Grid Connected Solar Photovoltaic in Island States: *Challenges, Opportunities and Waste Management.*

Ngalula Sandrine Mubenga, PE,MSEE (Author)
IEEE Member, IEEE PES Member, IEEE WIE Member,
Sustainability Energy Efficiency and Design Initiative
University of Toledo
Toledo, Ohio- USA
nmubenga@ieee.org

***Abstract*—Small island developing states (SIDS) strive to continue economic growth, mitigate climate change and reduce their dependence on imported fossil fuels. They offer a geographical landscape which encourages distributed generation in order to provide power to end users that are located in remote areas. Often times, this distributed generation is accomplished through grid connected solar photovoltaic (PV) systems. Because they do not emit greenhouse gas, and they use the free light from the sun to generate electricity, solar PV systems provide renewable energy in a sustainable way. This paper will respectively discuss the challenges and opportunities associated with grid connected solar PV in island states. It will also propose potential waste management strategies of such solar PV systems from cradle to grave.**

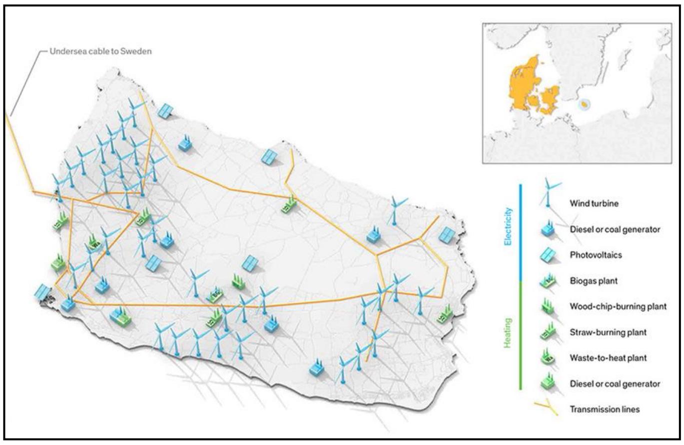
Keywords- SIDS; solar PV; islands; challenges; opportunities; waste management; climate change, renewable energy; sustainability; photovoltaic; energy; distributed generation, STEM, green economy, workforce, tariff, GDP, insolation.

I. INTRODUCTION

“Close your eyes, see yourself in paradise…”At this words, as they drift in relaxation mode, most people would picture a limpid turquoise ocean and sandy beaches. They would imagine a tropical island. Reality is that the coastal area where more tourist attractions are situated are connected to the electrical grid. However the innermost part of the island may not be connected to the grid as shown in Fig.1. As a result, inlanders have to rely on other sources of energy.

Islands offer a geographical landscape which encourages distributed generation in order to provide power to end users that are located in remote areas. Often times, this distributed generation is accomplished through grid connected solar photovoltaic (PV) systems. Because they do not emit greenhouse gas, and they use the light from the sun to generate electricity, solar PV systems provide renewable energy in a sustainable way [1].

Figure 1: Electric grid on Bornholm Island (Denmark) one of the “greenest island”. Picture from www.solarec.org



This paper will compare various island states demographic, economic and energy overviews. Then it will respectively discuss the challenges and opportunities associated with grid connected solar PV. Finally, it will propose potential waste management strategies of such solar PV systems from cradle to grave.

II. SMALL ISLAND DEVELOPING STATES

Small Island Developing States (SIDS) represent a group of 39 islands states and territories that came together- as part of the United Nations Earth Summit- in order to find ways to continue economic development, mitigate climate change, become energy independent and reduce their reliance on fossil fuels [7].Table 1 compares demographic, economic and energy profiles of 7 islands. Because islands are vulnerable to the rise of sea levels and are quickly impacted by climate change, they offer an interesting case study to mitigate climate change while growing economic development.

According to UN studies, 20% of people living without Electricity in the world are islanders [8]. Electricity is a major factor for development.

Table 1: Islands Demographic, Economic and Electricity Overview [9-14]

Island	***Population/ urban population share***	***Area (km2)***	***Gross Dom. Product (billions of US dollars)/ share for electricity***	***Main Utility Company***	***Total Generaton (GWh)/ source***	***Total Installed Capacity***	***Electrification Rate***	***Tariff (US dollars /kWh)***	***Grid configuration***
Haiti	9,997,000 54% urban	27,750	$18.54 B/ 4% on fuel imports	Eléctricité d 'Haiti	875 GWh/ 15% hydro 85% fossil	244 MW	25%	$0.35	Ten (10)isolated mini-grids
US Virgin islands (3 islands)	104,170 95.5% urban	1,910	$3.792 B/ 10% on fuel imports	Virgin Islands water and Power Authority. Serves 54,000 customers.	794 GWh	118 MW St Croix 198MW others		$0.47	One (1) interconnected grid between St Thomas and St john. A separate grid for St Croix. 1000 distributed generation systems
Jamaica	2,930,050 52% urban	10,991	$25.13 B/ 3% on fuel imports	Jamaica Public Service Company Limited	4,4142 GWh 3%hydro 94% fossil fuels	923 MW	98%	$0.39	
Puerto Rico	3,620,897 98.9% urban	13,790	$64.8B 7.66% on fuel imports	Puerto Rico Electric Power Authority. Serves 1.5 million customers	19,430 GWh 4.2% renewable energy 0.41% solar	4,878 MW	100%	$0.24	
Micronesia (607 islands)	105,681 22.4% urban	702	$0.33 B 6.9% on fuel imports	1. Chuuk Public Utility Corp. 2.Kosrae Utility Authority 3.Pohnpei Utilities Corporation 4.Yap Public Service Corporation	75GWh 4.2% hydro and solar	29.8 MW Total 6.6 MW Yap 4.6 MW Kosrae 13.4 MW Pohnpei 5.2 MW Chuuk	55% avg 26%-98%	$0.48 avg. $0.45-$1.09	Four(4) utilities each serving several islands
Seychelles (105 islands)	92,430 54% urban	455	$1.9B 70% from tourism	Public Utility corporation	304 GWh 100% fossils	85 MW 500 KW from solar PV rooftop project	99%	$0.34-$0.37	Production from two (2) main islands Mahe and Praslin. Most PV are off grid. 90% of pop. Live on Mahe.
Mauritius	1,270,000	2,150	$10B	Central Electricity Board	2,495 GWh 20% renewable energy	679 MW	100%	$0.09	

That is why, in order to achieve economic development, these countries have to increase access to electricity for their populations while reducing their dependence on imported fuels. What is learned from SIDS can be applied to island territories or continentals states as well. A study of 7 island states has revealed common traits as seen in Table 1.

Small islands are remote and heavily depend on imported fossil fuels to generate electricity. They are vulnerable to fluctuation in fuel cost. In the USA, users pay $0.12/kWh for power. With electricity tariff around $0.33/kWh on average in the Caribbean, and as high as $1.09/kWh in Micronesia, grid connected PV offer an economically viable solution for end-users.

III. CHALLENGES

There are 5 main challenges associated with deploying grid connected solar PV on islands: the geographical landscape, the electrical grid configuration, the marine weather, the availability of local technical workforce for system maintenance, and the supply chain for solar PV parts and components. Table 2, lists in detail various challenges and opportunities/benefits for each island.

A. Remoteness and Geography

The remoteness and geography often constitute the first challenge. The geographical landscape can dictate that major towns are located along the coast of the island. Which would leave the innermost part of the island with a limited access to the electrical grid as shown in Fig.1. A solar PV user that is located inland would have to extend the electrical line to the nearest point of connection to the grid.

Table 2: List of Challenges, Opportunities and Benefits [9-14]

Island	***Challenges***	***Opportunities/Benefits***
Haiti	**66%** of the electricity generated is **lost thru transmission and distribution** (T&D) losses. **Aging** electrical infrastructure was severely damaged by the earthquake. **Low electrification rate** at 25%:12.5% are from legal connections and 12.5% from **energy theft**. Because of these thefts, the utility company is unable to bill customers effectively. Resulting in $170millions annual operating subsidy in 2014. **Electricity is not reliable**; available for 5 to 15 hours per day.	Renewable energy (**RE**) has the potential **to meet 50% of energy demand.** **RE goals:** 30% reduction in energy intensity, 50% of electricity from renewable sources by 2020, 50% electrification rate by 2020
US Virgin Islands	**13%** of electricity generated is **lost through T&D** networks. 10% of GDP spent on imported fossil fuels. **Highly dependent on fossil fuels**. At $0.47/kWh, one of **the highest tariff** in the Caribbean where average is $0.33.	**High insolation** of 6 kWh/m2/day favorable to PV. **RE goals:** Reduce fossil based consumption by 60% by 2025. Generate 30% of peak demand from RE by 2025. **15MW** of distributed **solar PV in place** or under construction. **1500 solar water heating** and PV systems installed since 2010**. Installed RE** projects have **decreased** the fuel charge added to customers' electrical **bills by 25%.**
Jamaica	**9% T&D losses.** 17.5% **energy theft**. Resulting in a cost of $43.5 million dollars on ratepayers in 2013. **Vulnerability to oil prices**. Fluctuation on currency exchange rate impact the cost of electricity. No existing utility scale solar PV installed to date.	**20MW solar field** planned for construction. Installed 2.1MW solar PV and **58MW wind farm** in 2012. **RE goals:**12.5% electricity from RE by 2015 and 20% electricity from RE by 2030 **Tax exemption** for energy efficient equipment Development of **building energy efficiency standards**. **Government target 30% reduction of** energy cost for public buildings.
Puerto Rico	**13.8% T&D losses.** **Highly dependent on imported fossil fuels**. Spends 7.66% of GDP.	**Moderate insolation** of 4.5-5 kWh/m2/day. **22MW of PV installed**. Additional 1.2MW planned to be under construction in 2013.Implemented **Net metering** which compensate $0.10/KWh to customer. **Refine interconnection standard** to support increasing amounts of renewable energy while addressing energy storage separately. **RE goals**: 12% electricity from RE by 2015, 15% by 2020, and 20% by 2035.
Micronesia	**12% T&D losses**. **Remoteness** make it difficult to maintain generating equipment and get replacement parts. As a result utility companies maintain high reserve margin (100%) in order to avoid service disruption. This further increases electric rates. **Dispersed geography of 607 islands** causes high cost to develop and maintain electricity infrastructure. Geography extremely limits the economy of scale for power generation, fuel storage, and procurement of equipment. Large distances and small islands leads to **high cost of electricity interconnection**. Utility operates multiple independent grids as seen in Table 1. **High dependency on imported fossil fuels** for electricity generation and transportation. **Electrification rates vary widely**: 98% Kosrae vs. 26%Chuuk.	**Solar PV** paired with **energy storage** are **competitive** compared to high electricity tariff of $1/kWh. **500KW of solar PV installed**: 170kW off-grid, 330kW grid tied. Strong penetration of PV show that it is a viable solution. **RE goals:** 30% of electricity from RE by 2020.
Seychelles	**Remote** from mainland common market for eastern and southern Africa (COMESA) countries. This isolation increases transport cost. A deterrent to private sector.100% dependent on imported oil **Geography:** High mountains create micro-climate with increased rainfall and cloudiness on Mahe. This has to be accounted for during the design of solar Systems. Lacks large land for solar fields. **Policy, political, institutional barriers**: PUC is the sole authorized supplier of energy to the national grid, so there is no legal/regulatory framework for independent power producers. **Limited technical and institutional capacity** and experience with renewable energy technology. The experience with solar water heater showed that without trained technicians to repair the equipment, the equipment is not repaired and not used. **Financial barriers**: lack of investment capital. Lack of financial mechanism to allow buyers to pay for high upfront fees of solar PV.	**High insolation** of 5.7 kWh/m2/day favorable to PV. Strong potential for small grid connected rooftop PV. Government launched an **interest free loan** for solar water heater in 2012. Consolidated **national energy laws**, policies, and programs. **Lifted tariff and taxes on RE** technology imports. Removed taxes on solar water heater, prevalent RE technology. Implemented measures to increase energy conservation and RE. Capacity building and **technical expertise** will help insure a successful implementation. **RE goal:** 30% of electricity from RE by 2030.
Mauritius	**7.65% of T&D losses.** **Overlapping responsibilities at the institutional level**. Cost to environment does not factor into tariff from conventional electricity. So up front cost for RE appear much higher and not appealing to the utility company. **No energy policy.**	**High insolation** of 5 kWh/m2/day favorable to PV, **Install 10MW PV plant** in 2013, and **every 3 years** afterwards **2MW total** of small 50KW grid connected PV systems through Small Scale Distributed Generation (DG) Scheme. Developed **grid code** for small scale DG, and for connection to 22kv.RE grant and fiscal incentives are in place for RE. **Rural domestic electrification** is the fastest growing sector for solar PV market. **RE goal:** 35% of electricity from RE by 2025. Implement **education and training strategy** to teach **sustainable energy** at **all levels** of schools including pre-primary (kindergarten).

The geographical landscape and the configuration of the grid at the particular point of interconnection may dictate a distance such that it is cost prohibitive for the solar PV to be grid connected.

B. Grid Configuration

Indeed, the island grid can have many configurations per Table 1. It may be configured such that there is a long distance between two end users in the innermost part of the island per Fig.1. So when the grid connected solar PV generates electricity for one user, it may affect the flow of electricity in that part of the grid and impact the electrical protection for other users located in the vicinity of the generation. It would affect reliability of the grid as well.

C. Weather

The weather would be another defy to face. Depending on the season, the air is humid and has a high content of salt. This exposition to the weather could cause solar PV system components to rust and fail. So it is imperative to keep in consideration the weather while designing solar PV systems.

D. Availability of Local Workforce

SIDS often thrive on tourism industry. Indeed 70% of the GDP of Seychelles comes from tourism [12]. Thus, it may be challenging to find technical workforce to maintain the solar PV system locally. And if the local workforce is limited, warranty repair can take time before they are made, which impact customer service, and availability of electrical power from the PV system.

E. Limited Shipping and Supply Chain

Because of their remoteness, islands are limited to practicing trading through air freight and sea shipping. This can pose a challenge to establish a reliable supply chain for solar PV components; components needed for repair and maintenance may have a long lead time and incur high shipping costs.

IV. OPPORTUNITIES

With each of the main challenges, an opportunity awaits. The 5 main opportunities that are associated with grid connected solar PV are: the generation of electricity in an environmental friendly way, the generation of revenue for the end user, the strengthening of the electrical grid, the development of local technical workforce, the resurgence of green businesses, and the exposure of local populations to Science, Technology, Engineering and Math (STEM). Table 2, lists various opportunities and benefits that have been identified from grid connected PV installations in islands.

A. Generation of Electricity in a Sustainable Way

Solar PV offer the opportunity to generate electricity in a low carbon way, which avoids greenhouse gas emissions. This electricity in turn can be used by the end user to sell goods and services that would ultimately generate revenues.

B. Generation of Revenue for End-Users

The electricity from the PV system allows the end user to have a profitable business. Note also that the regulatory framework can provide additional revenues thru economic incentives. At the national level, islands are often perceived as pieces of paradise with unpolluted territories which are often listed in the UNESCO protected patrimonies list. Tourism often generates large revenue for SIDS, up to 70% of the GDP. So using grid connected solar PV, strengthens the idea of a pollution free paradise, which goes hand in hand with the tourism effort of these states.

C. Strengthen Reliability of Grid

Grid connected solar PV offer the opportunity to strengthen the grid by increasing grid reliability and capacity. For the utility company and the end user, solar PV may be economically preferable than extending the grid to the customer.

D. Develop Technical Workforce and Green Economy

In order to have a sustainable model, PV systems would need to be maintained and repaired locally. So, these solar PV systems offer the opportunity to develop a technical workforce that is local. Companies could train local islanders to become green collars. There will be a resurgence of green businesses that would supply products and services to design, install and maintain solar PV systems.

E. Encourage Local Population Towards STEM fields

In other words, solar PV would have the potential to create jobs for local islanders. These grid connected systems would also expose local population to Science Technology Engineering and Mathematics (STEM), and encourage more native to study and pursue a career in STEM.

V. POTENTIAL WASTE MANAGEMENT STRATEGIES

Similarly to electronics, semiconductors and electrical equipment, solid waste generated by the processes to create solar PV, batteries, inverters, and balance of system usually comes in the form of contaminated metals [2]. Fig. 2 shows the life cycle of photovoltaic panels.

The cycle starts with the production of photovoltaic panels. Then, PV panels are installed and used for about 25 years. Once the reach end of life, the PV panels are collected. Ideally they then get recycled, and generate materials that can be reused to produce PV panels and so on. Most of the strategies presented in this paper will focus on waste minimization at end of life.

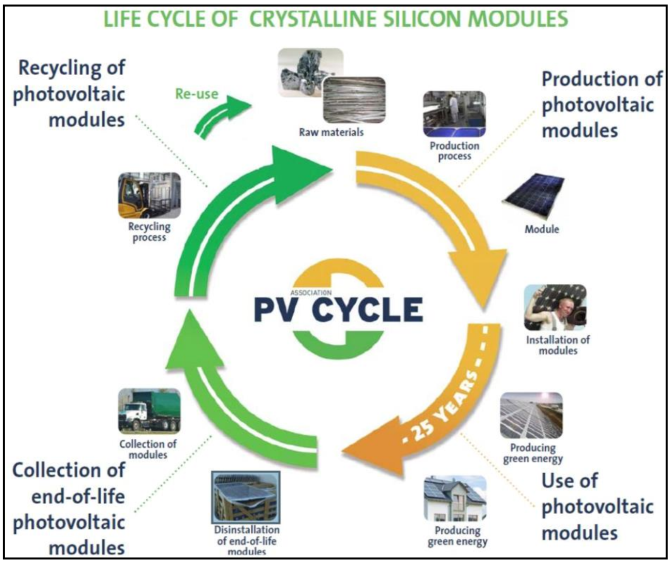


Figure 2: Life Cycle of PV Panels from www.PVCycles.org .

The state of California Department of Toxic Substance Control organized a conference with semiconductors facilities to define ways to minimize waste and prevent pollution. Below are some of the strategies applicable to solar PV [2]:

(1) *Recycle and reuse equipment* at end of life. For instance, recycle batteries when they reach their end of life. In the US, 99% of auto batteries are recycled [2]. Such strategy can be successfully applied to batteries from solar PV systems.

(2) *Industrial ecology*: the waste of one facility can provide raw material for another, similar to a waste exchange.

(3) *Waste minimization during decommissioning and decontamination:* each facility has to identify savings from waste management in the decommissioning process.

(4) *Chemical management* services supply and manage the customer chemicals at a cost that is often cheaper than what companies can do.

(5) *Product changes:* substitute material, conserve product, change product composition with materials that contains less contaminants, and change design.

(6) *Technology changes:* change the process equipment, temperature, automation, waste separation.

(7) *Operating practices and process changes*: prevents materials losses, impacts production scheduling and controls overflow.

(8) *Administrative steps* to control inventory and educate employees through programs.

(9) *Customer pay a recycling fee* at time of purchase of PV: the recycling fee can then fund the recycling and collection of PV panels when they reach their end of life. A customer can request the collection of the PV panels at any time in the future without additional cost. It is a program that First Solar currently implements. [3].

(10) *Solar PV panel take-back and recycling* at the manufacturing level: In the PV industry, stakeholders have gathered to implement program to take back and recycle PV panels when they reach end of life [4]. These program are voluntary and are implemented on an industry wide basis. Europe launched PV Cycle- a trade association to develop and industry wide take back program in Europe [5]. In the USA, these take back and recycling program vary by manufacturer.

CONCLUSION

Multiple challenges and opportunities exist for grid connected solar PV in small islands. We have seen that the opportunities far outweigh the challenges. In addition, an overview of waste management strategies for the life cycle of solar PV systems from cradle-to-grave was presented. A more holistic approach was used, from which one can see how combining these waste management strategies with the use of solar PV provides a more sustainable use of solar PV systems from cradle to grave. These strategies can help achieve energy independence and decrease the dependence on fossil fuels.

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