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TRINIDAD AND TOBAGO

FEASIBILITY STUDY ON THE USE OF SOLAR ENERGY AT PIARCO INTERNATIONAL AIRPORT

ICAO-EUROPEAN UNION ASSISTANCE PROJECT: CAPACITY BUILDING FOR CO_2 MITIGATION FROM INTERNATIONAL AVIATION

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EXECUTIVE SUMMARY

The International Civil Aviation Organization (ICAO) is collaborating with international organizations and States to create State Action Plans and to implement a basket of measures toward achieving the global aspirational goals for CO_2 emissions reductions. These goals, adopted by the 37th Session of the ICAO Assembly in 2010, seek to improve fuel efficiency by 2 per cent per year from 2020 and to keep net CO_2 emissions at the same levels (i.e. carbon neutral growth from 2020).

One such partnership is the *Capacity Building for CO_2 Mitigation from International Aviation* Project, a joint initiative of the European Union (EU) and ICAO. It aims at providing assistance to a selected group of fourteen States in Africa and the Caribbean to support their efforts in developing and implementing their national Action Plans for the reduction of CO_2 emissions from international aviation; to improve their aviation environmental systems; and to identify, evaluate and implement mitigation measures in selected States. Trinidad and Tobago is one of the States receiving assistance from the Project.

A mitigation measure for emissions reductions included in Trinidad and Tobago's Action Plan is the use of electrical 400 Hz Ground Power Unit (GPU) frequency converters and Pre-Conditioned Air (PCA) units powered by renewable energy to replace aviation fuel-powered Auxiliary Power Units (APUs) and some diesel power GPUs. As part of the ICAO-EU Assistance Project, a comprehensive feasibility study has been prepared on the use of renewable energy at Piarco International Airport (ICAO: TTPP IATA: POS) in Port-of-Spain, Trinidad and Tobago. This study complements the current progress on the technical, regulatory and economic measures planned, or already in place, to reduce CO_2 emissions from international aviation.

Aircraft require power while docked at the gate to run on-board systems and keep the cabin properly conditioned. Traditionally, this power has been supplied by the aviation fuel-powered APU located in the tail of the aircraft and diesel-powered mobile GPU operated at the airport. Given that aircraft docking time is typically between 1 and 3 hours, the cumulative impacts of aircraft at-gate emissions can be significant. While installing gate electrification equipment (400 Hz GPUs and PCAs) eliminates all of the local emissions at the gate, there remains some CO_2 emissions in the electricity used to power the aircraft which originates from a regional power plant. The CO_2 emissions remaining depends on the source of electricity (e.g., coal, gas, renewables) produced by the national grid. The adoption of renewable energy to provide electricity to the gate equipment mitigates CO_2 gate emissions from international aviation and can also be designed to reduce domestic aviation CO_2 emissions generated by the airports facilities, as a co-benefit.

ICAO seeks to assess and demonstrate the feasibility of replacing carbon-intensive gate equipment with electric types powered by solar energy consistent with the UN's Clean Development Mechanism Small-scale Methodology "Solar Power for Domestic Aircraft At-Gate Operations." The purpose of this study is to evaluate the technical and financial feasibility of locating a compatible solar energy facility to generate required power that would be coupled with gate power retrofits previously completed by the airport to reduce CO_2 emissions from international aviation. The study has also considered opportunities to develop a larger solar facility to supply power to the entire airport as a co-benefit.

Using data provided by airport staff and stakeholders, the study has identified six specific locations where solar photovoltaic (PV) projects could be developed cost-effectively and compatibly with airspace safety and the long-term development of the airport business. Projects range in size from a 1.5 hectare site adjacent to the airport carpark to a 9.5 hectare site in the undeveloped area to the north of the airport, near the proposed business park. The smallest project would provide approximately 7 per cent of the airport's annual electricity while the largest site would provide 45 per cent of its electricity. Designs include ground-mounted facilities that could be constructed in undeveloped lands and car park structures that would provide airport customers with covered car parking facilities.

Project sites are consistent with existing airport infrastructure, airport design standards, and operations. The study also considered the airport's future development and the sites will not inhibit the growth of aeronautical uses that are critical to the national economy. The sites have been evaluated relative to environmental resources, including wetlands and rivers, forested areas, and flood zones, and will avoid natural resource impacts in compliance with existing regulations. Potential locations for interconnecting the facilities to the existing electricity network have been identified which will minimize the area of construction and maintain project cost-effectiveness.

The study's findings were presented to stakeholders at a workshop in April 2018 convened jointly by the Trinidad and Tobago Civil Aviation Authority (TTCAA), the Airports Authority of Trinidad and Tobago (AATT), and ICAO. Input was collected from these partners, as well as from representatives of other government agencies including the Ministry of Planning and Development and the Ministry of Energy and Energy Industries, the Trinidad and Tobago Electricity Commission, the Energy Chamber, and airport tenants, such as Caribbean Airlines and Swissport.

The benefits of developing solar projects at major airports are compounded. Solar is most economical when installed at facilities that consume significant quantities of electricity and are part of the permanent national infrastructure; both of which are characteristics of international airports. In addition, airports represent a State and a region, with business and tourist visitors passing through to enter or exit the country. It is at the airport where the intentions of economic development, environmental protection, and social well-being can be displayed through progressive projects like solar development.

ICAO has been responsible for overseeing this activity and ensuring that the programme and implementation activities meet the various UN Policies and Standards and Recommended Practices and also the fiduciary standards of the project donors.

CONTENTS

ABBREVIATIONS AND ACRONYMS

AATT - Airport Authority of Trinidad and Tobago
AC - Alternating Current
ACI - Airports Council International
ACERT - Airport Carbon Emission Reporting Tool
APU - Auxiliary Power Unit
ATAG - Airline Transport Action Group
BCF - Billions Cubic Feet
CDM - Clean Development Mechanism
CIF - Caribbean Investment Facility
CNG - Compressed Natural Gas
CO_2 - Carbon Dioxide
CO_2 e - Carbon Dioxide equivalent
CREF - Caribbean Renewable Energy Fund
C-SERMS - Caribbean Sustainable Energy Roadmap and Strategy
CWR - Carbon War Room
DC - Direct Current
ECLAC - Economic Commission for Latin America and the Caribbean
EDF - European Development Fund
EIA - Energy Information Administration
EMA - Environmental Management Act
EU - European Union
EV - Electric Vehicles
FAA - Federal Aviation Administration
GDP - Gross Domestic Product
GHG - Greenhouse Gas
GoRTT - Government of Trinidad and Tobago
GPU - Ground Power Unit
GSE - Ground Support Equipment
GWh - GigaWatt hour
Hz - Hertz, a unit of frequency as in classifying electrical currents
iNDC - Intended Nationally Determined Contribution
IPP - Independent Power Producers
IATA - International Air Transport Association
ICAO - International Civil Aviation Organization
IDB - Inter-American Development Bank
IEA - International Energy Agency
IRENA - International Renewable Energy Agency
kg - Kilogram
kV - Kilovolts
kVA - Kilovolt Amps
kW - Kilowatt
MDB - Main Distribution Board
MEEA - Ministry of Energy and Energy Affairs
MEEI - Ministry of Energy and Energy Industries
MRO - Maintenance Repair and Overhaul
MW - Megawatt
MWh - Megawatt hours
LNG - Liquefied Natural Gas
PCA - Pre-conditioned Air
PPA - Power Purchase Agreement
PV - Photovoltaic
REN21 - Renewable Energy Policy Network for the 21st Century
RIC - Regulated Industries Commission
SARPS - Standards and Recommended Practices
SGHAT - Solar Glare Hazard Analysis Tool
SIDS - Small Island Developing States
T&TEC - Trinidad and Tobago Electricity Commission
TTCAA - Trinidad and Tobago Civil Aviation Authority
TTD - Trinidad and Tobago Dollars
TWh - TerraWatt Hours
UNDP - United National Development Programme
USD - United State Dollars
W - Watts
WRAP - Wind Resource Assessment Programme

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1. INTRODUCTION

International aviation emissions currently account for 1.3 per cent of total global anthropogenic carbon dioxide (CO_2) emissions, and this is projected to increase as a result of the continued growth of air transport. ICAO and its Member States recognize the critical importance of providing continuous leadership in order to limit or reduce emissions that contribute to global climate change. The ICAO 39th Assembly reiterated the global aspirational goals for the international aviation sector of improving fuel efficiency by 2 per cent per annum and keeping the net carbon emissions from 2020 onward at the same level, as established at the 37th Assembly in 2010. The Assembly also recognized the work being undertaken to explore a long-term global aspirational goal for international aviation in light of the 2°C and 1.5°C temperature goals of the Paris Agreement and more ambitious goals are needed to deliver a sustainable path for aviation, as the aspirational goal of 2 per cent annual fuel efficiency improvement is unlikely to deliver the level of reduction necessary to stabilize and subsequently reduce aviation's emissions contribution to climate change.

The Government of Trinidad and Tobago (GORTT) supported by the ICAO–European Union joint assistance Project, *Capacity Building for CO_2 Mitigation from International Aviation*, updated and submitted an improved State Action Plan to reduce CO_2 emissions from international aviation in 2015. The State Action Plan for CO_2 Emissions Reduction for Trinidad and Tobago (APERTT), which was updated in 2018, provides a comprehensive approach with a basket of measures for Trinidad and Tobago to reduce aviation CO_2 emissions, including the initiative to explore the feasibility of developing solar power at Piarco International Airport.

The purpose of the solar power feasibility study is to identify options for developing carbon-free electricity as a replacement for grid-supplied electricity generated by regional fossil fuel power stations. Solar power generated at the airport would be sized at a minimum to power all international aircraft parked at the gate between flights significantly reducing CO_2 emissions from gate power activity. Options for larger solar facilities represent a co-benefit by also reducing emissions from domestic aviation activities associated with operating the airport.

An evaluation of the feasibility of deploying solar power at Piarco International Airport requires an understanding of the regional and national renewable energy landscape. This section provides an overview of regional conditions, a detailed assessment of national economy and energy policy effects on renewable energy development, and a summary of the airport solar opportunity.

1.1 REGIONAL CONDITIONS

1.1.1 OVERVIEW OF ENERGY SECTOR

The Caribbean region is significantly impacted by price volatility associated with its dependency on fossil fuel-based energy which accounts for about 90 per cent of its demand. More than half of the energy capacity of 10 of 13 Caribbean States comes from diesel or oil, with the exceptions being Belize (hydro-electric), Suriname (hydro-electric), and Trinidad and Tobago (natural gas)[1]. The cost of electricity in the Caribbean averages between USD 0.34 per kWh and USD 0.50 per kWh, which is four times higher than those of the United States due to the high price of petroleum [2]. Spending on oil imports is a tremendous drain on the hard currency reserves of these islands and can account for up to 10 per cent of their Gross Domestic Product (GDP). While volatility can be managed for

[1] McIntyre, A., A. El-Ashram, M. Ronci, J. Reynaud, N. Che, K. Wang, and S. Mejia. 2016. "Caribbean energy: macro-related challenges." (2016).

[2] Familiar, J. 2015. "Unlocking the Caribbean's energy potential." World Bank. January 31, 2015. http://www.worldbank.org/en/news/opinion/2015/01/31/unlocking-the-caribbeans-energy-potential

domestic production through price controls, the world market will still have a dramatic effect on the national economy. For importers, oil price spikes can cause a major shock to their economies. Overall, the high cost of energy has a negative effect on the economy of the region making alternatives, such as renewable energy, economically attractive.

As was displayed in the autumn of 2017 by Hurricanes Irma and Maria, island States are also vulnerable to the negative effects of climate change including rising sea-levels, higher temperatures and increased natural disasters from changing weather patterns. These island States are low-lying making them sensitive to even small increases in sea level. The tropical climate of the region means that island States are already susceptible to extreme weather events, exposing them to potentially more frequent and severe storms, resulting in catastrophic impacts of storm surge and hurricane force winds. Recent hurricanes have reinforced the need for more resilient and reliable energy systems in the region. Redevelopment of electricity grids can also consider the high electricity prices in the region and provide an opportunity to develop lower, long-term solutions that are less dependent on fossil fuels.

1.1.2 PROSPECTS FOR RENEWABLE ENERGY

A number of Caribbean States have set renewable energy and renewable electricity targets for the near future. These goals range from those of Trinidad and Tobago who want 5 per cent of peak electricity demand to be renewable by 2020, to those of Dominica, Grenada, and Guyana who have slated 90 per cent renewable power by 2030[3]. The renewable energy and renewable electricity targets for each State in the region is provided in **Table 1**.

Prospects for generating renewable energy in the region are also strong due to its sunny and maritime climate. Annual solar irradiance (the power received from the sun in a certain area) ranges from 1 700 to 2 300 kWh/m^2. The velocity of wind averages five to nine m/s depending on location and elevation. As a result, most Caribbean States have adequate solar and wind resources to efficiently generate renewable energy. In addition, some larger islands with high mountains have the potential for hydro-electric power generation, and there are several volcanic islands, including Grenada, St. Vincent, and Dominica that could tap geothermal power. Biomass (organic matter used as fuel) may also be an option on islands with large agricultural sectors and as part of an environmental approach to domestic waste management[5].

Despite these attractive characteristics, technological, economic, political, and social barriers have adversely affected Caribbean States from adopting renewable energy. A survey of 30 participants from the private sector, utilities, international organizations, and governmental and academic institutions indicated that the most important barriers were economic and political, with lack of regulatory framework, gap between policy targets and implementation, and high initial investments, being cited as the most critical[6].

State	Energy Target[1]	Electricity Target
Antigua and Barbuda	15% by 2030	20% by 2020
Bahamas	30% by 2030	15% by 2020, 30% by 2030
Barbados	20% by 2026	29% by 2029
Belize	50% reduction in fossil fuel use by 2020	89% by 2033
Dominica	100% by 2020	100% by 2020
Grenada	20% by 2020	20% by 2017
Guyana	None	90% (no date)
Haiti	None	46% by 2027
Jamaica	20% by 2030	20% by 2030
Montserrat	None	100% by 2020
Saint Lucia	35% by 2020	35% by 2020
St. Kitts and Nevis	None	St. Kitts 20% by 2015, Nevis 100% by 2010
St. Vincent and the Grenadines	None	60% by 2020
Suriname	None	None
Trinidad and Tobago	None	5% of peak demand by 2020

TABLE 1

Renewable Energy Targets in Caribbean Nations[4]

[1] Energy includes electricity, thermal power, and transportation

[3] Ochs, A., M. Konold, K. Auth, E. Musolino, and P. Killeen. 2015. Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS): Baseline Report and Assessment. Worldwatch Institute, 2015.

[4] Ochs, A., M. Konold, K. Auth, E. Musolino, and P. Killeen. 2015. Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS): Baseline Report and Assessment. Worldwatch Institute, 2015.

[5] Blechinger, P., K. Richter, and O. Renn. 2015. "Barriers and solutions to the development of renewable energy technologies in the Caribbean." In Decentralized Solutions for Developing Economies, pp. 267-284. Springer, Cham, 2015.

[6] Blechinger, P., K. Richter, and O. Renn. 2015. "Barriers and solutions to the development of renewable energy technologies in the Caribbean." In Decentralized Solutions for Developing Economies, pp. 267-284. Springer, Cham, 2015.

1.1.3 INTERNATIONAL SUPPORT FOR RENEWABLES

Non-governmental organizations that recognize the financial and environmental co-benefits of renewable energy to the region have become focusing on the Caribbean. In 2012, the Carbon War Room (CWR) launched the "Ten Island Challenge" to work with Caribbean islands to accelerate their transition away from fossils fuels. CWR has reached agreements to work with the following States: Aruba, Anguilla, Bahamas, Belize, British Virgin Islands, Grenada, San Andres and Providencia islands in Colombia, St. Lucia, St. Vincent and the Grenadines, and Turks and Caicos. In 2014, the Rocky Mountain Institute took over management of the CWR and continues to implement the programme[7].

The International Renewable Energy Agency (IRENA), an intergovernmental organization based in Dubai, United Arab Emirates (UAE), has also been active in stimulating renewable energy projects in the region. IRENA's focus is on helping Small Island Developing States (SIDS) around the world to overcome the vulnerabilities they face from climate change and to help them serve as models for the rest of world through rapid renewable energy development. The goal is to enable SIDS to lead by example on climate change. To that end, in 2014 IRENA established its "SIDS Lighthouse Initiative" to offer a framework for SIDS to develop a structured and sustainable approach to renewable energy[8].

Several governments also are actively seeking to promote renewable energy in the region, including the United States (US), the UAE, and the EU and some of its member States, such as Germany and Spain. In January 2017, the UAE launched its Caribbean Renewable Energy Fund, a USD 50 million fund to develop renewable energy projects in the region. The first cycle's projects are due for completion in the final quarter of 2018 and include solar photovoltaic (PV) installations, electric vehicle (EV) charging stations, and advanced battery storage. A second cycle was announced in late 2017. Both cycles include enhanced resilience considerations to mitigate risks underscored by the 2017 hurricane season, which devastated Barbuda and Dominica and affected many other islands. The UAE contributed USD 10 million additional to the UAE-CREF to support relief efforts.

The EU implements the Caribbean Investment Facility (CIF), which is one of the EU's regional blending facilities, aiming at mobilizing funding for development projects, including renewable energy projects. The CIF combines grants from the European Development Fund (EDF) with loans from other sources. The US provides direct funding to Puerto Rico and the US Virgin Islands trough national grants and tax incentive programs. In May 2016, the US seeded a program launched by the Caribbean Community (CARICOM) known as the Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS) Platform as a mechanism to manage regional coordination and action on energy security.

1.1.4 RENEWABLE ENERGY AT AIRPORTS

Airports have increasingly become sites for renewable energy projects worldwide. A 2015 report from the Air Transport Action Group (ATAG) shows a map of 98 airports around the world that have installed solar power[9]. Solar PV, in particular, is well-suited for airports because it can easily be integrated into the airport landscape on the ground, taking into account all appropriate safety concerns, on buildings, or over carparks. The Caribbean region offers examples of solar projects constructed at airports. **Table 2** lists the projects which are shown on **Figure 1**.

State	Airport	Type	Size	Year
Antigua	VC Bird	Ground-mounted	3 MW	2016
Aruba	Beatrix	Carport	3.5 MW	2014
Dominican Republic	Cibao	Ground-mounted	1.5 MW	2013
Dominican Republic	Las Americas	Ground-mounted	1 MW	2017
Jamaica	Norman Manley	Carport	100 kW	2018
St. Kitts and Nevis	Robert L. Bradshaw	Ground-mounted	1 MW	2013
St. Thomas	Cyril E. King	Ground-mounted	451 kW	2011
St. Vincent and Grenadines	Argyle	Ground-mounted	300 kW	2017

TABLE 2

Solar PV Projects at Airports in the Caribbean Region

[7] https://rmi.org/our-work/global-energy-transitions/islands-energy-program/
[8] http://islands.irena.org/
[9] ATAG. 2015. Aviation Climate Solutions. Air Transport Action Group. September 2015.

In the aftermath of Hurricanes Irma and Maria and the destruction caused to centralized power systems, there is considerable study being conducted on rebuilding electricity systems, so they are more resilient to such severe weather events. The concept is to include more decentralized generation systems supplied by renewables and including storage such that repairs can more quickly restore power. Airports, as critical infrastructure necessary for moving people, should be considered in this planning such that power can be restored quickly to facilitate transport of people and goods safely after destructive regional events.

FIGURE 1
Location of Airport Solar Projects in the Caribbean

1.2 NATIONAL CONDITIONS

1.2.1 ENERGY ECONOMY

Trinidad and Tobago is the third wealthiest State in the western hemisphere, after the US and Canada, as measured by per capita GDP. A central factor of its economy is the success of its petroleum extraction industry and the low cost of energy. The energy sector amounts to 45.3 per cent of national GDP (2011), provides almost 60 per cent of government revenue and is the most important export commodity with 83 per cent of merchandise exports, mainly refined oil products, liquefied natural gas (LNG), and natural gas liquids (Espinasa et al. 2016). In this way, it is very different from other island nations in the region because its domestic energy costs are low and standard of living high.

Natural gas extraction has increased in Trinidad and Tobago from 177 billion cubic feet (bcf) in 1990 to 811 bcf in 2011 (see **Figure 2**). In 2012, Trinidad and Tobago was the 6th largest LNG exporter in the world[11]. Gas exports in the form of liquefied natural gas (LNG) account for 56 per cent of the total gas production. Gas powers 100 per cent of electricity generation and consumption, but the gas required represents only 8 per cent of total gas production. Trinidad and Tobago also produces around 80 000 barrels of oil per day (2012). 20 per cent of total production is consumed locally, mainly by the transport sector[11].

In the 1970s, in response to world oil shortages and spiking prices, a petroleum subsidy and levy were introduced to protect consumers from the sharp price increases and ensuring low and stable prices. Initially, the entire cost of the subsidy was borne by oil-producing companies, but an amendment passed in 1992 capped the oil companies' levy at 3 per cent of the company's gross income. This percentage was raised to 4 per cent in a supplemental amendment in 2003; however,

[10] Marzolf, N., C. Caneque, J. Klein, and D. Loy. 2015. A Unique Approach for Sustainable Energy in Trinidad and Tobago. InterAmerican Development Bank. IDB Monograph; 382. http://www.energy.gov.tt/wp-content/uploads/2016/08/A-Unique-Approach-for-Sustainable-Energy-in-Trinidad-and-Tobago.pdf
[11] IDB. 2013. Trinidad and Tobago's Energy Market, http://blogs.iadb.org/caribbean-dev-trends/2013/12/02/trinidad-and-tobagos-energy-market Inter-American Development Bank.

this amendment also includes a new provision exempting any company producing less than 3 500 barrels per day. The consequence of the fuel subsidy is that the government bears a greater portion of the subsidy when oil prices increase.

Artificially keeping fuel process low also discourages both supply side and demand side efficiency improvements, which lead to high energy consumption. It also prevents alternative energy generation options from entering the market because they cannot compete with the low price of fossil fuels[12]. While these conditions have produced economic wealth and a high standard of living for Trinidad and Tobago, it has also prevented investment in energy diversification, policy that seeks to balance dependence on fossil fuel exports and focus on meeting environmental targets.

97 per cent of the population has access to electricity[13]. The peak demand of the public electricity service in Trinidad and Tobago has grown annually by 4 per cent from 557 MW in 1990 to 1 275 MW in 2012, as shown in **Figure 3**, and electricity consumption is predicted to double between 2010 and 2032[14]. A few existing power plants have recently been retired which also must be considered when evaluating future electricity generation capacity.

FIGURE 2
Natural Gas Production and LNG Exports, Trinidad and Tobago

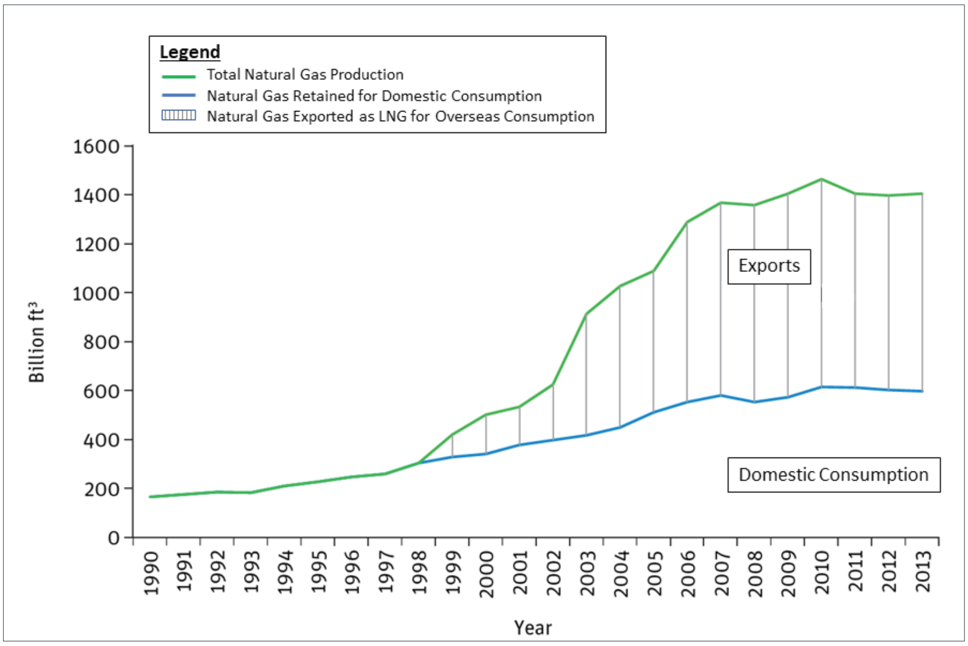
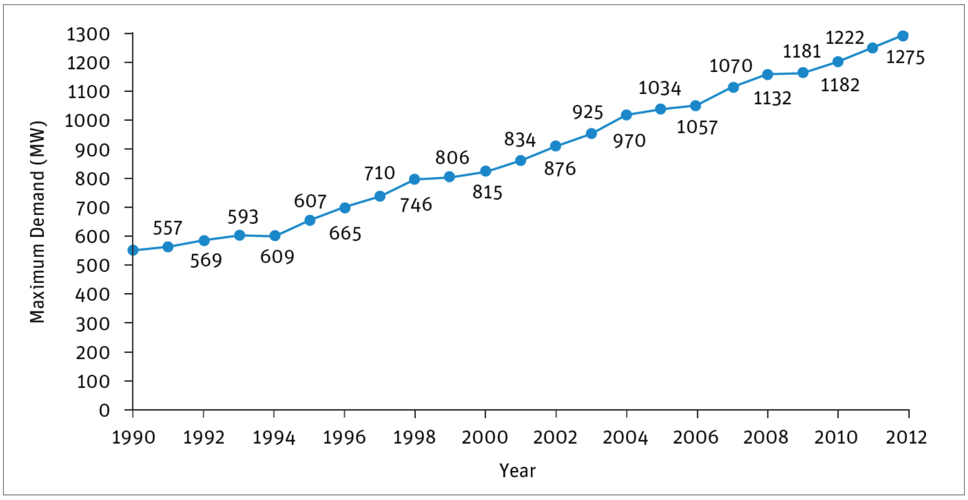


FIGURE 3
Peak Electricity Demand in Trinidad and Tobago (TTEC 2013)



[12] Greigg, K., 2011: Managing in a volatile economic environment: addressing the challenge before us. Department of Economics, The University of the West Indies.
[13] REN 21. 2017. Renewables 2017: Global Status Report. Paris, REN Secretariat. ISBN 978-3-9818107-6-9.
[14] Marzolf, N., C. Caneque, J. Klein, and D. Loy. 2015. A Unique Approach for Sustainable Energy in Trinidad and Tobago. InterAmerican Development Bank. IDB Monograph; 382. http://www.energy.gov.tt/wp-content/uploads/2016/08/A-Unique-Approach-for-Sustainable-Energy-in-Trinidad-and-Tobago.pdf

Trinidad and Tobago contributes approximately 0.1 per cent of global CO_2 emissions. However, as a result of its oil and gas development, it currently ranks 2nd in per capita emissions and produces an estimated amount of 52 million metric tonnes of CO_2 annually[15].

Power prices have remained low in Trinidad and Tobago relative to the region due to abundant gas supply and subsidies to support consumption. Other States in the Caribbean must import fuel to power traditional electricity generation and have a greater incentive to construct renewable energy to offset high electricity prices and lessen dependency on foreign sources of fuel. Given the comparatively high installed cost of renewable energy, the low market price of power in Trinidad and Tobago has limited investment in alternative forms of energy[16].

Several factors have come together in recent years to increase the prospects for renewable energy investment in Trinidad and Tobago. First, falling global petroleum prices have impacted the State's economy through large reductions in profits from exported LNG highlighting the need for energy diversity. Second, an increasing focus on climate change and the potential impact on island States in particular has led Trinidad and Tobago to make global commitments to reduce carbon emissions. In February 2018, Trinidad and Tobago ratified the Paris Agreement on climate change committing to a reduction in greenhouse gas (GHG) emissions by 15 per cent from industry, power generation, and transportation by 2030. And third, the cost to generate electricity from renewable energy sources such as solar and wind has decreased significantly in recent years. In response, the GoRTT has been developing policies to increase investment in sustainable energy to meet future supply, increase reliability, stabilize prices, and address climate change.

1.2.2 EXISTING ENERGY STRUCTURES

The Trinidad and Tobago Electricity Commission (T&TEC), a state-owned company, is responsible for all electricity transmission and distribution in Trinidad and Tobago. In 1994, it divested from its generation holdings on Trinidad and now purchases electricity supply for the island from three Independent Power Producers (IPPs):

- the Power Generation Company of Trinidad and Tobago, which purchased the former T&TEC-operated plants and presently controls 1 386 megawatts (MW) of gas-fired capacity across three facilities in which T&TEC holds a 51 per cent ownership interest;
- Trinidad Generation Unlimited, which operates a 720 MW natural gas combined cycle power plant and is solely owned by the GoRTT; and
- Trinity Power Limited, which owns a 225 MW simple cycle natural gas plant.

T&TEC remains the sole owner and operator of generation on Tobago, where it maintains two power plants with a combined capacity of 75 MW. The two islands of Trinidad and Tobago are separated by a distance of roughly 30 kilometers and are not electrically interconnected[17].

The regulatory framework for the electric sector is estab¬lished by the Regulated Industries Commission (RIC). T&TEC reports annually to the RIC on various service quality metrics such as frequency and duration of outages and resolution of customer complaints. In past proceedings, RIC has pointed to quarterly fluctuations in T&TEC's system loss rates as an opportunity to improve T&TEC's metering and billing operations.

1.2.3 RENEWABLE ENERGY RESOURCE POTENTIAL

A study by the Economic Commission for Latin America and the Caribbean (ECLAC) presents the potential for renewable energy on a High-Medium-Low scale for each State in the region[18]. **Table 3** lists the renewable energy potential for specific renewable resources in Trinidad and Tobago.

Resource	Potential	Description
Hydro		One or more sites can be equipped with a small scale hydropower facility (<1 MW)
Wind		No area identified with average wind speed above 5 m/s
Solar		Several areas with global horizontal irradiation/insolation above 1800 kWh/m^2 per year
Geothermal		--
Biomass		Maximum identified theoretical. Potential below 10 PJ incl. agriculture, wood and residues
Ocean		Wave power below 10 kW/m

TABLE 3

Renewable Energy Potential in Trinidad and Tobago by Resource

Note: The information on resources should be taken as an indication only. It refers to a general trend of available resources and does not prejudge the feasibility of individual projects. The thresholds are indicative, and do not refer to any technological choice. The analysis is based on the literature.

[15] UNEP. 2011. Report of the first national workshop and the first sectoral workshop for the capacity building for the clean development mechanism (CDM) sub component of the capacity building related multilateral environmental agreements in African, Caribbean and Pacific countries project; Workshop Report 2011.

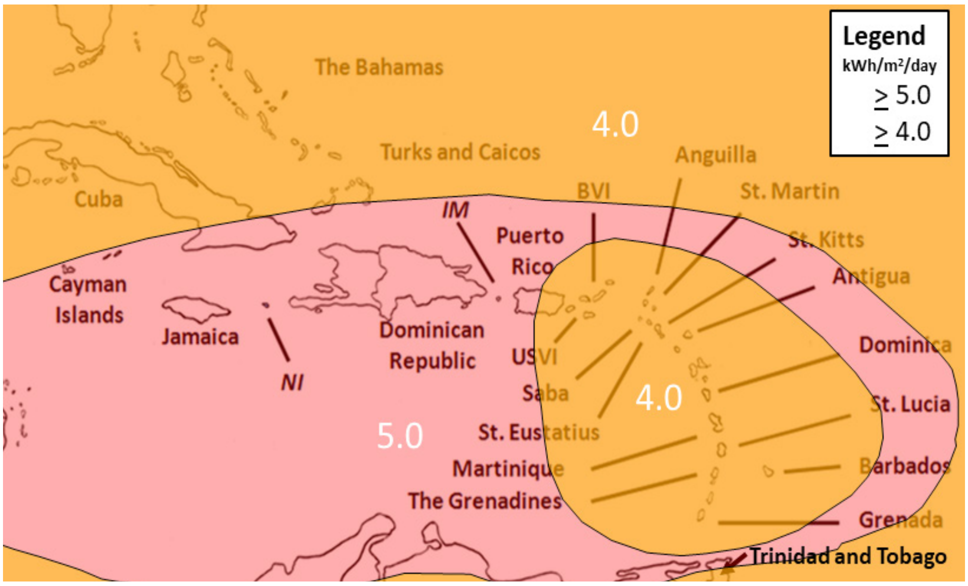
[16] Griffith-Jones, S., S. Spratt, R. Andrade, and E. Griffith-Jones. 2017. Investment in Renewable Energy, Fossil Fuel Prices, and Policy Implications for Latin America and the Caribbean. Financing for Development Series. No 264. Economic Commission for Latin America and the Caribbean (ECLAC). http://repositorio.cepal.org/bitstream/handle/11362/41679/1/S1700188_en.pdf

[17] Espinasa, R. and M Humpert. 2016. Energy Dossier: Trinidad and Tobago. Technical Note No. IDB-TN-938. Inter-American Development Bank. February 2016.

[18] IRENA. 2012. Renewable Energy Country Profiles: Caribbean. International Renewable Energy Association. September 2012 edition. Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/_CaribbeanComplete.pdf

Solar insolation is a measure of the amount of solar energy available per a unit area. **Figure 4** shows a solar insolation map for the Caribbean. Trinidad and Tobago is located at the boundary of the 5.0 kWh/m2 per day, the highest solar insolation in the region.

FIGURE 4
Solar Insolation Map of the Caribbean



1.2.4 RENEWABLE ENERGY POLICY DEVELOPMENT

In 2010, the University of the West Indies (UWI) Engineering Institute supported the Ministry of Energy and Energy Industries (MEEI) with development of a Renewable Energy Policy Framework for Trinidad and Tobago[19]. Its objective was to identify conditions for growth and development of the State's renewable energy resources to maximize opportunities for clean energy generation, and energy efficiency and conservation. The Framework was approved by the Cabinet in late 2010 and has served as the basis for a "Green Paper on Sustainable Energy" which continues to be in development[20].

In 2011, the GoRTT through the Ministry of Energy and Energy Affairs (MEEA) received technical assistance in the development of policies and activities that will promote the deployment of renewable energy and the implementation of energy efficiency measures under a policy-based loan from the Inter-American Development Bank (IDB). This information is contained in the IDB final report "A Unique Approach for Sustainable Energy in Trinidad and Tobago."[21] The report contains recommendations on policy measures in the context of the Government's "Green Paper on Sustainable Energy", which will provide the overall guidelines for implementation of energy efficiency and renewable energy measures in the future. While the draft Green Paper proposes to increase the share of renewable energy to about 2.5 per cent of overall power generation by 2020, the authors recommend raising this target to at least 4 per cent to create sufficient market size that could then lead to lower specific costs and a strengthened business sector. Assuming renewable energy markets become more attractive, the report forecasts a 0.5 per cent increase in renewable energy development per year in the first 8 years up to 2020, followed by a 1 per cent increase thereafter, yielding a 16 per cent share of renewable electricity by 2032.

In 2015, the GoRTT issued a Carbon Reduction Strategy to develop the country's options for meeting potential international GHG reduction agreements. Later the same year, the GoRTT announced a specific target for renewable energy; 10 per cent of power generation from renewables by 2021. Colm Imbert, the Minister of Finance, stated this objective in his budget speech on 5 October, 2015. Solar and wind energy were the two renewable energy technologies that were identified. Trinidad and Tobago currently uses approximately 150 GW of power and therefore the target entails generating 150 MW of renewable power by 2021[22].

[19] MEEA. 2011. Framework for Development of a Renewable Energy Policy for Trinidad and Tobago. A Report to the Renewable Energy Committee. January 2011.

[20] MEEI. 2018a. Development of a Renewable Energy Framework. Accessed on January 9, 2018. http://www.energy.gov.tt/our-business/alternative-energy/development-of-a-renewable-energy-policy-framework/

[21] Marzolf, N., C. Caneque, J. Klein, and D. Loy. 2015. A Unique Approach for Sustainable Energy in Trinidad and Tobago. InterAmerican Development Bank. IDB Monograph; 382. http://www.energy.gov.tt/wp-content/uploads/2016/08/A-Unique-Approach-for-Sustainable-Energy-in-Trinidad-and-Tobago.pdf

[22] http://energynow.tt/blog/target-10-renewables-by-2021.

In order to create the legal and regulatory requirements for renewable energy in Trinidad and Tobago, it will be necessary to amend the Trinidad and Tobago Electricity Commission Act that currently does not allow for wheeling[23]. It also prohibits independent operators from generating electricity and feeding it into the grid without consent of the State-owned utility. Once the legal framework is in place, it is suggested to concentrate on the development of feed-in tariffs for grid-connected smaller-scale renewable energy facilities, namely solar PV and on-site wind, as sources of renewable energy with the largest potential. The GoRTT Carbon Reduction Strategy states that the introduction of a net-metering or net-billing schemes is not advisable under the current conditions with highly subsidized consumer tariff rates, as PV investments would need significant additional financial and fiscal incentives to be competitive. For utility-scale wind and solar plants, competitive bidding is recommended, which will allow site and capacity planning that fits generation expansion plans and uses existing resources adequately. To stimulate the initial uptake of household PV systems, it recommended funding a residential solar initiative known as the "100 roofs" programme[24].

Low electricity tariffs are one major reason for low energy efficiency in Trinidad and Tobago. Therefore, any effort to encourage renewable energy must include elimination of fuel subsidies.

1.2.5 LEGISLATION

The MEEA is working with stakeholders on various initiatives to encourage renewable energy and energy efficiency. These programmes include assessing financial incentives, review of the legislative and regulatory environment, revision to the National Electrical Code, producing technical and product standards, and building capacity and creating awareness.

Currently, the Trinidad and Tobago Electricity Commission Act, Chapter 54:70 and Regulated Industries Commission Act, Chapter 54:73, make no provision for renewable energy power generation by IPPs. The GoRTT is seeking to establish a legislative framework for the generation of electricity from renewable energy sources. This involves the review and amendment of Acts that govern the RIC, T&TEC and Electrical Inspectorate Division (EID). To inform this review, the MEEA has collaborated with the United Nations Environment Programme (UNEP) to develop a framework for policy and legislation to govern feed-in tariffs.

The above-mentioned T&TEC and RIC Acts are currently under review. To this end, a UNEP sponsored consultancy was undertaken to develop a Framework for feed-in-tariffs. With Trinidad and Tobago's ratification of the Paris Agreement in 2018, legislative action is expected on one or more of these in initiatives in the coming years.

1.2.6 RENEWABLE ENERGY PROJECTS AND PROGRAMMES

According to Climatescope, Trinidad and Tobago, through 2017, has no renewable energy generation that is directly contributing to its electricity grid[25]. This is in part due to low domestic energy prices and a lack of legislation to incentivize renewable energy development. The government has funded 25 solar PV projects at secondary schools and 13 at community centres.

The Renewable Energy Policy Network for the 21st Century (REN21), the global renewable energy policy multi-stakeholder network, lists the availability of regulatory and financial incentives in its 2017 Renewable Energy Annual Report[26]. **Table 4** includes the availability of such programmes in Trinidad and Tobago.

[23] "Wheeling" refers to the transportation of electric energy from within an electrical grid to an electrical load outside the grid boundaries

[24] Marzolf, N., C. Caneque, J. Klein, and D. Loy. 2015. A Unique Approach for Sustainable Energy in Trinidad and Tobago. InterAmerican Development Bank. IDB Monograph; 382. http://www.energy.gov.tt/wp-content/uploads/2016/08/A-Unique-Approach-for-Sustainable-Energy-in-Trinidad-and-Tobago.pdf

[25] http://global-climatescope.org/en/country/trinidad-and-tobago/#/enabling-framework

[26] REN 21. 2017. Renewables 2017: Global Status Report. Paris, REN Secretariat. ISBN 978-3-9818107-6-9.

Regulatory Programme	Is it available in Trinidad and Tobago?
Feed-in Tariffs	No
Electric Utility Quotas/Obligations	No
Net Metering	No
Transport Obligations	No
Heat Obligations	No
Tradeable RECs	No
Tendering	No

Financial incentive	Is it available in Trinidad and Tobago?
Investment of Production Tax Credits	Yes
Reduction in Sales, VAT, and Other Taxes	Yes
Energy Production Payment	No
Public Investment, Grants, Loans, Capital, Subsidies, or Rebates	No

TABLE 4
Availability of Renewable Energy Regulatory and Financial Incentives in Trinidad and Tobago

Additional details on the fiscal incentive programs is included on the MEEI website[27].

As part of the GoRTT's implementation of programmes to encourage renewable energy and energy efficiency, the following measures are being pursued[28]:

- fiscal support mechanisms: tax credits, import duty exemptions, 0-rating for Value Added Tax (VAT) purposes, wear and tear allowances etc.;
- legislative support: amendment to the T&TEC Act and the RIC Act;
- government to lead by example (e.g., renewable energy installations in government buildings including hospitals, medical clinics and schools);
- education and training initiatives: inclusion of renewable energy and energy efficiency in education curricula of schools, workshops to engage personnel who would be directly engaged in the renewable energy industry (e.g., technicians/electricians including T&TEC inspectorate, teachers, 'do-it-yourself' individuals);
- awareness creation re. communication fairs, workshops, various media, micro marketing of incentives for renewable energy and energy efficiency; and
- strategic pursuits including renewable energy installations in community centres which would also serve as demonstration centers and thereby promote education and awareness.

A Wind Resource Assessment Programme (WRAP) has also been announced. It comprises three phases and will be conducted over a period of approximately 20 months, where one of the key outputs is the identification of five candidate sites for wind farm development. The GoRTT will then be seeking to attract potential investors and project developers.

The MEEA has taken the lead in promoting renewable energy and energy efficiency through a number of Pilot initiatives involving the nation's community centres and schools. The renewable energy and energy efficiency in Community Centres Project is a pilot involving the installation of PV lighting for the exterior of 15 Community Centres to satisfy the primary exterior lighting needs of these buildings, promote public sensitization and support the use of these buildings as disaster relief centres. This Programme was officially launched in 2013. Nine centres have already been outfitted under the MEEA's Public Sector Investment Programme (PSIP) and a further six are currently being undertaken by the National Gas Company.

The "National Energy Policy Green Paper" of Trinidad and Tobago which is currently being finalized, recognizes the importance of clean energy production and energy efficiency in promoting the State's sustainable development. Consistent with this policy, capacity-building through education and training is one of the critical success strategies. As such, the Renewable Energy Committee (REC) initiated a one-year Renewable Energy and Energy Efficiency Education Pilot Project, targeting 25 secondary schools distributed across the eight educational districts of Trinidad and Tobago. The range of benefits to be derived include: support to the schools serving as disaster-relief centres, and provision of a power source for public address systems, and students' laptop charging stations. The technologies are being introduced to support the learning process and are not intended to substitute the electricity supply

[27] MEEI. 2018b. Renewable Energy and Energy Efficiency Fiscal Incentives. Accessed January 9, 2018. http://www.energy.gov.tt/our-business/alternative-energy/renewable-energy-and-energy-efficiency-fiscal-incentives/

[28] MEEI. 2018c. Brief on Renewable Energy and Energy Efficiency. Accessed on January 12, 2018. http://www.energy.gov.tt/our-business/alternative-energy/renewable-energy/

at these institutions. Implementing the project will increase the cadre of trained professionals in the area of renewable energy and energy efficiency technologies, as well as sensitize the academic community and the general public to the benefits to be derived from utilizing renewable energy and energy efficiency technologies.

1.3 SOLAR POWER AT PIARCO INTERNATIONAL AIRPORT

The overview of regional and national renewable energy activities discussed above presents two different scenarios. On the one hand, most States in the region have been investing in renewable energy to offset high domestic power costs. On the other, Trinidad and Tobago has moved cautiously in developing alternative energy sources due to the economic success of domestic fossil fuel production and low energy prices. However, in recent years, Trinidad and Tobago has begun to implement strategic investments in renewable energy primarily due to a recognition of its dependence on the fossil fuel economy and to make progress on its international climate change commitments.

Communications between the AATT and the T&TEC regarding a potential solar PV project were initiated in early 2017. Subsequently, the AATT Board has approved steps to move forward in evaluating this opportunity. Given the continued low cost of existing power and the relatively high cost of solar, any progress toward developing a significant solar project at the airport will require support from the national government and T&TEC, and recognition of the broad benefits that would be afforded by an airport solar project.

Specifically, a solar project at Piarco International Airport would meet many national objectives. These include:

- showcasing the State's commitment to a future energy policy;
- investing in energy resiliency for Piarco International Airport to support its operations in the aftermath of a failure in the national electric grid;
- generating a new source of electricity as part of a programme to diversify the electricity portfolio and mitigate risks associated with fossil fuel dependency; and
- contributing to national commitments to offset CO_2 emissions as part of international agreements.

This Solar Feasibility Report evaluates the technical considerations of developing a solar PV project at Piarco International Airport. It will involve evaluating the existing and planned airport facilities, existing electrical infrastructure, potential environmental constraints, and site-specific benefits of various locations including visibility. A list of potential sites that are compatible with the screening analysis will be produced. A glare analysis will be performed on each potential site to avoid hazardous impacts on sensitive airport receptors.

Using the list of sites identified in the technical feasibility, a financial feasibility of a solar project at Piarco has also been prepared. This analysis includes estimating the project development costs, the amount of electricity that will be generated, the value of that electricity, and the costs to interconnect the facility to the electric grid. Then the cost of developing the project assuming government ownership and third-party ownership has been estimated. Finally, several financing options including government, electricity customers, and international contributions are presented. The product is a detailed analysis of the costs and benefits of a solar project at Piarco International Airport, and the options for funding and developing such a project.

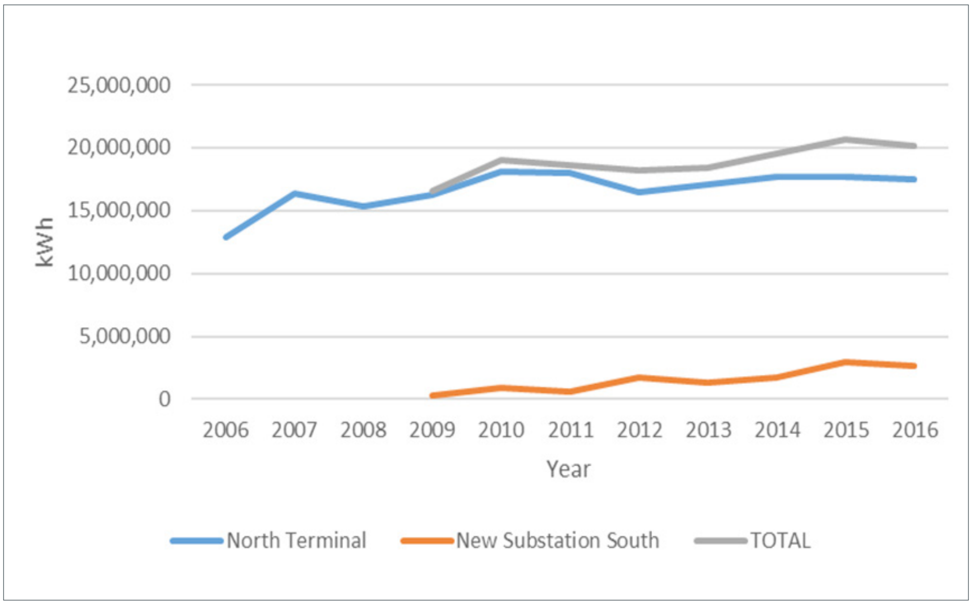
2. POWER USE AND EMISSIONS

The primary objectives of a solar power project at Piarco International Airport are to limit CO_2 emissions consistent with national goals, reduce and stabilize long-term power costs, and increase electricity reliability. This section evaluates the airport's electricity consumption patterns and costs to understand how much electricity could be provided by solar energy. It also evaluates emissions from current uses, both those originating from international aviation that could be off-set by solar, as well as those associated with grid-generated electricity.

2.1 AIRPORT ELECTRICITY CONSUMPTION

Total electricity consumption at Piarco International Airport for an 11-year period (2006-2016) is shown in **Figure 5**[29]. Over that time, electricity use has increased from 12 878 479 kWh in 2006 to 20 171 587 in 2016; an annual increase of 5.6 per cent. This includes electricity servicing the North Terminal complex, as well as the South Terminal area since construction of a new substation in 2009. The annual increase for the seven-year period since the new substation came online is 3.1 per cent.

FIGURE 5
Electricity Use at Piarco International Airport, 2006-2016



Daily and seasonal electricity use has also been considered to understand different patterns in electricity use at the airport. Data for different seasons is not presented as the airport staff indicated that there is little seasonal difference in electricity demand. However, a weekly and hourly analysis is presented.

A snapshot of electricity use measured from the seven 12 kV meters at the airport over a week in July 2013 is shown in **Figure 6**[30]. It shows that the largest amount of electricity (51 per cent) is fed through UM2 which is the main utility meter for the airport. The second largest amount (17 per cent) serves the Main Distribution Board (MDB) which provides power for the Chilled Water System for the airport. The data for that week shows little variability among the days of the week.

[29] Data provided by AATT.
[30] Ibid

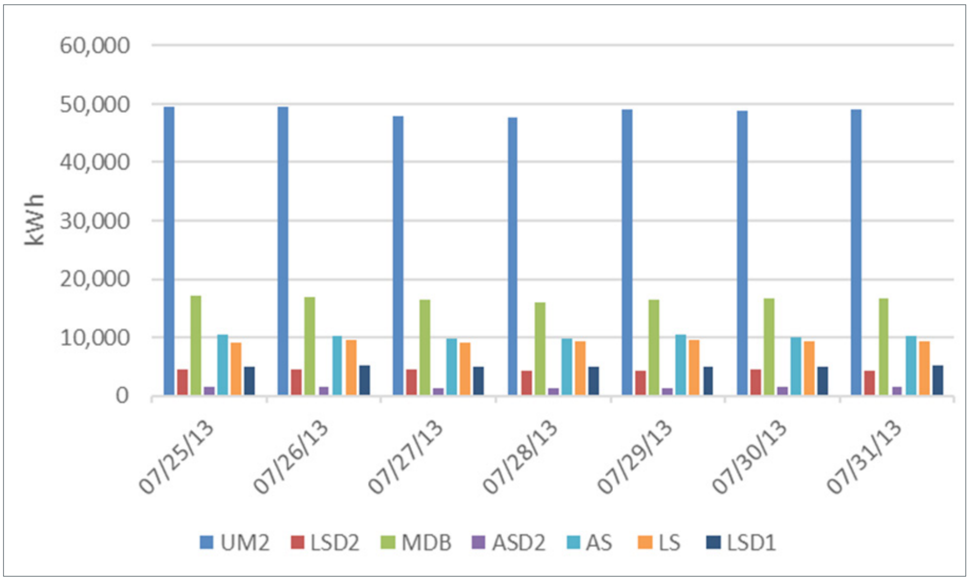


FIGURE 6
Electricity Demand at the Airport's 12 kV Meters, July 25-31, 2013

Figure 7 presents the hourly electricity demand from the airport's main meter (UM2) averaged for the week of 25-31 July, 2013. It shows that the electricity use increases before sunrise, drops shortly thereafter, and then holds relatively steady throughout the day.

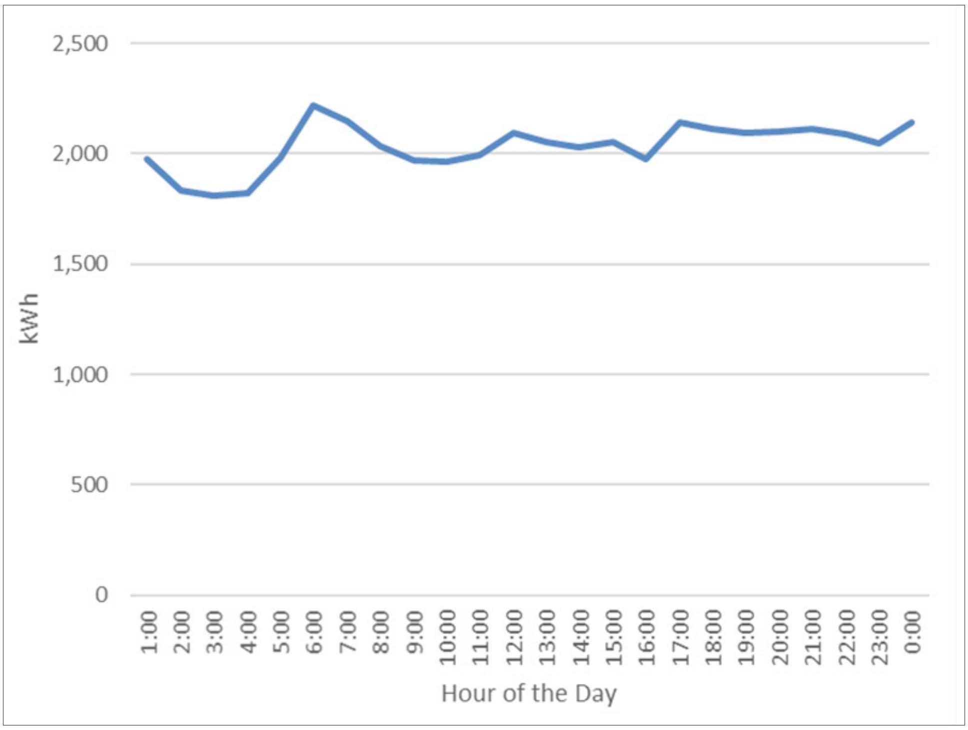


FIGURE 7
Hourly Average Electricity Demand, Airport Main Meter, July 25-31, 2013

Figure 8 presents the hourly electricity demand from the MDB meter which measures the electricity consumed to power the airport's chiller system averaged for the week of July 25-31, 2013. It shows that the electricity use increases after sunrise, peaks in mid-afternoon, and the decreases at the end of the day.

FIGURE 8
Hourly Average Electricity Demand, Chillers, July 25-31, 2013

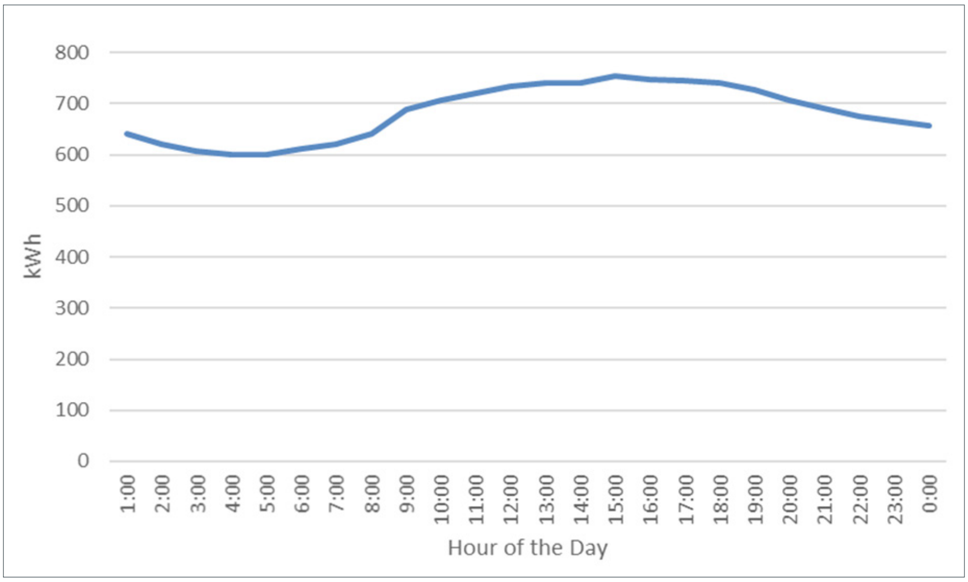


TABLE 5
Sub-meters with Annual Electricity Bill October 2016 – September 2017

State	Numbers	Annual Cost (TTD)
Golden Grove Rd, Piarco	902881	$87,977.18
Piarco Airport Ext	9001073	$684,945.05
LP 191 Caroni North Bank Rd	8247426	-$437,433.80
Brisrow Caroni North Bank Rd	901198	$6,479,898.03
Brisrow Caroni North Bank Rd	1251511	$4,468.37
Golden Grove Rd, Piarco	1294904	$20,772.59
Golden Grove Rd, Piarco	8248353	$85,708.38
Caroni North Bank Rd	1251671	$1,879.56
Golden Grove Rd, Piarco	1241445	$3,558.89
LP 95 Golden Grove Rd	8998737	-$200,405.30
Off Golden Grove Rd Booth 6	1400920	$212.34
LP 95 Golden Grove Rd	8989888	$30,150.70
Caroni North Bank Rd	1251463	$4,004.29
Golden Grove Rd, Piarco	1251417	$442.52
Golden Grove Rd, Piarco	1294902	$2,864.19
Caroni North Bank Rd	8993378	$49,971.41
LP 95 Piarco St. Helena Village	1251462	-$3,156.80
Mausica Rd, D'Adadie	8992327	$52,964.54
Piarco Rd, St. Helena Village	1251709	$7,599.23
Caroni North Bank Rd	9000684	$1,149,048.03
TOTAL		$8,025,469.40
Charges		$10,105,217.34
Credits		-$640,995.90

Annual electricity costs were considered by sub-meter[31]. These data provide information on how much the airport paid for electricity on a monthly basis from October 2016 through September of 2017. The sub-meter names and annual electricity cost associated with each is included in **Table 5**. The annual cost of electricity from those meters during the period was Trinidad and Tobago dollars (TTD) 9,464,221.44 (or USD 1,404,869.03) (as of 15 March 2018).

The electricity use by Swissport from their facility at the South Terminal was also assessed[32]. For 2017, there total electricity consumption was 1 496 700 kWh. Peak demand was 3 871 kVA. Total cost of electricity was TTD 584 246.65. Swissport's electricity consumption represents about 7.5 per cent of the total airport's annual demand.

2.2 AIRPORT CARBON EMISSIONS

Airport carbon emissions originate from several sources. The electricity used by the airport is generated from regional power plants that are primarily powered by fossil fuel combustion which is once source of emissions. Aircraft may operate their on-board engines and APU while parked at the gate which is another source of emissions. A third source are the airport vehicles that support the airport operations both on the airside (i.e., ground support equipment (GSE)) and automobiles and trucks operating on the landside. This analysis focuses primarily on the contribution from electricity generation and aircraft parked at the gates as these sources can be reduced through a short-term programme using with solar power.

2.2.1 EMISSIONS FROM ELECTRICITY CONSUMPTION

The Airport Carbon Emissions Reduction Tool (ACERT) created by the Airports Council International enables the calculation of CO_2 emissions from airport uses. The ACERT includes a table of CO_2 emission factors for grid-generated electricity by country originating from common sources. The electricity grid emission factor for Trinidad and Tobago is 7.66 g of CO_2 / kWh[33]. The airport consumed approximately 20 000 MWh of electricity in 2016. Using the ACERT conversion factor and the airport electricity consumption, the airport emitted 153 340 kg CO_2 in 2016 from its electricity use.

2.2.2 EMISSIONS FROM AIRCRAFT ENGINES

Upon landing, aircraft taxi to the gate, off load passengers and luggage, and prepare the aircraft for the next flight. While at the gate, the aircraft must continue to power on-board systems and maintain heating and cooling in the cabin during the transition. The period between securing the aircraft at the gate after landing and leaving the gate for departure is often referred to as the "turn time." Larger aircraft with more passengers typically have a longer turn time than smaller aircraft. Larger aircraft also require more power to maintain cabin temperatures and power on-board systems. At many airports, the power generated for gate operations is supplied by an on-board APU located in the tail of the aircraft. Smaller aircraft do not have on-board APUs, and may obtain power on the ground from a diesel-powered GPU. New gates are typically designed to include gate electrification equipment comprised of a 400 Hz frequency converter, which allows the aircraft to "plug-in" to the terminal electricity system, and a Pre-conditioned air (PCA) unit which provides heating and cooling to the aircraft at the gate.

Piarco International Airport has 14 gates. All are equipped with gate electrification equipment. The 400 Hz Frequency Converters are listed in **Table 6** [34].

Number	Specification (kVA)	Unit Electricity Rating (kW)
12	90	90
2	120	120

TABLE 6
Specifications of 400 Hz Frequency Converter Units at Piarco

[31] Data provided by AATT.
[32] Data provided by Swissport.
[33] Ecometrica 2011.
[34] Data provided by AATT.

The PCA units are listed in **Table 7**[35].

TABLE 7
Specifications of PCA Units at Piarco International Airport

Number	Specification (tons)	Unit Electricity Rating (kW)[a]
4	45	94.0
2	60	109.5
6	75	124.0
1	90	138.7
1	120	168.0

[a] Consumption generated from the specifications of AXA 3400 units

Therefore, per design, there should be no emissions from APUs. The emissions from aircraft are from the electricity that they consume from the Terminal. Installation of the gate equipment has decreased, but not eliminated, emissions from international aviation associated with the aircraft turn time.

Using the ACERT emission factor for APUs and electricity from the national grid in Trinidad and Tobago, the amount of CO_2 emissions that was avoided through the installation of the gate equipment can be presented, as well as the amount of emissions that continue to be emitted through the use of grid electricity. The assumptions of the analysis are included in **Table 8**.

TABLE 8
Assumptions for Estimating CO_2 Emissions from APUs and Gate Electrification

Category	Value	Source
CO_2 Emission Factor, APU, Narrow Body	45	94.0
CO_2 Emission Factor, APU, Wide Body	60	109.5
CO_2 Emission Factor, Grid Power, Trinidad and Tobago	75	124.0
APU Operating Time, Narrow Body	90	138.7
APU Operating Time, Wide Body	120	168.0

Using the assumptions above, the CO_2 emissions for each aircraft turn, narrow and wide body, can be calculated for the APU condition and the Grid Power condition. These results are provided in **Table 9**.

TABLE 9
CO_2 Emissions Per Turn for APU and Electrification Scenarios

Scenario	Calculation (kg CO_2)
CO_2 Emissions, APU, Narrow Body	291.2
CO_2 Emissions, APU, Wide Body	945.0
CO_2 Emissions, Grid Power, Narrow Body	121.4
CO_2 Emissions, Grid Power, Wide Body	251.9

The difference in emissions from using the APU to using electricity is significant. The major reduction in international emissions associated with gate operations is achieved through gate electrification. Reducing carbon emissions from the gate equipment is a subset of the emissions associated with the airport's electricity use, albeit accounted for under international aviation.

[35] Ibid

Using the current flight schedule, Piarco International Airport has 378 scheduled international flights a week[36]. About 57 per cent (or 217) are prop aircraft that do not have APUs and do not use gate power, leaving 43 per cent (or 161) as using the jet bridges and gate power. Of these 161 weekly flights, 155 are narrow body aircraft (737, 757, A320) and only six are wide body aircraft (767, 777). Table 6 provides the daily and annual CO_2 emissions from Piarco with no gate electrification equipment and the APUs operating, CO_2 emissions from the gate equipment as currently operating, and the amount avoided by eliminating the use of APUs using the narrow and wide body factors provided in **Table 10**.

TABLE 10
International Aviation CO_2 Emissions, Weekly and Annual, APU and Electrification Scenarios

Scenario	Factor Used (kg CO_2)	Weekly (kg CO_2)	Annual (kg CO_2)
CO_2 Emissions, APU, Narrow	291.2	45,136	2,347,072
CO_2 Emissions, APU, Wide	945.0	5,670	294,840
CO_2 Emissions, Electric Gate, Narrow	121.4	18,824	978,834
CO_2 Emissions, Electric Gate, Wide	251.9	1,511	78,590
CO_2 Emissions Avoided through Gate Power	--	50,583	2,641,912

These data show that approximately 60 per cent of the CO_2 reduction originating from aircraft in Trinidad and Tobago occurs when switching from the APU to gate power (supplied by the national grid). The remaining 40 per cent reduction is achieved when switching the electricity supply from the grid to a renewable energy source.

The flights that do not use jet bridges, which represent 214 scheduled flight per week, obtain power from ground power units or GPUs. These aircraft do not have APUs and therefore must power on-board avionics and conditioning systems operate with GPUs powered by diesel. These services are provided by Swissport and Piarco Air Services. The electric gate equipment is not compatible with these aircraft.

With the information on electricity use and associated emissions presented, the study will next look at potential areas of airport property where solar projects could be sited that can meet the electricity needs of the airport in a safe and cost-effective manner.

[36] Data provided by the TTCAA.

3. SOLAR SITE EVALUATION

With the airport's power use described and associated emissions sources calculated, an analysis of solar PV project siting can be undertaken. Solar PV panels or modules convert light energy into electricity. The PV module is designed to maximize light capture which, through a series of chemical reactions, generates an electrical current. While there are other technologies for converting the sun's energy into usable power, solar PV is the most cost-effective and easiest to integrate into existing and future development due to its modular construction.

The steps in assessing project siting consider consistency with long-term airport development, compatibility with airport design standards, proximity to electrical interconnection, and protection of environmental resources. Guidance provided in ICAO Doc 9184, *Airport Planning Manual, Part 2 – Land Use and Environmental Control*, was used to assess the compatibility of project sites[37]. In addition, Annex 14 – *Aerodromes*, Volume I – *Aerodrome Design and Operations*, was used to identify solar sites consistent with aerodrome design guidance[38]. Once preliminary sites have been identified using these criteria, each project site is evaluated for potential impacts of glint and glare on airport sensitive receptors. The outcome is a list of project sites that can be assessed for solar electricity production to meet airport needs and offset associated emissions from both international and domestic aviation.

3.1 AIRPORT PLANNING

Existing airport facilities at Piarco International Airport (IATA: POS, ICAO: TTPP) are shown in **Figure 9**. Main access to the airport is from the north on Golden Gate Road. The North Terminal Area is where the main airport terminal is located, and passenger service is provided. The South Terminal Area is located on the opposite or south side of the airport runway. It is where private, cargo, and military aircraft operate. The main air traffic control (ATC) tower is located adjacent to and east of the South Terminal.

The airport has a single west-east runway 10/28. A taxiway parallel and north of the runway provides access to the east runway end. A taxiway south of the runway provides access to the west end of the runway. A crossing of the runway is required for aircraft from the North Terminal Area to access the west end of the runway and for aircraft from the South Terminal Area to access the east end of the runway. Aviation development on the north and west side of the airport, including facilities occupied by Caribbean Airlines, are proposed to be re-located in the future to allow for the extension of the north-side parallel taxiway to the end of the west end of the runway and avoid the need for runway crossings by any aircraft operating from the main terminal. In addition, there is an existing roadway that has been built from the main terminal entrance north of the airport and parallel to the runway to facilitate future airport development. **Figure 10** shows the long-term development plan for the airport[39].

The North Terminal is expected to be expanded and areas north and east are programmed to meet that expectation. The expansion may include additional gates and associated aviation infrastructure, additional parking, and car rental facilities. Adjacent and north of the Terminal, there are plans for hotels, a conference centre, and offices. A utility area is specified to the west of the terminal which includes existing treatment lagoons and electrical infrastructure and includes a proposed employee parking area.

Existing facilities located in the Northwest Airport Zone, notably, Maintenance Repair and Overhaul (MRO) facilities, air cargo and customs facilities, crash, fire and rescue facilities, Bristow Caribbean Ltd.'s helicopter hangar, Light Aero plan Club Hangar, Trinidad and Tobago Police Service Station, and Caribbean Airlines Administration Offices, will be removed and relocated to allow for the extension of Taxiway A. The East Terminal Area is specified for general aircraft servicing including the MRO and GSE maintenance area. It will also be occupied by Bonded Warehousing, an industrial complex, the Trinidad and Tobago Meteorological Services, a fuel facility, and a free trade zone.

The South Terminal Zone will continue to support the expansion of private and corporate aircraft. The western part of the area will accommodate customs, immigration, port health and other agencies of the State. The eastern part of the South Terminal Building into an Air Cargo facility which will include cargo warehouses and supporting administrative facilities. The South East Area will be developed into general/private hangar estate and will include the relocated crash/fire/rescue emergency response facility. A second parallel runway is planned north of the existing airport development.

3.2 AERODROME DESIGN CONSTRAINTS

Recommendations on the design of aerodromes is presented in ICAO Annex 14, Volume 1. It includes guidance on siting objects to ensure they do not represent a hazard to aircraft. These design considerations are critical when evaluating potential sites for solar panels.

The siting of solar panels is prohibited in certain areas given their close proximity to airport runways. Runway strips are defined as areas adjacent to runways extending from the runway ends and laterally from the side of runways. The strip extends 60 meters from

[37] ICAO. 2016. Airport Planning Manual, Part 2 – Land Use and Environmental Control. Doc 9184. International Civil Aviation Organization. XXX Edition (advance unedited) — 2016

[38] ICAO. 2016. Annex 14 – Aerodromes, Volume 1 – Aerodrome Design and Operations. 7th Edition. July 2016. International Standards and Recommended Practices. International Civil Aviation Organization.

[39] Provided by AATT.

the end of most runways and either 75 (code 1 or 2 airports) or 150 meters (code 3 or 4 airports) from the runway side measured from each side of the runway centre line. Piarco is a code 4 airport requiring a 150-meter setback. A schematic showing the dimensions of the runway strip are shown in **Figure 11**.

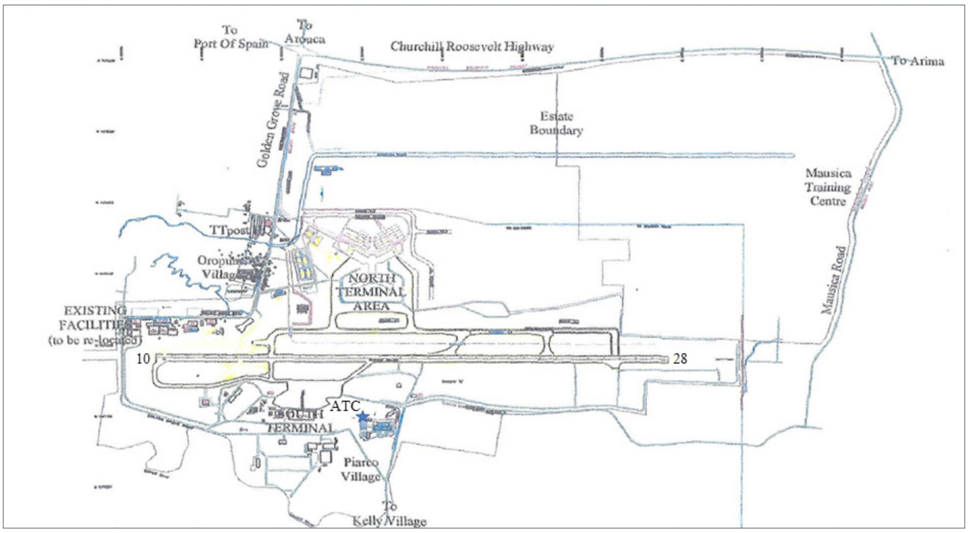


FIGURE 9
Existing Airport Facilities

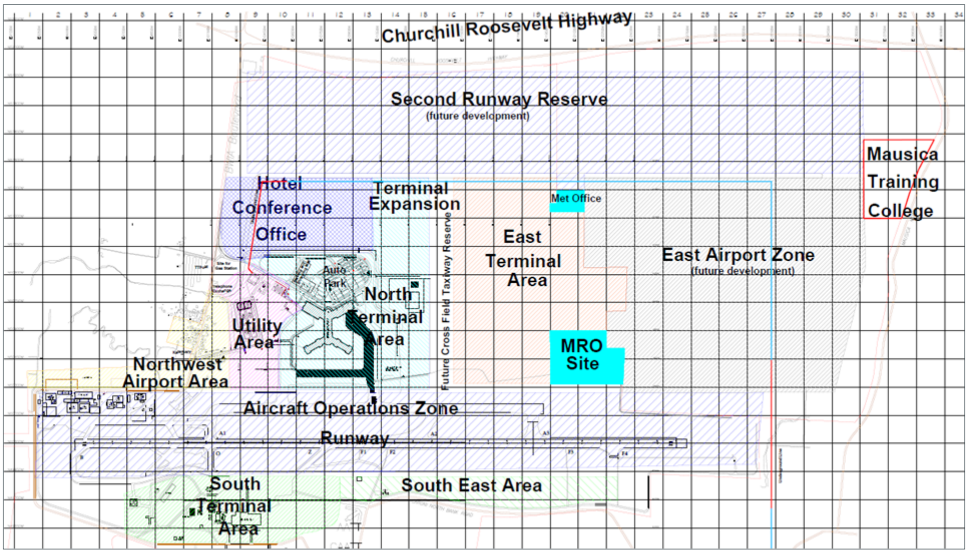


FIGURE 10
Piarco International Airport Master Plan

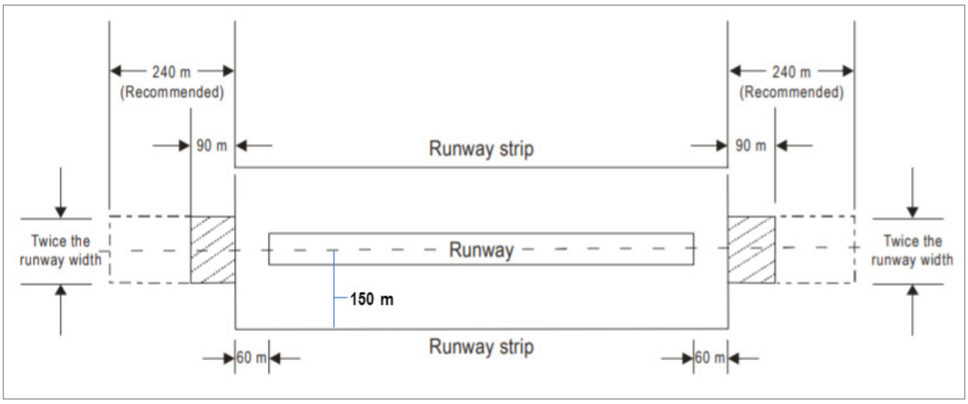


FIGURE 11
Characteristics of the Runway Strip

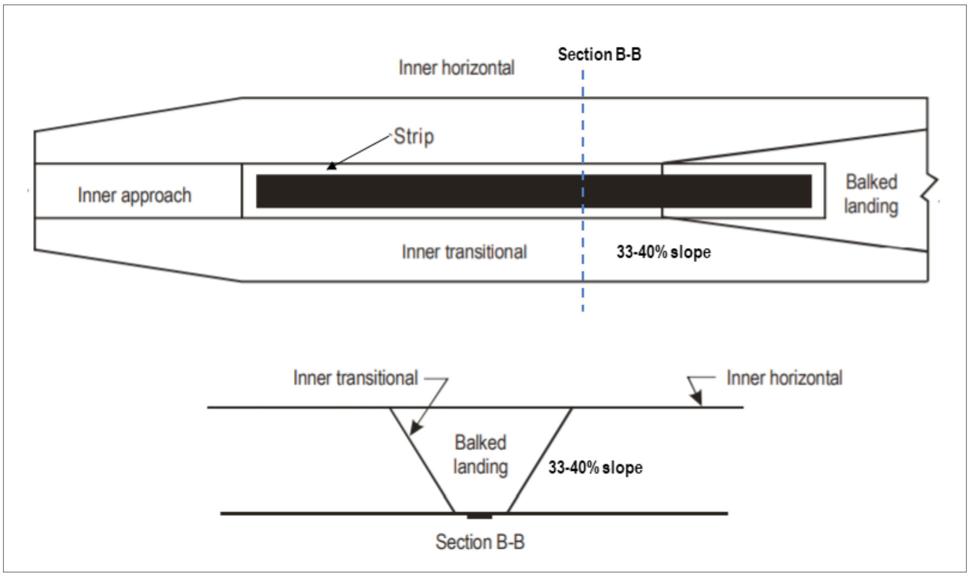
No fixed object shall be located in a runway strip unless its function requires it to be there for air navigation or for aircraft safety purposes. These locations are also referred to as the "Object-Free Area".

A runway safety area extends beyond the runway end and associated runway strip an additional 90 meters, though as much as 240 meters is recommended, as shown in Figure 3. The runway safety area is also considered to be an object-free area.

A setback from the taxiway is also recommended. This is defined by the taxiway strip. No objects should be located in the taxiway strip. For an airport with a runway code 4E or F, which would be applicable for Piarco, the taxiway strip should be no less than 115 meters wide.

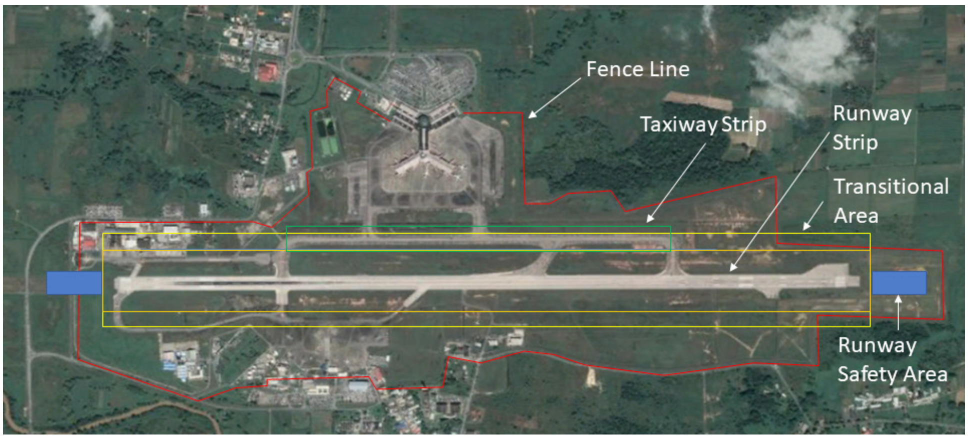
A transitional surface extends out from the edge of the runway strip up to the inner horizontal surface positioned 45 meters above ground level. The slope from the edge of the runway strip at ground level up is 33 per cent for larger airports and 40 per cent for smaller. The transitional surface is shown on **Figure 12**.

FIGURE 12
Characteristics of the Inner Transitional Area



These constraints limit the viability of certain areas close to runways for locating solar panels. The approximate location of these restricted areas at Piarco is shown on **Figure 13**.

FIGURE 13
Airport Constraints to Siting Facilities



3.3 ENVIRONMENTAL RESOURCES

Trinidad and Tobago has sustainable development goals and all development must comply with the Environmental Management Act (EMA) of 2000. The EMA's purpose is to ensure the protection, conservation, enhancement and wise use of the environment of Trinidad and Tobago. A solar project would be subject to review under the EMA to ensure that it is consistent with the goals of the State's environmental law. From a planning perspective, the solar project should be located in areas of the airport that are not "sensitive" and where the facility will not cause damage to the environment and vice versa. In addition to the EMA, there may be other regional and local environmental laws, and projects must be designed to avoid natural resource impacts.

Notable environmental resources in the region include the Arena Forest Reserve approximately 10 km southeast of the airport; the Aripo Savannah approximately 13 km to the northeast; and the Caroni Bird Sanctuary 8 km west of the airport. No components of a solar project at Piarco International Airport would affect these national resources.

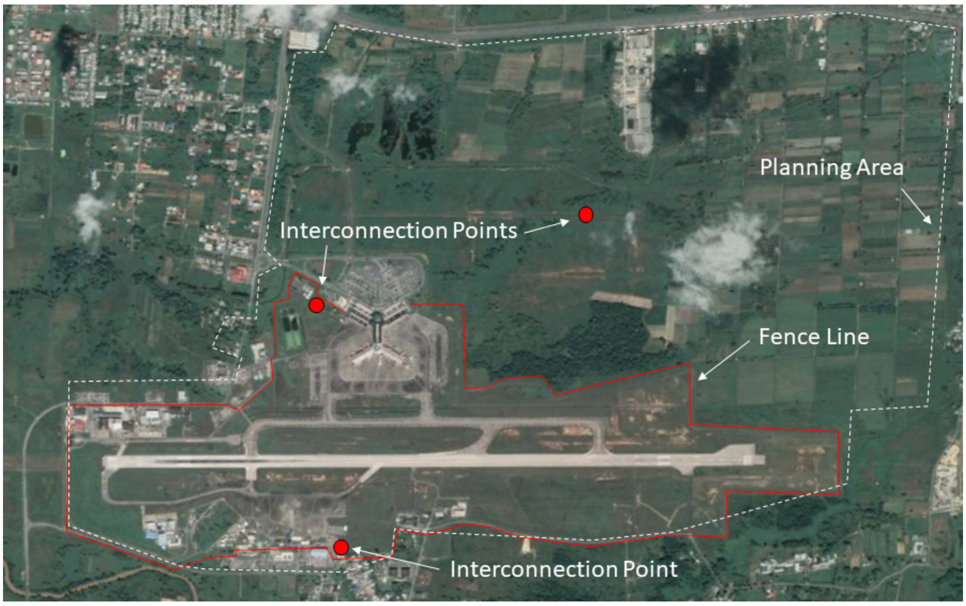
Environmental resources on airport property are in two topographical areas. There is a single forested area identified to the east of the North Terminal Building which is currently protected. There are also river and floodplain areas associated with the Oropuna River flowing east to west, situated north of the airport and the Caroni Rover southwest of the airport. Flooded areas associated with these rivers should be avoided, including a pond complex adjacent to the Oropuna, and lands on the approach to runway end 10 from the west. The approximate locations of these resources are shown on **Figure 14**. There may be other flooded and wetland areas elsewhere on the property that may be discovered during detailed site investigation which may affect project design.

FIGURE 14
Environmental Resources at Piarco International Airport

3.4 ELECTRICAL INTERCONNECTION

Based on data collected from the airport, it is understood that there are three potential points of interconnection for a solar facility of the size and capacity considered in this study. The main airport meter is located where the grid power is delivered to the airport, located to the west of the North Terminal Building. A second interconnection point is a 12 kV meter at the south terminal area. A third option, which is also a 12 kV capacity line, is located in the undeveloped part of the airport to the north associated with the existing roadway constructed to facilitate complementary airport development. These interconnection points are shown on **Figure 15**.

FIGURE 15
Potential Electrical Interconnection Points



3.5 SOLAR PROJECT SITE IDENTIFICATION AND DESIGN

When combining the constraints of the aerodrome design, future development, and environmental resources, a single map can be produced that shows all of the constraints to siting a solar project at Piarco International Airport. This is provided in **Figure 16**.

FIGURE 16
All Constraints on Siting Solar Projects at Piarco International Airport

The best options for a solar project are those that are compatible with existing operations and future development plans, while avoiding environmental resources. Proximity to interconnection points will also reduce project costs. Smaller scale projects may be able to interconnect directly to a building that uses electricity. However, larger projects need to interconnect at a point that has sufficient capacity to accept the electricity being generated.

When considering what areas remain outside of the siting constraints, solar project sites are identified in **Figure 17** and described below. The three potential interconnection points to the existing power network are shown as well. The characteristics of each site are presented in **Table 11**.

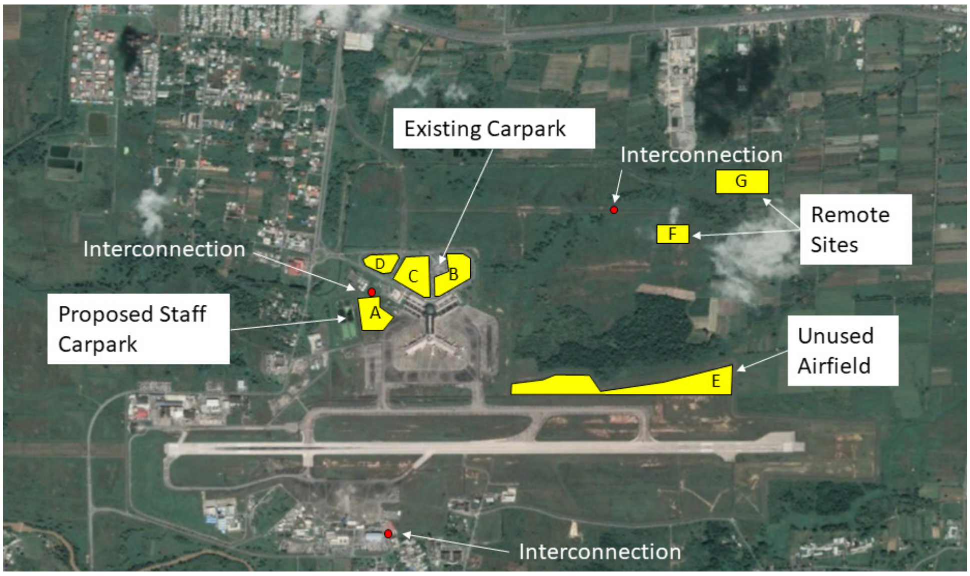


FIGURE 17
Potential Solar Project Sites at Piarco International Airport

Site #	Site Name	Project Design	Tilt Angle	Azimuth Angle	Sizes (hectares)
A	Proposed Employee Car Park	Canopy	5°	180°	1.88
B	Existing Car Park – East	Canopy	5°	150°	2.70
C	Existing Car Park – West	Canopy	5°	210°	3.11
D	Existing Car Park – Open	Ground-mount	10°	180°	1.54
E	Runway 10 Airfield	Ground-mount	10°	180°	8.74
F	Remote Site – South	Ground-mount	10°	180°	3.37
G	Remote Site – North	Ground-mount	10°	180°	9.57

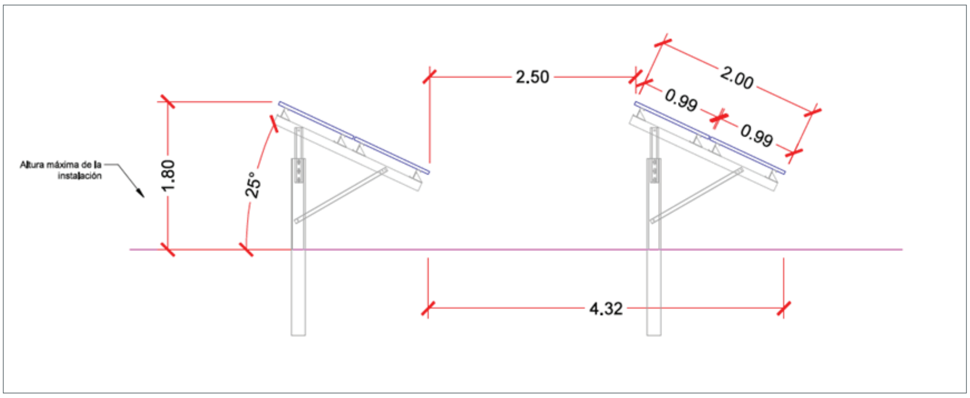
TABLE 11
Potential Solar Project Sites and Design

3.5.1 DESIGN OPTIONS

Design considerations generally vary for different types of sites with an overall preference for the solar panels being tilted toward and facing south (in the Northern Hemisphere). The southern orientation is referred to as the "azimuth" and is measured based on a compass heading with south being 180° (and north being 0°). The tilt angle is generally set at the latitude of the project site, with shallower tilt angles closer to the equator and steeper tilt angles with distance away from the equator.

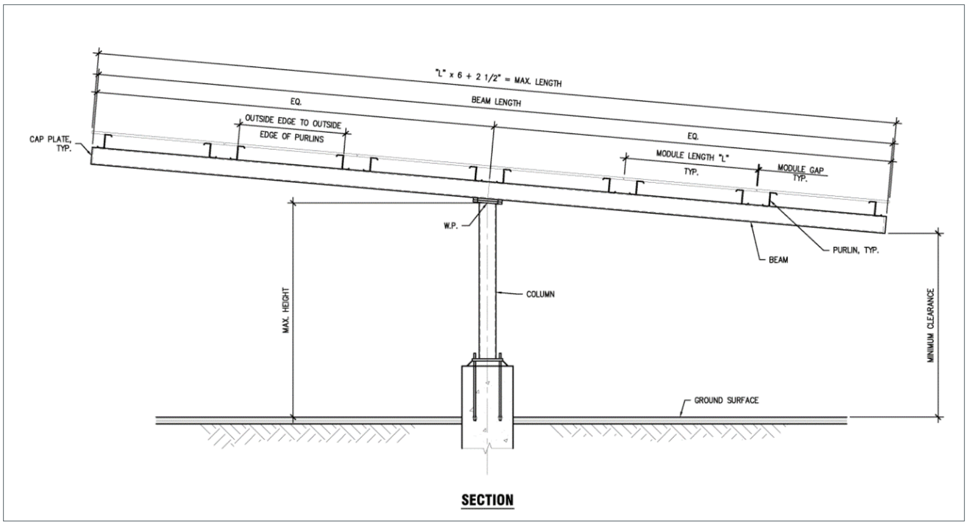
Projects mounted on poles on the ground (i.e. ground-mounted designs) have the greatest flexibility in siting and design and will customarily have an azimuth of 180° and a tilt angle of 10° (the latitude of PIR). **Figure 18** shows the cross-section and spacing for a ground-mounted project. Each pole represents a row of panels with spacing between each row shown.

FIGURE 18
Fixed Ground-mounted Solar Panel Design and Row Spacing



Projects located over surface parking will include a canopy structure that is aligned to the parking design such that vehicles can park under the structures. Canopies also have a lower tilt angle to maximize shading benefits to vehicles and limit engineering stress from wind loads. Canopy tilt angles are typically 5° or less. **Figure 19** shows a cross-sectional view of a typical canopy structure.

FIGURE 19
Cross-section of a Typical Solar Canopy Structure



Panels on building rooftops will typically need to conform to the roof design with panels on flat roofs being tilted ~5° to permit drainage and minimize wind loads, while projects on sloped roofs are fastened directly to the roof. The preferred design characteristics for ground-mounted, canopy, and building-mounted sites are shown in **Table 12.**

TABLE 12
Preferred Design Characteristics

Mounting System	Orientation	Tilt Angle	Panel Height (AGL)
Fixed Ground-mounted	180°	10°	10 feet
Fixed Canopy	Dependent on parking orientation	5°	18 feet
Fixed Building-mounted	Dependent on building roof orientation	Either directly attached to a sloped roof or tilted 5° off a flat roof	No additional structure, use roof height

Ground-mounted solar projects can also be designed with tracking systems which adjust the panel's position to follow the sun throughout the day and vary with the seasons. This is in contrast to fixed arrays discussed above where the panels do not move. Tracking systems maximize solar electricity generation but are also costlier to build, operate and maintain. For the purposes of this analysis, tracking systems have not been analyzed for the ground-mounted sites though they could easily be evaluated in the future once a prospective site is selected for a tracking system.

3.5.2 SITE DESCRIPTIONS

Seven sites have been identified. They are shown in Figure 18 and listed in Table 11.

Site A – Proposed Employee Car Park – a new parking area to accommodate airport employees is proposed to the west of the North Terminal Building. A solar project has been shown in the general area where the car park is considered. The final location and layout would be incorporated into the design of the parking. The tilt angle for a carport of 5° has been used and, without a parking lot layout, a standard 180° azimuth angle (due south) has been used. The car park would include canopy structures under which the cars would park providing shading. The solar panels would be located on top of the canopy structures and electricity distributed either to the main airport electricity meter just to the north, or to a meter inside the North Terminal Building.

Site B – Existing Car Park – East – solar canopies can also be located on the existing car park north of the North Terminal Building. Site 2 is for the east side of the existing car park. The tilt angle for a carport of 5° has been used and the azimuth of 150° aligns with the current car park striping. Power would be distributed either toward the North Terminal Building or to the Main Airport Utility Meter to the west of the building.

Site C – Existing Car Park – West – solar canopies could also be located on the west side of the existing car park. The tilt angle for a carport of 5° has been used and the azimuth of 210° aligns with the current car park striping. Power would interconnect similar to that described for Site 2.

Site D – Existing Car Park – Open – there is also an open area at the entrance to the airport to the west of the existing car park where solar panels could be placed. As there is no parking in this undeveloped open area, the solar panels would be mounted on poles driven into the ground. A tilt angle of 10° and an azimuth of 180° (due south) has been used to maximize power output from a ground-mounted system. The power would be distributed similar to that described for Site 2. The location would be highly visible to the traveling public passing through the airport. Power would be distributed either toward the North Terminal Building or to the Main Airport Utility Meter to the west of the building.

Site E – Runway 10 Airfield – there is an area of underutilized airfield inside the airport fence north of the runway but outside of the runway taxiway strip object free areas that could potentially be utilized for solar. This would also be a ground-mounted installation with applicable tilt and azimuth angles to maximize power output. The power would be distributed back towards the North Terminal Building.

Site F – Remote South – this site is located in areas programmed for future airport development. It is near the existing roadway that has been developed to accommodate future airport development but not occupying valuable frontage on the roadway. The size and location of the site may be altered based on other development and design considerations and what is shown is representative of a project. It would be developed as a ground-mounted system with a tilt angle of 10° and an azimuth of 180° (due south) has been used to maximize power output. Power would be distributed to the existing power line installed with the roadway if capacity is sufficient. If not, it would likely have to interconnect with existing electrical lines on Golden Gate Road.

Site G – Remote North – this site is similar to Site 6 described above. It is located further north and is shown as a larger site. It would also be a ground-mounted project with the applicable tilt and azimuth angles that would interconnect in a similar fashion to Site 6.

These seven sites must be analyzed for glare to ensure that they are compatible with safe aviation activities.

3.6 GLARE STUDY

ICAO Doc 9184 provides guidance on considerations for assessing solar PV facilities[40]. It states that modern land use planning must avoid "light pollution or glint/glare effects that might affect a pilot's interpretation of navigational aids, or air traffic control tower personnel's ability to visually monitor aircraft." In the section discussing renewable sources of power generation, it states "consideration of a large solar array should be accompanied by an ocular analysis of glint (a brief flash of light) and glare (a continuous source of bright light). This would help identify solar panel orientations that maximize system performance while eliminating risk of glint and glare which could be hazardous to air traffic controllers and pilots."

In 2013, the US Federal Aviation Administration (FAA) published "Interim Policy, FAA Review of Solar Energy System Projects on Federally-Obligated Airport", which communicates the methods for assessing glare from solar PV projects proposed on airport property and the standards for determining their impact. It also requires the use of modelling to assess glare and directs project proposers to the Solar Glare Hazard Analysis Tool (SGHAT). This method and tool have been adopted in many other countries to assess glare impacts on aviation sensitive receptors.

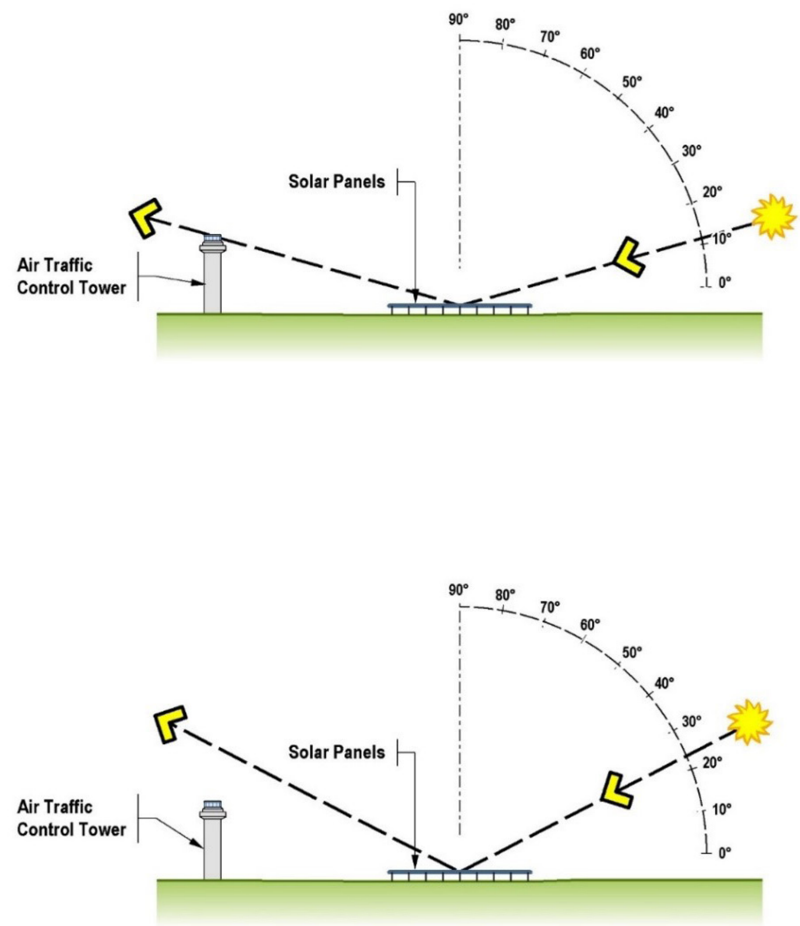
[40] ICAO. 2016. Airport Planning Manual, Part 2 - Land Use and Environmental Control. Doc 9184. International Civil Aviation Organization. [Advance unedited edition] — 2016

Absent international guidance on evaluating the potential impacts of glare on sensitive aviation receptors, the FAA methodology has been used for this study. It is important for the Civil Aviation Authority to formally approve any project including assessing glare impacts as part of its responsibility for national aviation safety.

3.6.1 GLARE METHODOLOGY AND STANDARD OF IMPACT

Prediction of potential glare occurrence from a solar PV project requires knowledge of the sun position, observer location, and the solar module/array characteristics (e.g., tilt, azimuth or orientation, location, extent, etc.). Vector algebra is then used to determine if glare would be visible from the prescribed observation points. **Figure 20** provides a simple representation of how the sun can produce glare on an ATC tower for a specific time and location. As the sun moves, the incidence of glare subsides.

FIGURE 20
Geometric Representation of Potential Glare Impacts from the Sun



If glare is recorded by the SGHAT model, the predicted intensity of the glare is reported in a colour-coded system at three levels:

- green for a low potential for an after-image[41];
- yellow for a potential for an after-image; and
- red for a potential for retinal burn.

[41] An after-image occurs when you look directly into a bright light, then look away. It typically takes several seconds for your vision to readjust and return to normal. It is also referred to as a "temporary visual disability" or "flash blindness".

The policy includes an ocular hazard standard which sets forth the intensity of glare using the colour-coded system that is deemed significant and thereby determined to produce a potential hazard to air navigation. The FAA standard prohibits any glare from impacting the ATC tower (i.e. results with green, yellow or red represent a significant impact), but allows for a low potential for an after-image (green) for pilots on approach to the airport with yellow and red results representing a significant impact. **Table 13** presents the airport sensitive receptors that must be evaluated for glare using the SGHAT model, the potential results reported by the model, and whether the result complies with the FAA's Interim Solar Policy.

TABLE 13
SGHAT Model Levels of Glare and Compliance with FAA Policy

Airport Sensitive Receptor	Level of Glare	Glare Colour Result	Does Result Comply with FAA Policy?
ATC Tower	No glare	None	Yes
	Low Potential for After-Image	Green	No
	Potential for After-Image	Yellow	
	Potential for Permanent Eye Damage	Red	
Aircraft on approach	No glare	None	Yes
	Low Potential for After-Image	Green	
	Potential for After-Image	Yellow	No
	Potential for Permanent Eye Damage	Red	

3.6.2 MODELLING METHODOLOGY

SGHAT was used to assess potential glare from each solar project site identified above on airport sensitive receptors. The receptors analyzed were controllers in the ATC tower and pilots on final descent to each runway end.

For each analysis, the footprint of the project array was outlined on the model's interactive Google map and details on the project design including azimuth angle and tilt angle input as described below in the design considerations. Information was then input on each of the airport sensitive receptors. The ATC was located on the model's aerial map and 100 feet above ground level (AGL) was input as the height of the observer in the tower cab. For the pilot analysis, the runway threshold was selected with the flight path tool and a second point away from the runway was also selected to represent the direction of the flight path. The model then automatically identifies the location and height above ground of the flight path based on a 3-degree glide slope out two miles from the threshold and determines if the pilot along the flight path would be exposed to glare. The ATC and flight path analyzed by the model for each runway are shown in **Figure 21**.

FIGURE 21
Airport Sensitive Receptors Assessed For Glare

3.6.3 DESIGN CONSIDERATIONS

Project design, particularly related to azimuth and tilt angle, affect the potential for glare and need to be identified prior to assessing compliance with glare standards.

In conducting the glare modelling and where there is spatial flexibility in siting, a larger project footprint was identified, and the size decreased if glare did not meet the standards (because larger surface areas produce higher intensity glare). The appropriate project characteristics of the preferred design for the site (ground-mounted sites 10° tilt facing 180°; canopies 5° tilt oriented closest to due south depending on orientation of the parking lot) was input. If non-compliant glare was detected for the preferred design, alternative design components were input to identify a design that would comply with the standard. As the tilt angle has only a slight effect on glare results, changes were primarily made to the azimuth followed at times by slight adjustments to the tilt angle.

For the solar module surface material, "smooth glass without ARC" (anti-reflective coating) was used to provide the installer with maximum flexibility in selecting a solar module. However, if excessive glare results were generated, the surface characteristics could be adjusted to use other premium material options that could mitigate glare.

3.6.4 RESULTS

The seven project sites were analyzed for glare. One site – E, Runway 10 Airfield – produced glare deemed a significant impact on pilots on approach to runway end 10, and has been eliminated from consideration. Site F, Remote South, also produced glare with a significant impact though when the site was decreased in size to that shown on Figure 9, the glare was minimized, and the project would comply with the glare standard. Glare was generated from some of the sites, though the glare is on pilots only and is compliant with the FAA standard. A summary of the results for all sites is included in **Table 14**. As listed, only Site E did not meet the glare standard and must be eliminated from further consideration.

The siting analysis has identified six potential sites for large scale solar projects at Piarco. In the next stage of the feasibility study, the amount of electricity generation from these sites will be calculated and compared to the existing electricity use at the airport to determine how much electricity can be provided for airport use and to offset emissions. A cost estimate for constructing the projects will also be provided and a simple payback period for avoided electricity costs will also be calculated.

Site #	Site Name	Glare Results ATC	Rwy 10	Rwy 28	Comply with Standard?
A	Proposed Employee Car Park	--	G	G	Yes
B	Existing Car Park – East	--	G	--	Yes
C	Existing Car Park – West	--	G	--	Yes
D	Existing Car Park – Open	--	G	G	Yes
E	Runway 10 Airfield	--	G	Y	No
F	Remote Site – South	--	G	G	Yes
G	Remote Site – North	--	G	G	Yes

-- no glare; G = Green Glare (low potential for an after-image); Y = Yellow Glare (potential for an after-image

TABLE 14
Glare Modelling Results

4. PROJECT SIZING AND FINANCING

Several potential solar project sites have been identified at Piarco International Airport. The sites have been selected such that they support long-term development initiatives, protect aviation safety, can readily interconnect with the existing electricity infrastructure and avoid impacting environmental resources. Each site has been evaluated specifically for potential glare on airport sensitive receptors. The projects moving forward for further analysis are shown in **Figure 22**.

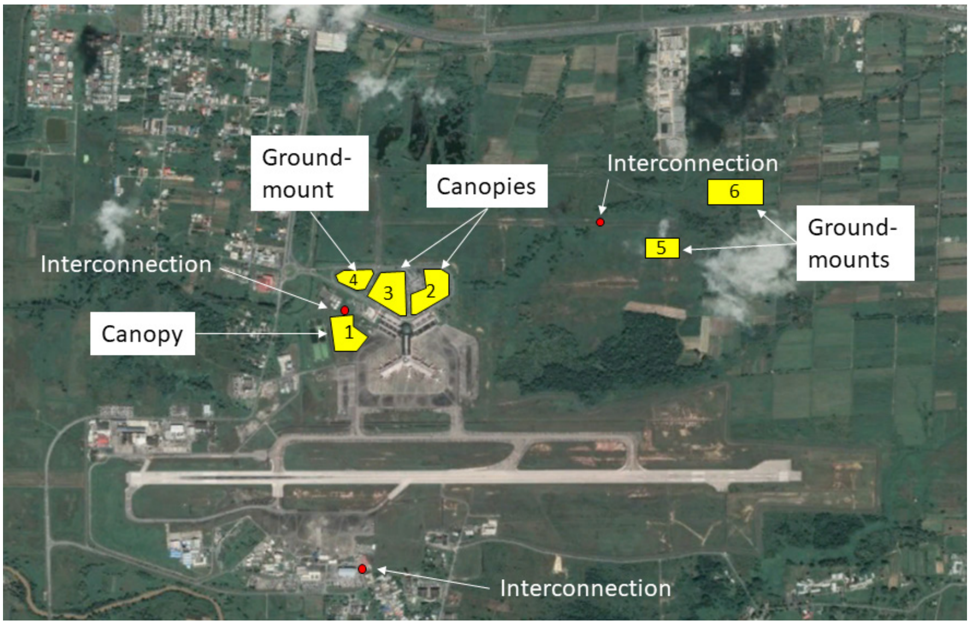


FIGURE 22
Potential Solar Project Sites

The next step is to examine the electricity generation potential of each site and the approximate cost for development in order to evaluate the financial implications of the project. Should the project be developed, the solar power will displace existing electricity sources and the cost of the project must be compared on a project-life basis to understand real costs and benefits. As part of the financial analysis, different ownership models and applicable financing opportunities will also be presented.

4.1 SOLAR POWER GENERATION

The characteristics of each solar project can be further defined using various tools and standards. The nameplate capacity of each project site can be determined using information available from credible sources. The nameplate capacity is calculated based on the project area and proposed design type. It determines the number of solar modules that could be deployed in a particular area and array type, and estimates the total solar power production (nameplate) capacity based on an average solar panel output. **Table 15** lists the nameplate capacity per hectare for ground-mounted, roof-mounted, and canopy installation and the source of the information.

TABLE 15
Factors for Estimating Solar Photovoltaic Project Nameplate Capacity

Design Type	Nameplate by Hectare	Source
Ground-mounted	106 kW / hectare	NREL/TP-7A30-52615, February 2013
Roof-mounted	202 kW / hectare	NREL/TP-7A40-51297, September 2011
Canopy	154 kW / hectare	Estimate calculated from the above references

The National Renewable Energy Laboratory's (NREL) PVWatts Calculator, which provides site-specific information based on solar irradiance, weather, and system size and design, was used. PVWatts estimates the energy production and cost of energy of grid-connected PV energy systems throughout the world. It allows homeowners, small building owners, installers and manufacturers to easily develop estimates of the performance of potential PV installations[42]. The model was applied to estimate potential electricity generation using meteorological conditions specific to STIA's exact location.

Using the nameplate capacity estimate and PVWatts, the solar power generation for each of the solar project sites has been assessed and is provided in **Table 16**.

#	Site Name	Project Design	Sizes (hectares)	Nameplate Capacity (kW)	Annual Generation (kWh)
1	Proposed Employee Car Park	Canopy	1.88	1,719	2,545,950
2	Existing Car Park – East	Canopy	2.70	2,469	3,649,927
3	Existing Car Park – West	Canopy	3.11	2,844	4,208,904
4	Existing Car Park – Open	Ground-mount	1.54	972	1,443,830
5	Remote Site – South	Ground-mount	3.37	2,127	3,159,491
6	Remote Site – North	Ground-mount	9.57	6,041	8,973,430

TABLE 16
Forecasted Power Generation for Proposed Solar Project Sites

The output from these projects can be considered relative to the overall airport electricity demand to assess how much solar power can support the airport's supply. **Table 17** presents the power generation and contribution to the airport's supply, the chiller demand, and the amount used by the gate electrification equipment.

#	Site Name	Generation (kWh)	(kWh)	Power (kWh)	Total (kWh)
			3,429,169	**1,511,254**	**20,171,587**
1	Proposed Employee Car Park	2,545,950	74.24%	168.47%	12.62%
2	Existing Car Park – East	3,649,927	106.44%	241.52%	18.09%
3	Existing Car Park – West	4,208,904	122.74%	278.50%	20.87%
4	Existing Car Park – Open	1,443,830	42.10%	95.54%	7.16%
5	Remote Site – South	3,159,491	92.14%	209.06%	15.66%
6	Remote Site – North	8,973,430	261.68%	593.77%	44.49%

TABLE 17
Percentage of Airport Electricity That Could be Supplied by Each Site

The table provides estimates on how much electricity each project can generate and the percentage of supply for different airport loads. For example, if the remaining emissions associated with gate power were to be converted from the fossil fuel grid supply to solar, that could be substantially achieved through the installation of Site 4. Projects at the existing car park east side or the remote site south would supply the existing needs of the chillers. A combination of projects would need to be built to meet the existing electricity needs of the entire airport though the remote site to the north could produce about half of the required supply.

[42] http://pvwatts.nrel.gov/

4.2 SOLAR PROJECT DEVELOPMENT COSTS

The best source of solar development costs come from the US market. Costs are typically reported for direct material and installation costs in a dollar per watt (USD/W DC nameplate capacity) installed cost basis. Source were obtained from NREL/TP-6A20-66532, September 2016, and are reflective of current nominal industry costs reported by sources such as the NREL and Rocky Mountain Institute.

The following direct installation and labour costs were initially considered:

- Commercial (roof): 100 kW = USD 2.29/W; 200 kW = USD 2.13/W; 1000 kW = USD 2.03/W
- Utility-scale (ground-mount): 5 000 kW = USD 1.82/W
- Canopy: costs listed above plus USD 0.35/W (Rocky Mountain Institute, Insight Brief, March 2016)

A solar installer who has recently been supporting a variety of projects in the Caribbean has reported similar costs based on project size as follows[43]:

- <500 kW systems – USD 2.00-2.50/watt
- 500 kW – 1 MW – USD 1.75-2.25/watt
- 1 MW - 5 MW – USD 1.50-1.75/watt
- Canopy – plus USD 0.35 to 0.50/watt

Table 18 presents the estimated cost to develop each project, the avoided cost of electricity, and the simple payback period based on the avoided cost. The unit for cost for each project was calculated from the industry and local sources described above.

#	Site Name	Nameplate (kWh)	USD/W	Installed Cost (USD)	Annual Generation (kWh)	Electricity Cost (USD/kWh)	Simple Payback (Years)
1	Proposed Employee Car Park	1,719	$2.17 ($1.75 + $0.42)	$3,730,230	$3,730,230	$0.05	29
2	Existing Car Park – East	2,469	$2.17 ($1.75 + $0.42)	$5,355,560	$5,355,560	$0.05	29
3	Existing Car Park – West	2,844	$1.92 ($1.50 + $0.42)	$5,458,560	$5,458,560	$0.05	26
4	Existing Car Park – Open	972	$1.75	$1,701,000	$1,701,000	$0.05	24
5	Remote Site – South	2,127	$1.75	$3,722,250	$3,722,250	$0.05	24
6	Remote Site – North	6,041	$1.50	$9,060,000	$9,060,000	$0.05	20

TABLE 18
Solar Project Cost

The table shows that Site 6, the largest site, has the lowest installed cost (USD 1.50 / W) and therefore has the shortest payback period (20 years). The sites with canopy structures (1-3) are the costliest to develop and have the longest payback period.

Payback is directly linked to the cost of existing electricity (USD 0.05 / kWh). As the existing cost of electricity in Trinidad and Tobago is low, the avoided costs of paying for that electricity and supplying it with solar power is relatively high. Whereas elsewhere in Caribbean, the existing cost of electricity may be seven times more expensive, replacing it with solar will be much more cost effective. This demonstrates one of the negative consequences of national subsidies to keep electricity prices low and how it can discourage energy conservation programmes and the development of alternative energy generation sources.

[43] Michael Vance, Asante Energy, Personal Communication, February 28, 2018

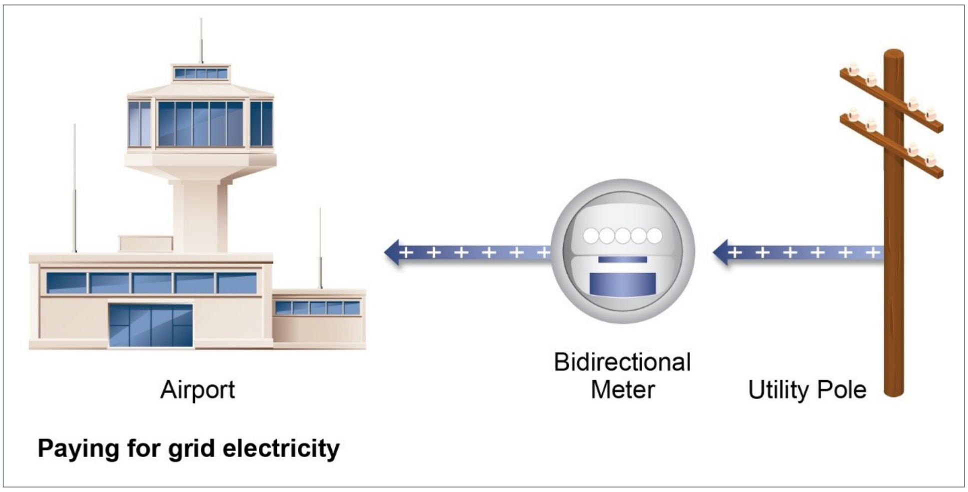
4.3 OWNERSHIP MODELS

There are two primary ownership scenarios for airport renewable energy projects: airport-owned and third party-owned. Other lesser arrangements are utility-owned and tenant-owned. Each is addressed below.

4.3.1 AIRPORT-OWNED

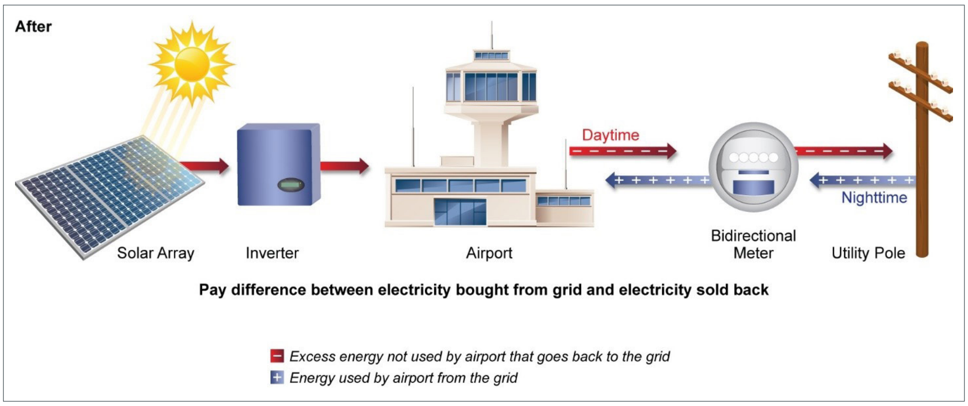
Under existing conditions, the airport purchases electricity from the utility drawing on the grid as demand warrants. The utility sends the airport a monthly bill for the electricity it consumes based on an accounting at the utility's electrical meter. This is illustrated in **Figure 23** below.

FIGURE 23
Typical Condition When Airport Buys Electricity from the Grid



If the airport funded, constructed, owned and operated its own renewable energy facility, it would generate electricity from the system on-site and consume the power behind the meter. At times when the system generates more electricity than the airport can consume, the excess electricity is exported to the grid and sold back to the utility. At times when the airport consumes more electricity than the system can produce (e.g., at night), the airport purchases the required electricity from the utility. The meter records the amount of electricity drawn from the grid and credits back excess electricity sold to the utility. The amount of electricity that can be sold and the value of that electricity (e.g., wholesale or retail rate) varies based on a utility's rules. However, the difference between what is bought and sold is the airport's electricity bill. This process is illustrated in **Figure 24**.

FIGURE 24
Airport-owned Renewable Energy System



4.3.2 THIRD PARTY-OWNED

In a third party-owned project, the airport leases out property (land or building) to a private developer who will construct, own and operate the facility under a long-term lease agreement. Third party-owned projects are particularly attractive in States where there is a strong solar power market and private entities are actively looking for development sites and green power purchasers.

In the case where there is a third party-owner and the airport is the host, the third party simply pays the airport an annual land lease payment for the right to operate the facility and it sells the power generated by the facility to an off-site customer. These agreements typically work where the fair market value of the land is relatively low and can be absorbed into the project finances, while keeping the electricity price at a competitive level. The airport will continue to receive its electricity as it always has, as illustrated in Figure 2. The third party will produce power and send it onto the grid and an off-site party will execute a power purchase agreement (PPA), which is a contract for the airport to purchase all of the power produced for a long-term period (usually 15 to 25 years) at specified annual rates, with the third party to acquire the electricity and any environmental attributes such as carbon credits. The PPA is a critical aspect of project financing because it guarantees a long-term revenue stream during facility operation which assures that investors will receive a return on their investment based on the established PPA price of electricity.

In a variant, the airport may also execute the PPA with the third party to purchase the electricity from the facility. **Figure 25** shows that the power is purchased by the airport to meet a portion of its demand, while purchasing the remainder of the power from the electric grid.

FIGURE 25
Third Party-owned with Airport Purchasing the System Power

PPAs provide airports with two benefits: one that is assured; the other that is assumed. By purchasing power for the next 15-25 years, the airport is assured that its price of power will be stable and predictable. The primary benefit is that the PPA provides cost certainty and is a hedge or an insurance policy against episodic price volatility and long-term significant price increases. It is not a guarantee of long-term cost savings because the future price of electricity is not known.

The third party-ownership arrangement is most effective where there is an active solar market and individual developers can compete to build a project at the airport and drive prices down. This arrangement is unlikely to occur in Trinidad and Tobago where the solar market is not strong. However, if the utility were to issue a PPA that guaranteed an annual price for the electricity generated over a long-term, a third party-owner could develop a cost-effective project on airport property.

4.3.3 UTILITY-OWNED WITH AIRPORT HOST

Depending on how utilities are regulated within a State, utility companies may be owners of energy generation projects. It is generally feasible for a utility company to own a renewable energy generation facility that is sited on airport property either through a government authority or through a lease similar to that described above for a third party-owned project.

The utility will develop such projects to provide its customers with a green power electricity mix, diversify its electricity supply sources, and ensure a potential long-term savings from renewable energy. Irrespective of the compensation agreement with the utility, the airport will obtain ancillary benefits associated with public exposure that the airport is generating green power.

T&TEC provides 85.7 MW of capacity and is also solely responsible for distributing generated electricity. For this task it purchases all produced electricity from the three IPPs before transmitting and distributing it to consumers. PowerGen operates as an IPP with its own PPA, although it is technically a majority-owned subsidiary of T&TEC. In 1998 T&TEC signed another PPA with the IPP Trinity Power, followed by a third PPA with the newest IPP Trinidad Generation Unlimited in 2009. Under this arrangement, T&TEC could either be the owner and operator of a solar project, or could execute a PPA with an IPP who would build, own, and operate the solar facility.

4.3.4 TENANT-OWNED

Airport tenants may seek to construct renewable energy projects on property or buildings owned or leased on airport property. As the tenant executes a contract to lease airport property, which contains the specific terms and conditions of the lease arrangement, the airport has considerable control over what the tenant can do, and any compensation.

Renewable energy projects at tenant-owned facilities are most common when new hangars and buildings are constructed. In some cases, the tenant includes the renewable energy project as part of an airport requirement that the new structure meet a sustainability standard, typically communicated in airport policy associated with new construction.

As tenants typically pay their own electricity bills, the installation of a renewable energy project to offset power purchased from the grid does not inherently provide a financial benefit to the airport. Airports could impose a fee for allowing the renewable energy system that does not adversely affect the project economics, but provides the airport with a modest revenue source. However, airports that have a sustainability requirement on tenants may not be able to justify profiting from the requirement by adding a surcharge.

Swissport is a major tenant that provides ground support services for 90 per cent of flight operations at Piarco. Swissport could evaluate the installation of a solar project on its main building at the South Terminal. As part of a long-term project, Swissport could consider installing solar and electric vehicle chargers to transition from diesel-powered GSE to electric-powered vehicles.

4.4 FINANCING OPTIONS

There are three primary options for financing the project: airport financed, utility financed, and grant financed.

4.4.1 AIRPORT

Under the airport financed scenario, the AATT would fund the solar project in a similar manner to how it funds its other capital improvement projects. Those funds are likely supported by operational rates and fees from airlines, customers, and tenants, as well as potential low interest bonding and borrowing capabilities associated with expected growth. While a solar project owned by the airport would result in cost savings associated with avoided electricity bills, it would not generate new revenue sources to fund annual borrowing. It is likely with the need for many fundamental aviation improvement projects, like the extension of Taxiway A, applying airport revenues to a solar project may be a difficult choice to make.

4.4.2 UTILITY

A utility financed project would require T&TEC to subsidize the extra cost of constructing a solar project. Currently, T&TEC sells electricity for approximately USD 0.05 per kWh, which is significantly less than the first-year price of electricity from solar. It generates the electricity from its power plants or buys the power from the IPPs for less than USD 0.05. Over its lifespan, the solar project is expected to produce a comparably priced kWh (retail rate) though the cost of tying up the installation costs and earning them back over a 25-year period decreases operational flexibility. T&TEC could subsidize the cost by funding and constructing the solar facility and selling the power to the airport at their existing retail rate though it is not clear if T&TEC sells power to customers under PPAs. Or it could execute a PPA with the airport or another entity (IPP) at an above market electricity rate to make the project profitable.

4.4.3 GRANTS AND CONCESSIONARY FUNDS

Regardless of project owner and developer, grants and concessionary funds could be sought from national and international organizations focused on mitigating climate change to pay down the upfront cost of installing the project and making the cost of electricity produced more cost-effective. There are several programmes that might be considered.

- Caribbean Renewable Energy Fund: The UAE has created a fund to develop renewable energy projects in the Caribbean region. Since its launch in January 2017, two funding cycles have been announced facilitating planning and development for renewable energy projects in 14 island states: Antigua and Barbuda, Bahamas, Barbados, Belize, Dominica, the Dominican Republic, Grenada, Guyana, Haiti, Saint Kitts and Nevis, Saint Lucia, and St. Vincent and the Grenadines. Up to USD 50 million is available for projects, which must be requested by the national government.
- Green Fund: started in 2006 and capitalized quarterly by a 0.1 per cent levy on business operating in Trinidad and Tobago. It funds activities that lead to remediation, reforestation and conservation of the national environment. Eligible recipients of the grants are non-governmental organizations and community groups. One project funded and implemented by the Environmental Management Authority was the installation of solar photovoltaic equipment for surveillance cameras at 13 police surveillance bays along the Uriah Butler and Solomon Hochoy Highways at a cost of TTD 9 635 191 (USD 1 429 765).
- Green Climate Fund: In 2015, the Government of Trinidad and Tobago submitted its intended Nationally Determined Contribution (iNDC) to the United Nations Framework Convention on Climate Change (UNFCCC), committing to reduce its carbon emissions by 15 per cent through the year 2030. It specified various mitigation measures to achieve this reduction, including clean technology and renewable energy. It predicted the cost of mitigation measures to equal USD 2 billion and stated that some of the funding would need to come from the Green Climate Fund and other international sources. A proposed project to decarbonize Piarco Airport could be included on a list of projects receiving international support.

5. CONCLUDING SUMMARY

The Solar Feasibility Study for Piarco International Airport presents the environmental and economic opportunities and challenges to developing solar power projects in Trinidad and Tobago. Significant amounts of solar power have not been developed in Trinidad and Tobago due to low electricity prices benefitting from the oil and natural gas economy and supported by price subsidies that protect consumers from world fossil fuel price spikes. However, the GoRTT ratified the Paris Agreement on Climate Change in February 2018 and has made commitments to increase renewable energy generation. The opportunities at Piarco International Airport include an abundant amount of solar energy, decreasing costs of solar PV equipment, and the need to diversify energy sources and reduce carbon emissions.

Working with airport staff and stakeholders, the study has identified six specific locations where solar PV projects could be developed in a cost-effective manner and compatibly with airspace safety and the long-term development of the airport. Project sites are consistent with existing airport infrastructure, airport design standards, and operations. The study also considered the airport's future development and the sites will not inhibit the growth of aeronautical uses that are critical to the national economy. The sites have been evaluated relative to environmental resources, including wetlands and rivers, forested areas, and flood zones, and will avoid natural resource impacts in compliance with existing regulations. Potential locations for interconnecting the facilities to the existing electricity network have been identified which will minimize the area of construction and maintain project cost-effectiveness.

Designs include ground-mounted facilities that could be constructed in undeveloped lands and car park structures that would allow parking underneath and provide customers with the added benefit of shading. Projects range in size from a 1.5 hectare site adjacent to the airport carpark to a 9.5 hectare site in the undeveloped area north near the proposed business park. The smallest project would provide approximately 7 per cent of the airport's annual electricity while the largest site would provide 45 per cent of its electricity. Cost estimates for development have been generated, carbon emission reduction benefits have been calculated, and the opportunity to reduce emissions from international aviation activities has been demonstrated.

The study's findings were presented to stakeholders at a workshop in April 2018 convened jointly by the Trinidad and Tobago Civil Aviation Authority, the Airports Authority of Trinidad and Tobago, and ICAO. Input was collected from these partners as well as representatives of other government agencies including the Ministry of Planning and Development and the Ministry of Energy and Energy Industries, the Trinidad and Tobago Electricity Commission, the Energy Chamber, and airport tenants like Caribbean Airlines and Swissport.

The benefits of developing solar projects at major airports are compounded. Solar is most economical when installed at facilities that consume significant quantities of electricity and are part of the permanent national infrastructure, both characteristics of international airports. In addition, airports represent a State and a region with business and tourist visitors passing through to enter or exit the country. It is at the airport where the intentions of economic development, environmental protection, and social well-being can be displayed through progressive projects like solar development.

The next step could be to convene the relevant stakeholders to review the concept of developing one or more solar projects at Piarco International Airport and discuss the costs and benefits of proceeding. Partners would need to confirm the study's conclusions on project site identification and that the sites are compatible with airspace safety, facilitate long-term aeronautical development, and protect environmental resources. Other considerations for pursuing project implementation could include funding, and ownership and power purchasing. Representatives from government ministries will want to evaluate the projects benefits for carbon emission reduction goals and economic development proposed at the airport. Once stakeholders have fully discussed the project, a plan of action including pursuit of funding options, can be developed and implemented.

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