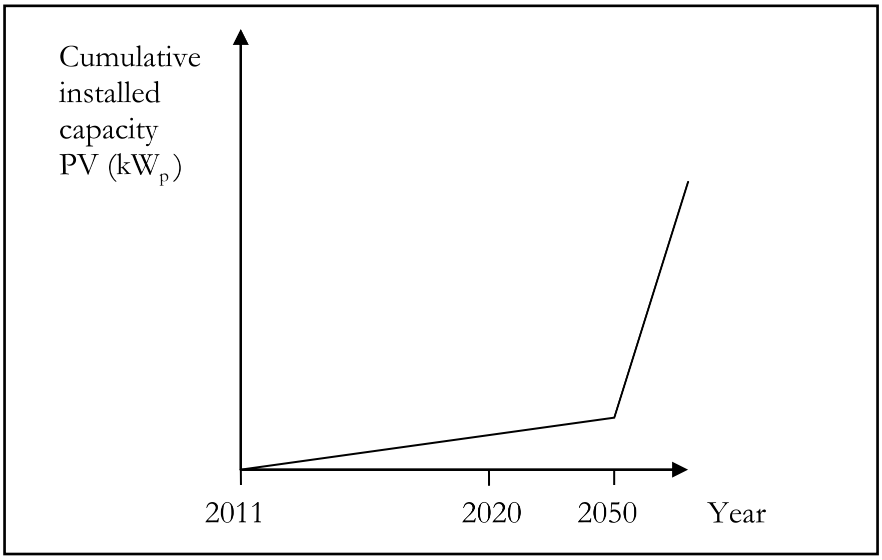

Figure 4-4 Scenario 3 – Reaching grid parity after 2050 with capacity building policy (subsidy not removed)

Source: Authors design

The consequence of this scenario is that the yearly installed capacity of PV is less than the other two scenarios before the year 2020 and it takes longer before the country scales up PV. Scenario 3 therefore takes the longest time for PV to increase. The main problem in this scenario is that the natural gas reserves which are predicted to last another 10 years, will already have run out and the country may be forced to purchase gas for electricity production from another country such as Venezuela.

4.3.5 Summary of scenarios for the deployment of PV in T&T

T&T has many opportunities to address the low ranking energy sustainability index through the adoption of renewable energy and energy efficiency technologies. This thesis provides one suggestion that the country could use to improve its sustainability: PV. Solar photovoltaic systems have the potential to provide renewable electricity for the country which will assist in supplying power for the expected increase in demand for electricity. The Government of Trinidad and Tobago and the relevant stakeholders involved in seeking to deploy PV can review the following three scenarios that were developed and the respective outcomes (Table 4-1).

Table 4-1 Summary of Scenarios 1, 2 and 3

Elements	Scenario 1	Scenario 2	Scenario 3
Characteristics	Use FIT policy to encourage rapid deployment of PV before grid parity	Remove energy subsidy, and wait until grid parity in 2020 and rapidly deploy PV after. Build capacity and when grid parity occurs, increase installed capacity of PV rapidly.	Keep energy subsidy and build capacity. Grid parity occurs in 2050 or later.
Advantages	Rapid deployment of PV which occurs before grid parity. Once grid parity is reached, there will be limited use of FIT. Creating an early 'home market' for PV systems could enable T&T to be a forerunner in the Caribbean region and the country can capitalise on this by exporting knowledge and even PV products to other countries in the Caribbean.	Grid parity occurs sooner because subsidy is removed. Investors will deploy PV themselves without the need for financial policy incentives. Helps to build learning and capacity.	Cost of electricity remains cheap for the lifetime of the natural gas reserves.
Disadvantages	Costly to final consumers as extra costs for PV electricity will be reallocated to consumers.	Longer time to deploy PV and incorporate it into the electricity mix.	Longest time to deploy PV. Natural gas already depleted and T&T has to import it. Small amount of PV installed when natural gas depleted.

Source: Authors design

5 Conclusion and Recommendations

This section answers the research question and provides recommendations for PV deployment in T&T based on the research conducted in the thesis.

Trinidad and Tobago can explore the development of solar photovoltaic powered systems particularly grid-connected PV. PV systems offer a range of benefits to the country. One such benefit includes that it has the potential to diversify the electricity mix and increase the energy security of the country by using PV as an alternative method for generating electricity. A calculation of energy sustainability rankings for 91 countries ranked T&T at number 85 which placed T&T as one of the countries with the lowest energy sustainability rankings. The Energy Sustainability Country Index illustrated that T&T has a low diversity of electricity production since the country is highly reliant on natural gas to provide electricity for the industrial, commercial and residential sectors in the country. Although approximately 97% of the country currently has access to electricity, the natural gas reserves are expected to last approximately 10 years so solar PV systems can be an option to provide electricity for consumers in the future when the gas reserves deplete. PV however, does not have to be deployed after the natural gas supplies are depleted. Using an alternative source of electricity, such as PV, reduces the need for electricity production from natural gas. This enables the natural gas supplies to be exported which provides revenues for the country. The revenues can be beneficial for the development of government projects especially if the projects are inclined toward renewable energy projects.

Trinidad and Tobago has a relatively high CO_2 emission per capita and can consider PV as an alternative source of electricity to reduce the emissions. PV is characterised as a low carbon technology, therefore utilising PV technologies has the potential to reduce the country's CO_2 emissions per capita. Approximately 28% of the country's CO_2 emissions are derived from the power generation sector. If an alternative source of renewable electricity such as PV is used, the percentage of CO_2 emissions could be reduced.

Although the country currently has sufficient electricity capacity, the demand for electricity is rising and the electricity supply can incorporate PV generated electricity. PV has the possibility to supply electricity during the day for the day-time peak demand for electricity. Buildings with PV on the rooftops could feed the electricity produced during the day to the utility grid. The grid can then supply consumers with electricity.

PV offers a range of benefits and opportunities for Trinidad and Tobago but the research question seeks to answer how PV could be deployed in the country.

5.1 Answer to research question:

How could PV be deployed in T&T?

Trinidad and Tobago can adopt a range of policies to encourage the deployment of solar photovoltaic systems. Three scenarios were constructed to represent the pathways on how PV can be deployed in T&T. In Scenario 1, the feed-in tariff (FIT) policy can be adopted to rapidly increase the installed capacity of PV in the country. This policy mechanism was employed by countries such as Germany and Spain which were successful at increasing the installed capacity of PV with attractive FIT rates. Spain however, introduced capacity caps which caused the market to collapse thereby taking some time before new PV capacity was installed. As such, T&T should incorporate a minimum target for PV but not place a capacity cap so investors are encouraged to achieve the goal of the minimum target. Employing the

FIT policy in T&T will encourage investors such as private homeowners to install PV panels on their rooftops and feed renewable electricity into the grid while receiving payments for each kWh fed into the grid. However, the stakeholders involved in setting a FIT rate should be mindful that too high a tariff can lead to windfall profits for the renewable electricity producer and too low a tariff is a discouragement. Although the FIT policy has the potential to rapidly scale up the cumulative installed capacity of PV, the cost of electricity for customers will become more expensive. This is due to the extra costs incurred for the generation of PV electricity as the FIT scheme may re-allocate these costs amongst all electricity consumers.

Scenario 2 displays another pathway for the deployment of PV in Trinidad and Tobago. The country can wait until grid parity is reached before scaling up or rapidly deploying PV but it will need to remove the subsidy so that the true cost of electricity production is revealed. Until grid parity is reached, the country can focus on capacity building where actors that are important to the deployment of PV will gain experience and knowledge in the field of PV technologies. The stakeholders that would be targeted in the capacity building program include T&TEC, select staff in the Ministry of Energy and Energy Affairs, the RIC, commercial providers of PV, installers and engineers, policy makers, banks and financial institutions, and the general public. The activities that will be part of capacity building include pilot projects with households or government buildings, radio and television broadcasting, brochures, workshops and training programmes. The capacity building ensures that when grid parity is reached, the stakeholders and actors in the field of PV deployment are experienced and familiar with the technology so that it can be effectively deployed. T&T can rapidly increase the installed capacity of PV since the technology is more affordable and the stakeholders are familiar and already experienced with the technology. The Government of T&T can therefore start promoting PV research so that there is learning about the technologies and policies applicable for the country. When grid parity occurs, other policies can be implemented to feed renewable electricity into the grid. Such policies include net metering and net billing which can be used to encourage PV investors to feed the electricity into the grid.

Finally, Scenario 3 represents another pathway for PV deployment. In this scenario, the country can focus on capacity building until grid parity is reached but without removing the subsidy for electricity. Scenario 3 can perform similar capacity building activities as described in Scenario 2 where stakeholders gain experience and knowledge with PV systems. However, if the country waits for grid parity to be reached, it may occur after 2050 with the current electricity rates. The country should be mindful of the fact that the natural gas reserves are expected to last another 10 years which means that by 2021, there will be no local natural gas to provide electricity. As such, the country would have to import the natural gas.

5.2 Recommendations

- The author recommends that the Government of Trinidad and Tobago commence capacity building activities as soon as possible to educate the public and private sectors. The energy subsidy should be removed and electricity tariffs should be increased to reflect their true costs; this would enable grid parity to be attained earlier than if the subsidy is kept. Additionally, an attractive feed-in tariff (FIT) can be designed so that renewable electricity generation is attractive to investors. The author therefore supports a combination of Scenarios 1 and 2. Scenario 3 follows a business-as-usual pathway which should be avoided and the author strongly advises against Scenario 3.

- In order to incorporate grid-connected PV into the electricity mix in T&T, the legislation needs to be amended. The legislation to enable open access is not available which means that the Government should amend the electricity legislation and open up the opportunity for electricity production so that power can be generated from grid-connected PV.
- If the country wants to take aggressive steps to deploy RE in the country, one of the ways that it can do this is to design and implement an attractive FIT which supports the growth of renewable electricity. However, this option requires changes in the structure of the electricity sector and the governing legislation as soon as possible.
- T&T can also set a minimum target of PV deployment by a specific time period. Having a target does not give rise to the outcome with capacity caps where new installations of PV technologies are hindered once the cap is reached. The target for PV should be encouraging but realistic and based on a feasibility study. This should be communicated to the public and private investors so that the vision is realised and brought to fruition.
- Capacity building is a prerequisite for the deployment of PV in T&T. It can be initiated at the preparatory phase of deploying PV. The Government could focus on building the capacity for PV while waiting for the costs of PV technologies to decrease. There are a range of activities that can be performed in this area. The Government can provide training and education in the field of RE development and ensure that employment opportunities are accessible to the local population.
- Subsidies provide benefits that are mainly short term in nature so it is important to reduce or remove them to address the challenges that they impose. If subsidies are removed or reduced, they can encourage energy efficiency, energy conservation and furthermore increase the attractiveness of renewable energy. Removing the subsidies enables PV to be more attractive and have a fair and competitive chance for deployment. Removing electricity subsidies can benefit decentralised PV electricity production since it can enable grid parity to be achieved earlier when the electricity subsidies are removed.
- The policy makers in T&T should take the experience curve concept into consideration when creating strategies for PV deployment. The PV experience curve concept states that grid parity can occur sooner if investment into PV systems occurs at faster rate. Therefore, as more countries around the world increase cumulative PV installations, the prices of PV modules are expected to decrease as a result.
- T&T is an energy rich economy that obtains revenue from the oil and gas sector which can be used to fund projects related to renewable energy including the FIT. Apart from the hydrocarbon revenues, the country can use funds from agencies such as the United Nations Development Programme's Global Environment Facility/Small Grants Programme. Overall, funding can be attained from the Government, multilateral funding, international and financing institutions, and other foundations. The clean development mechanism (CDM) can also offer potential sources of funding for renewable energy.
- T&T should start collecting data on monthly insolation levels at different sites in the country. Other countries in the Caribbean have already collected such data where they have measured monthly insolation on the horizontal plane (kWh/m^2/day).
- The policy should encourage as many actors and citizens as possible to participate. Government agencies as well as farmers, homeowners and communities should be inspired and informed to partake in the deployment of renewable energy projects. There should be increased awareness and capacity building amongst government ministries, private entities, non-governmental organisations and the general public.

- T&T should try to achieve grid parity before the natural gas reserves deplete.
- The promotion of renewable electricity has the possibility of transforming the transportation sector in the future whereby electric vehicles can be used instead of vehicles fueled from fossil fuels.

5.3 Suggestions for further research

Renewable energy deployment is a topic of growing interest to Trinidad and Tobago but more research is needed in the field of renewable energy policy in T&T for the various types of renewable energy technologies that can potentially be deployed in the country. Encouraging research in RE technologies contributes to capacity building. One topic in particular that can be researched is the use of solar water heating for homes in T&T especially since Barbados has been very successful in this activity. Other academics or researchers seeking to contribute to renewable energy literature applied to T&T can conduct in depth research into how to deploy other renewable energy technologies especially wind and biomass in T&T.

Bibliography

ADB (2005). Development of grid-connected photovoltaic for urban areas. Asian Development Bank.

Asano, N. and Saga, T. (2008, 15-17 December). *PV technology trends and industry's role*. Paper presented at Electron Devices Meeting, San Francisco, CA.

Bagnall D. and Boreland M. (2008). Photovoltaic technologies. *Energy Policy,* 36, 4390-4396.

Bhandari R and Stadler I. (2009). Grid parity analysis of solar photovoltaic systems in Germany using experience curves. *Solar Energy,* 83, 1634-1644

Boodlal, D., Furlonge, H., and Williams, R. (2008, 7-10 October). *Trinidad and Tobago's CO_2 inventory and techno-economic evaluation of carbon capture options for emission mitigation*. Paper presented at the 3rd Tobago Gas Technology Conference, Lowlands, Tobago. Retrieved May 22, 2011 from http://u.tt/ngia/papers/tgtc_2008_emission.pdf

Boon, I. (2011, January). *T&T's experience with renewable energy technologies to date* [PowerPoint slides]. Presented at the National Energy Policy Consultations, T&T. Retrieved April 5, 2011 from: http://www.energy.gov.tt/content/203.pdf

BP (2010). BP Statistical Review of World Energy. Retrieved April 17, 2011 from: http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/statistical_review_of_world_energy_full_report_2010.pdf

BP (2011). BP energy outlook 2030. London January 2011

Campoccia, A., Dusonchet, L., Telaretti, E., and Zizzo,G. (2009). Comparative analysis of different supporting measures for the production of electrical energy by solar PV and wind systems: four representative European cases. *Solar Energy* ,83(3), 287-297

CARILEC (2010). Tariff survey among member electric utilities. The Caribbean Electric Utility Service Corporation.

CBTT (2010). 2010 Annual economic survey. Central Bank of Trinidad and Tobago.

Chen, T., Yu, O., Hsu, G., Hsu, F., and Sung, W. (2009). Renewable energy technology portfolio planning with scenario analysis: a case study for Taiwan. *Energy Policy,* 37(8), 2900-2906

Couture, T.D., Cory, K., Kreycik, C., and Williams, E. (2010). A policymaker's guide to Feed-in Tariff policy design. National Renewable Energy Laboratory (NREL).

CSO (2010). Central Statistical Office, Ministry of Planning & Development. Government of the Republic of Trinidad and Tobago. Retrieved January 12, 2011 from: http://www.cso.gov.tt/Pages/default.aspx

Dawe, R.A. (2008). Developing sustainability during the oil and gas era for when the hydrocarbon resource is exhausted: the example of the Republic of Trinidad and Tobago. *Energy Sources,* Part B, 3, 76-88.

Dansie, G., Lanteigne, M., and Overland, I. (2010). Reducing energy subsidies in China, India and Russia: dilemmas for decision makers. *Sustainability*, 2, 475-493.

ECTT (2011). Energy commodity price index. The Energy Chamber of Trinidad and Tobago. Retrieved May 4, 2011 from: http://www.energy.tt/index.php?categoryid=1&p2001_articleid=1100

EIA (2009). U.S. Energy Information Administration. Independent statistics and analysis. Retrieved February 22, 2011 from: http://www.eia.gov/countries/cab.cfm?fips=TD

EIU (2011). Trinidad and Tobago: Energy Report. Economist Intelligence Unit. Retrieved April 6, 2011 from: http://www.eiu.com/index.asp?layout=ib3Article&article_id=637743448&pubtypeid=1142462499&country_id=700000070&category_id=775133077&rf=0

Energy-pedia (2010). Niko resources announces strategic acquisition of Voyager Energy. Retrieved April 6, 2011 from: http://www.energy-pedia.com/article.aspx?articleid=138934

EPIA (2004, September). *A vision for PV technology up to 2030 and beyond-an industry view.* [PowerPoint slides]. Presented in Brussels. Retrieved March 30, 2011 from: http://www.schott.com/photovoltaic/english/download/whoffmann_pv_vision_2030.pdf

Erge, T., Hoffmann, V.U., and Kiefer, K. (2001). The German experience with grid-connected PV-systems. *Solar Energy,* 70(6), 479-487.

Fahey, L. and R.M. Randall. (1998). *What is scenario learning? Learning from the future: Competitive foresight scenarios.* L.Fahey and R. Randall. New York, John Wiley.

Foroudastan S. and Dees O. (2006). Solar power and sustainability in developing countries. *Proceedings of the International Conference on Renewable Energy for Developing Countries.*

Godet, M. (2001). *Creating futures: Scenario planning as a strategic management tool*. London, Economica.

González, P. (2008). Ten years of renewable electricity policies in Spain: An analysis of successive feed-in tariff reforms. *Energy Policy,* 36(8), 2917-2929.

GORTT (2009). Government of the Republic of Trinidad and Tobago. Draft national climate change policy for Trinidad and Tobago. Retrieved March 3, 2011, from: http://190.213.5.22:81/policy/docs/Draft%20Climate%20Change%20Policy.pdf

GORTT (2007). Trinidad and Tobago Electricity Commission Act Chapter 54:70. Laws of Trinidad and Tobago. Ministry of Legal Affairs.

GSTT (2010). Geological Society of Trinidad and Tobago. Oil and gas in Trinidad and Tobago. Retrieved March 3, 2011, from: http://www.gstt.org/oil_gas/oilandgas.html

Haraksingh, I. (2001). Renewable energy policy development in the Caribbean. *Renewable Energy,* 24(3-4), 647-655

Held, A., Ragwitz, M., Huber, C., Resch, G., Faber, T., Vertin, K. (2007). *Feed-in Systems in Germany, Spain and Slovenia: A comparison*. Fraunhofer Institute Systems and Innovations Research

Huang, Y.H. and Wu, J.H. (2007). Technological system and renewable energy policy: a case study of solar photovoltaic in Taiwan. *Renewable and Sustainable Energy Reviews,* 11(2), 345- 356

IEA (2002). Market deployment strategies for PV systems in the built environment- an evaluation of incentives, support programmes and marketing activities. Report IEA-PVPS T7-06

IEA (2003). 16 case studies on the deployment of photovoltaic technologies in developing countries. Photovoltaic power systems programme (PVPS).

IEA (2008). International Energy Agency. Key world energy statistics.

IEA (2010a). CO_2 emissions from fuel combustion: highlights. IEA statistics. International Energy Agency

IEA (2010b). Key world energy statistics. International Energy Agency

IEA (2010c). Technology roadmap. Solar photovoltaic energy. International Energy Agency.

IEA (2010d). Trends in photovoltaic applications: Survey report of selected IEA countries between 1992 and 2009. International Energy Agency

IEA (2010e). World Energy Outlook 2010 executive summary. International Energy Agency

Iwaro, J. and Mwasha, A. (2010). Towards energy sustainability in the world: the implications of energy subsidy for developing countries. *International Journal of Energy and Environment,* 1(4), 705-714

Klessmann,C., Nabe, C., and Burges, K. (2008). Pros and cons of exposing renewable to electricity market risks- a comparison of the market integration approaches in Germany, Spain, and the UK. *Energy Policy,* 36(10), 3646-3661

Martin, L. (2009). *Power to the people: electricity, oil and gas in Trinidad and Tobago.* Trinidad and Tobago: Celebrating a Century of Commercial Oil Production. Official Centenary publication of the Ministry of Energy and Energy Affairs.

Martinot, E. (2001). The GEF portfolio of grid-connected renewable energy: emerging experience and lessons. Global Environment Facility

Matroo, C. (2011). Solar powered schools coming. Trinidad and Tobago Newsday.

MEEA (2009). Ministry of Energy and Energy Affairs. Retrieved March 31, 2011 from: http://www.energy.gov.tt/energy_industry.php?mid=69

MEEA (2011). Framework for development of a renewable energy policy for Trinidad and Tobago. A report of the Renewable Energy Committee.

MEEI (2010). Natural gas utilization and pricing. Ministry of Energy and Energy Industries.

Mendonça, M. (2007). Feed-in tariffs: accelerating the deployment of renewable energy. Earthscan: London

Mickwitz P. (2003). A framework for evaluating environmental policy instruments. *Evaluation,* 9(4), 415-436.

Moner-Girona, M. (2009). A new tailored scheme for the support of renewable energies in developing countries. *Energy Policy*, 37(5), 2037-2041.

Moseley L. and Headley O. (1999). Mediuim scale photovoltaic applications for Barbados. *Renewable Energy,* 17, 1-7.

Oxford dictionary (2011). Retrieved May 26, 2011 from: http://oxforddictionaries.com/search?searchType=dictionary&isWritersAndEditors=true&searchUri=All&q=policy&_searchBtn=Search&contentVersion=WORLD

Ramadhan, M. and Naseeb, A. (2010). The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait. *Renewable Energy,* 36(4), 1272-1276

REN21. (2010). *Renewables 2010 Global Status Report* (Paris: REN21 Secretariat). Renewable Energy Policy Network for the 21st Century.

Renwick, D. (2009). *Oil and money: financing the energy industry in Trinidad and Tobago*. Trinidad and Tobago: Celebrating a Century of Commercial Oil Production. Official Centenary publication of the Ministry of Energy and Energy Affairs.

RIC (2005). Performance indicators for the Trinidad and Tobago Electricity Commission. Information document. Regulated Industries Commission.

RIC (2008). Regulated Industries Commission. Retrieved April 21, 2011 from: http://www.ric.org.tt/cms/index.php?option=com_content&task=view&id=31&Itemid=39

RIC (2009). T&TEC granted annual tariff adjustment after meeting specific RIC directives. Regulated Industries Commission

Larsen, H. and Petersen (2010). Risø energy report 9: non-fossil energy technologies in 2050 and beyond. Risø National Laboratory for Sustainable Energy, Technical University of Denmark.

Rüther, R. and Zilles, R. (2011). Making the case for grid-connected photovoltaics in Brazil. *Energy Policy*, 39(3), 1027-1030

Saunders, R., Simon, J. and Jahoor, S. (1996). Use of diffuser in passive daylight solar lighting. *Renewable Energy,* 8 (1-4), 223-226.

Seepersad-Bachan (2011). *Mainstreaming renewable energy projects in schools.* Paper presented at the Formal launch of mainstreaming renewable energy projects in schools held at Hotel Normandie, Port of Spain, T&T.

Sharma, C and Aiyejina,A (2010, 15-16 April). *The requirements and effects of a RE portfolio standard on the economies of the Caribbean island chain: A case study of Trinidad and Tobago*. Paper presented at the IEEE Green Technologies Conference. Retrieved March 27, 2011, from: http://ieeexplore.ieee.org.ludwig.lub.lu.se/stampPDF/getPDF.jsp?tp=&arnumber=05453793&isnumber=5453775&tag=1

Shum, K.L. and Watanabe, C. (2008). Towards a local learning (innovation) model of solar photovoltaic deployment. *Energy Policy,* 36(2), 508-521.

Solangi K., Islam M., Saidur R., Rahim N. and Fayaz H. (2011). A review on global solar energy policy. *Renewable and Sustainable Energy Reviews,* 15, 2149-2163.

Strupeit, L. and Peck, P. (2008). Introduction to scenario development. The International Institute for Industrial Environmental Economics, Lund University.

Thomas, S. (2009, October 18-22). Impacts of economic growth on CO_2 emissions: Trinidad case study. Paper presented at the 45th ISOCARP Congress. Porto Portugal. Retrieved May 22, 2011, from: http://www.isocarp.net/Data/case_studies/1598.pdf

T&TEC (2004). Trinidad and Tobago Electricity Commission: Business Plan 2004-2008.

UN (2011). United Nations Statistics Division.

UNDP (2009). Supporting capacity development: the UNDP approach.

UNDP (2010). Human Development Index. Retrieved May 11, 2011, from: http://hdr.undp.org/en/statistics/

UNDP (2011a). Energy for sustainable development: overview. Retrieved May 11, 2011, from: http://www.undp.org/energy/

UNDP (2011b). Practitioner's guide: capacity development for environmental sustainability.

Valentin Software (2011). Retrieved April 11, 2011, from: http://valentin.de/calculation/pvonline/pv_system/en

Vliet, M., Kok, K. and Veldkamp, T. (2010). Linking stakeholders and modelers in scenario studies: the use of fuzzy cognitive maps as a communication and learning tool. *Futures,* 42(1), 1-14.

WB (2008). Phase I: an evaluation of World Bank win-win energy policy reforms. Retrieved April 29, 2011, from: http://siteresources.worldbank.org/EXTCLICHA/Resources/Climate_ESweb.pdf

WEC (2010). Pursuing sustainability: 2010 Assessment of country energy and climate policy, World Energy Council.

World Bank (2011). *Trinidad and Tobago Data*. Retrieved January 10, 2011, from http://data.worldbank.org/country/trinidad-and-tobago

WFC (2009). Unleashing renewable energy power in developing countries: proposal for a global renewable energy policy fund. World Future Council.

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Appendix 1

Location of Trinidad and Tobago

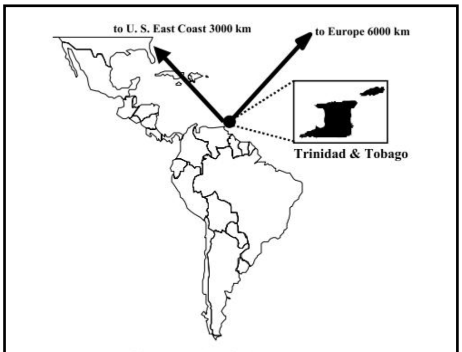
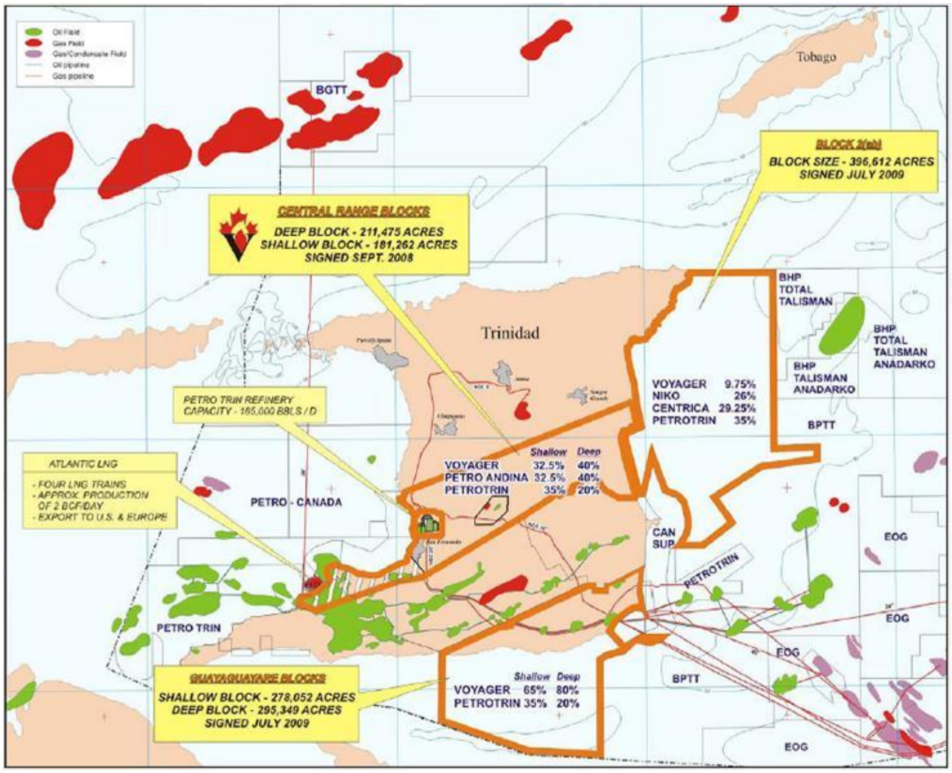


Figure 1. Location of Trinidad and Tobago.

Source: Dawe 2008

Appendix 2

Oil and Natural gas fields in Trinidad and Tobago



Source: Energy-pedia (2010)