Utilities Policy 54 (2018) 46–54

Contents lists available at ScienceDirect

Utilities Policy

journal homepage: www.elsevier.com/locate/jup

Comparison of energy systems in Small Island Developing States

Dinesh Surroop[a,*], Pravesh Raghoo[b], Zumar M.A. Bundhoo[a]

[a] University of Mauritius, Faculty of Engineering, Department of Chemical and Environmental Engineering, Réduit, 80837, Mauritius
[b] Oregon State University, College of Liberal Arts, School of Public Policy, Corvallis, OR, 97330, United States

ARTICLE INFO

Keywords:
Energy access
Energy mix
Renewable energy

ABSTRACT

Small Island Developing States (SIDS) have been amongst the most neglected group with regard to energy access until recently when several voices were raised to highlight the vulnerabilities of these small nations. Since then, their levels of energy access have become the focus of significant attention. These levels vary over a wide range, where some SIDS still have a low energy access although they may have the resources. The energy mix for electricity production is mostly dominated by fossil fuels where the transportation cost results in high cost of fossil fuels and this leads to a high cost of electricity.

1. Introduction

Small Island Developing States (SIDS)[1] is a diverse group of islands sharing similar social, economic and environmental challenges to achieve sustainable development goals. Physical and human geographies, however vary largely (Kelman and West, 2009). The smallest of SIDS is Nauru with a land area of 20 km^2 and the largest is Papua New Guinea (PNG) with a land area of 453,000 km^2 (World Bank, 2017a). Geographically, SIDS exists as single islands (for e.g., Cuba or Jamaica), consolidated group of islands (Fiji or Comoros) or an archipelagos of small islands, islets and low-lying atolls (e.g. Maldives). Population count as at 2017, varies from less than 100,000 residents (for e.g., Seychelles, Antigua and Barbuda (AB), Dominica, St. Kitts & Nevis (SKN), Marshall Islands, Nauru, Palau and Tuvalu) to over one million residents (Guinea-Bissau, Mauritius, Singapore, Cuba, Dominican Republic (DR), Haiti, Trinidad & Tobago (TT) and PNG) (World Bank, 2017a). Most of these islands are of volcanic origin and enjoy tropical climatic conditions. Main economic sectors are agriculture, sand mining, tourism, fisheries and forestry (UNEP, 2014). Their relative small physical size, geographic isolation and high dependence on international trade make them 'price-takers' (Briguglio, 1995) and hence, initiatives to make these islands self-sufficient and reduce import costs are encouraged.

SIDS has been in the limelight since 1987 when, at the UN General Assembly, the President of the Maldives stressed the issue of climate change and the disappearance of its islands under rising sea-level (Wong, 2011). Since then, the UN has adopted the Barbados Program of Action (BPOA) in 1994, the Mauritius Strategy of Implementation (MSI) in 2004 and the SIDS Accelerated Modalities of Action (SAMOA Pathway) in 2014 as policy documents to reflect upon existing challenges in SIDS and to provide mitigation strategies and spur investment in SIDS economies (UN, 1994, 2005; 2014).

Among several thematic issues of the BPOA, MSI and SAMOA Pathway, SIDS′ heavy dependence on imported fossil fuels (mainly oil) and the need to diversify their energy mix with indigenous renewable energy sources to ensure access to affordable, reliable, clean and modern energy for all is always on the agenda and often discussed. Over the years, an international panel of researchers has worked on the technical and technological, economical, policy and political aspects of sustainable energy consumption and production but it still appears that more have to be done along the line to low-carbon energy transition. In some SIDS (for e.g. Haiti, Solomon Islands, Vanuatu, PNG, Guinea-Bissau), the issue of low access to energy still persists which has hindered the improvement of multiple facilities like education, proper health care, water, sanitation and slowed down industrial and commercial development affecting employment of residents (Surroop et al., 2018). The lack of sufficient energy thus constitutes a social issue which should be urgently looked into and addressed. Hence, SIDS' energy

* Corresponding author.
E-mail address: d.surroop@uom.ac.mu (D. Surroop).

[1] Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS) SIDS are Mauritius, Maldives, Seychelles, Comoros, Cape Verde (CV), São Tomé & Principe (STP), Guinea-Bissau, Singapore; Caribbean SIDS are Trinidad and Tobago (TT), Guyana, St Vincent & Grenadines (SVG), Antigua and Barbuda (AB), Belize, Suriname, Dominican Republic (DR), Dominica, Haiti, St Lucia, Bahamas, Cuba, Grenada, Jamaica, Barbados, St Kitts & Nevis (SKN); Pacific SIDS are Fiji, Vanuatu, Papua New Guinea (PNG), Kiribati, Nauru, Samoa, Tonga, Tuvalu, Federated States of Micronesia (FSM), Marshall Island, Solomon Island, Palau and Timor–Leste. Only SIDS UN Members are considered in this article.

https://doi.org/10.1016/j.jup.2018.07.006
Received 27 February 2018; Received in revised form 24 July 2018; Accepted 24 July 2018
Available online 06 August 2018

sector is highly complex as they are faced with a trilemma of (a) low energy access, (b) high vulnerability to energy security from high dependence on oil imports and (c) substantial barriers to renewable energy sector development (Raghoo et al., 2018; Surroop et al., 2018; Timilsina and Shah, 2016).

This study is an excellent opportunity to review the present state of energy affairs in SIDS UN member states. The three main aspects of this paper are (a) an overview of research endeavors in SIDS for the last two decades, (b) a comprehensive overview of the current energy situation in SIDS, and (c) recommendations and areas for development for more renewable energy. Such study is essential for policymakers and project developers for judicious decision–making and planning of a more sustainable energy future for these territories. The paper also aims to attract more attention in SIDS for more research in energy and climate change.

The rest of the paper is structured as follows: Section 2 presents an overview of research endeavors in SIDS and Section 3 discusses the energy situation in SIDS and other characteristics of their energy sector. It also gives an overview on the energy access, electricity mix and the cost of electricity in the three SIDS regions. Section 4 provides the challenges and recommendations for greater development of renewable energy in SIDS and conclusions are provided in Section 5.

2. Data sources, method and scope of research

Data and literature for this paper was sourced from peer–reviewed academic papers, conference proceedings, think–tanks and other international and national reports. Publications were retrieved from international organizations, Web of Science and Google Scholar databases. This activity was repeated twice to ensure that no paper was left out of the analysis. Non–English, books, non–dated papers, dissertations and online articles were excluded from the review. Published papers were used as a proxy to evaluate research endeavors in SIDS. A systematic review of existing literature was taken as the methodological framework for this paper as it is a useful method for analyzing, evaluating and monitoring development in a particular field and thus appealing to scholars.

From the list of publications compiled, particulars of these publications related to their authors' affiliations, date of publication, 'renewable energy focus' (whether the study involved a single renewable energy source or discussed renewable energy in general), region (whether the publication is on SIDS regions in general or in a member state) and classifications (whether they discuss technical, social or issues on the economics of renewable energy) among other details were noted. The search retrieved a significant number of publications on SIDS and SIDS member states from 1994 to 2017 on all types of exploitable renewable energy sources. The majority of the publications were peer–reviewed articles and a small number of them were think–-tank reports from reliable sources (for e.g. IRENA, 2013 among others). Over the last 23 years, research papers in SIDS have been published in various peer–reviewed outlets in renowned energy journals.

The number of publications in SIDS has seen a rise as from 2010 where this number has increased nearly three–fold. A possible explanation for this increase can be attributed to the special attention that some intergovernmental organizations (like the Intergovernmental Panel on Climate Change) have given to island nations as they recognized islands' vulnerability with regard to the growing threat of climate change. As the extent of research in SIDS has increased, the literature has also become more refined dealing from a wide range of issues and shifting from traditional renewable energy sources like hydropower to modern renewable energy sources like ocean–based energy sources, wind, solar and biofuels.

Fig. 1 illustrates the distribution of publications per year and the 'renewable energy focus' under study in these publications. In all, 65 publications looked at more than one renewable energy source while another 31 were exclusively based on solar energy, 19 on wind energy,

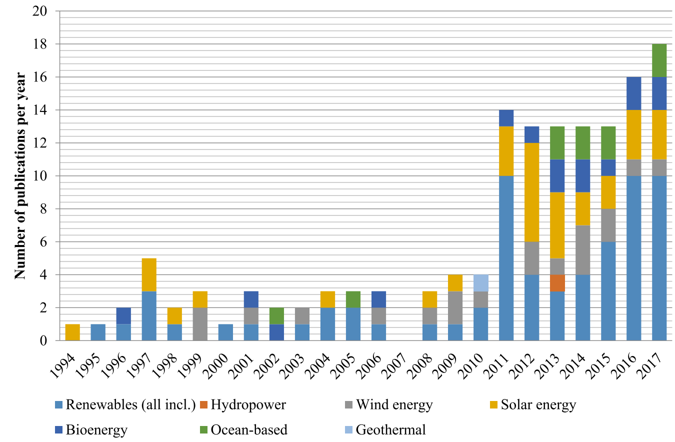

Fig. 1. Number of publications by year and by 'renewable energy focus'.

15 on bioenergy systems, 10 on ocean–based energy and the remaining on hydro and geothermal energy. Eventually, judging from the extent of research in the field, solar and wind energy seemed to be the most preferred, appropriate or exploitable renewable energy sources in SIDS. No publications in 2007 were found during the data search and only one paper on hydropower (see Elahee, 2013) was found.

The nature of these publications is also interesting to note. These publications can be classified into five main categories based on their content which are (a) social, (b) technical or technological, (c) economics, (d) environmental and (e) policy and political aspects.[2] Fig. 2 gives the distribution of publications based on content of the papers. Five publications have been excluded here because they combined two of the categories listed above in their study and thus difficult to classify them accordingly. Sovacool et al. (2011) discussed about the socio–-technical aspect of solar home systems (SHS) in PNG; Hsu et al. (2014) conducted a techno–economic analysis of a photovoltaic system in Kiribati; Kumar and Nair, 2013 determined the wind potential and economics of wind power in Fiji; Chandra et al. (2017) discussed the environ–economic implications of bioethanol in Fiji Islands and Lal and Raturi (2012) focused on the techno–economics of hybrid energy system in Fiji.

Most of the papers collected are either technical (43%) or dealing with policy and political ideas (49%) for renewable energy development in SIDS as shown in Fig. 2. Technical papers are mostly resource–assessment of the particular type of renewable energy under study and policy/political publications elaborated mostly on frameworks for renewable energy development, market–based mechanisms and efforts at governmental level to develop renewable energy resources on these islands. Little research has been conducted on the economics of renewable energy generation and infrastructure – procurement and standards of technologies, freights costs, insurance etc. – as to recall most SIDS do not have any technology manufacturers in their countries and rely entirely on imports of these technologies, thereby increasing costs.

The social/socio–cultural and environmental aspects of renewable energy development remain understudied in SIDS. Previous work by Yaqoot et al. (2016) has highlighted the impacts that social and cultural barriers have on renewable energy development. Social and cultural barriers are related to vandalism, theft of the technology and asymmetry information on the technology leading to poor acceptance of these technologies among residents. For example, over–expectations of residents on the extent SHS can go to power appliances (due to lack of knowledge of the technology) and sabotage, vandalism, tribal wars and

[2] Fiscal policies given to investors and project developers are included in 'policy/political'. Under 'Economics' categories lie publications dealing with the costs of the renewable energy infrastructure.

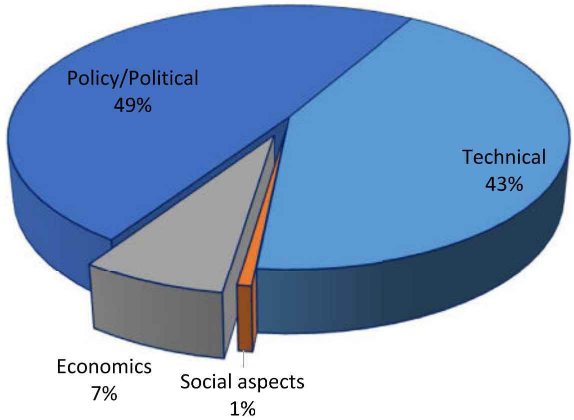

Fig. 2. Classification of publications based on their content.

acts of vengeance in PNG has caused damages to SHS and hence, hindering acceptance of the technology among people (Sovacool et al., 2011). Other similar socio–cultural issues exist in SIDS which have not yet been addressed – for example, the acceptance of biofuel among SIDS' residents has not been studied and this might be a possible explanation why biofuel development is not picking up speed in some SIDS.

The environmental impacts of renewable energy technologies were not often mentioned in the energy literature. In comparison with fossil fuels use, these technologies are better as they emit negligible amount of carbon in the atmosphere but rarely discussed in the case of SIDS is the degradation of other natural resources and acoustic noise pollution that it produces (Wright, 2001; Yaqoot et al., 2016). For example, Chandra et al. (2017) reported that bioethanol production can affect water footprint and affect clean water bodies however, few studies exist in SIDS on this issue.

Publications can also be categorized by country or regions (Fig. 3). Only one publication was retrieved discussing a possible framework for collaboration of AIMS SIDS to drive energy development (Tung, 2017) and more than 15 publications were published in the Caribbean and Pacific SIDS in general. Taking SIDS as a whole, six publications were collected, half of which were on policy interventions for renewable energy development and the rest on the economics of renewable energy technologies and international aid to finance renewable energy projects. SIDS member states like Mauritius (21) and Fiji (25) record the highest number of publications followed by TT, Maldives, PNG, Barbados, Cuba and Cape Verde (CV). Other countries had less than 5 publications in the last 23 years. No individual papers were recorded for at least 17 SIDS (For e.g. Comoros, AB, and others) which is pretty alarming. Generally, islands have adequate renewable energy resources but without resource assessment studies (among others) of the different sources, the exploitable capacity cannot be known and thus causes little interest and investment from government and private investors.

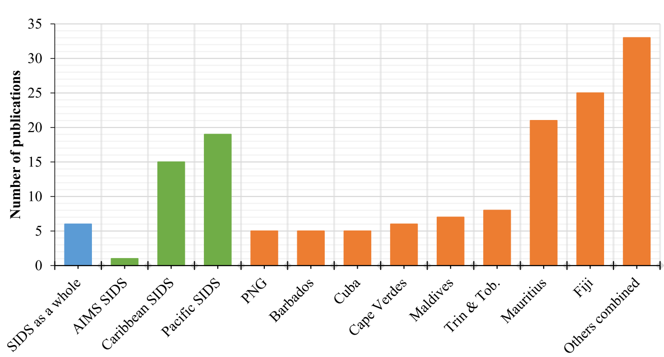

Fig. 3. Number of publications by country or region.

After the relevant studies have been compiled and described, the next sections will outline and explain the energy situation in SIDS UN member states.

3. Energy systems

3.1. Energy access – current status

Alarmingly, not all SIDS member states enjoy full access to energy (Fig. 4). While Mauritius, Nauru, Singapore Tuvalu, TT and others have 100% access to electricity, in other SIDS like Haiti, Guinea–Bissau, Solomon Islands, PNG, Vanuatu and Kiribati, less than 50% of the population have access to electricity (Raghoo et al., 2017a,b; Surroop et al., 2018; The World Bank Group, 2018a; Wolf et al., 2016). On average, electrification rate in AIMS, Caribbean and Pacific SIDS are 73.6%, 88.3% and 72.9% respectively (Surroop et al., 2018). Limited access to electricity posits a huge social problem rarely discussed in the scientific literature (Dornan, 2014, 2015). Moreover, education of children, businesses and industrial activities are compromised and are the first to be affected. Since most of the energy poor people live in rural areas, they tend to migrate to urban regions causing problems of urbanization. The causes for low electrification rates in SIDS can be summed up into three categories – technical causes, financial causes and institutional barriers. Extending grids is the preferred option to electrify some regions as power outages might seldom occur, but since some households are located far from demand centres where the grid is concentrated, it is not feasible to extend grids (Dornan, 2014, 2015; Surroop et al., 2018). Especially, when the electricity demand from these remote households are not significant, utility companies cannot balance costs of extending grids to benefits of having access to electricity.

One solution to expand electricity to rural remote areas lies in decentralized renewable energy systems (DRES), but again, investing and maintaining of DRES require funding and expertise which are lacking in SIDS (Urmee and Harries, 2012). Institutional and market barriers to improve electrification are also existent. In addition, policymakers may implement poor market–based mechanisms and inadequate policies sometimes pushing investors away and hence, private participation remains low.

Another issue with the lack of accessibility to electricity and modern cooking fuel (gas) is the high reliance of some households on traditional biomass sources such as wood, crop residues and dung. The burning of traditional biomass in households contributes largely to the production of air pollution affecting women and children. It is estimated that in 2004, over 1500 people have died from pollution caused by the burning of traditional fuels in PNG and Haiti (Legros et al., 2009).

3.2. Electricity generation mix

Electricity consumption in 2014 averaged 2125 kWh/capita for the AIMS SIDS, 2309 kWh/capita for the Caribbean and 1214 kWh/capita for the Pacific SIDS region (The World Bank Group, 2018a; The World Bank Group, 2018b; EIA, 2018; IRENA, 2012). Since 84% of Pacific population lives in PNG, Solomon Islands and Vanuatu where electrification levels are less than 40%, energy consumption in Pacific is below world average level (Timilsina and Shah, 2016). Electricity is mostly supplied by fossil fuels (mainly coal and petroleum products) and a small share by renewable energy.

3.2.1. AIMS SIDS

AIMS SIDS are highly dependent on fossil fuels (coal, oil and to a lower extent natural gas) for electricity production while the contribution of renewable energy is relatively small. Renewable electricity production is highest in CV (30.7%) and Mauritius (23.8%) while less than 10% of electricity is generated from renewable energy sources in other AIMS SIDS. In CV, renewable electricity production is solely based

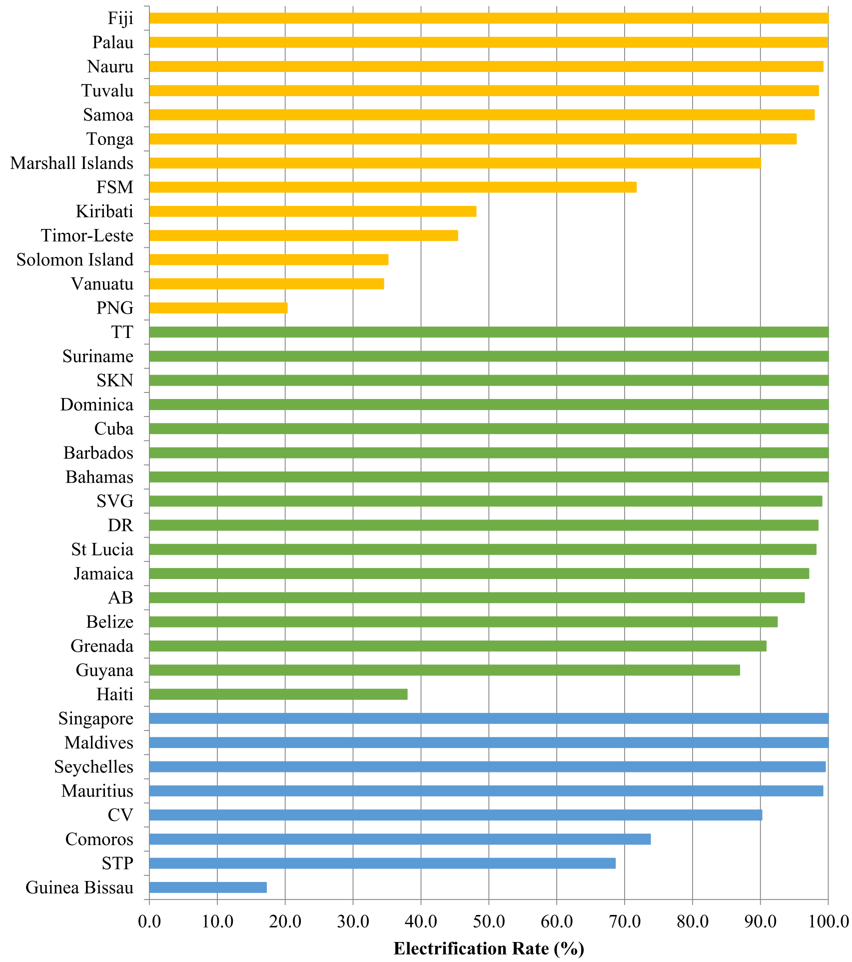

Fig. 4. Electrification rate in SIDS (Authors' compilation; data from The World Bank Group, 2018a).

on wind energy, with the island blessed with an average wind speed of 9.1 m/s (Cabeólica, 2016). Owing to its relatively high wind resources, there is a potential for further harnessing wind energy in CV through off-grid systems, energy storage systems or optimised systems (Segurado et al., 2011; Ranaboldo et al., 2014; Yuan et al., 2017; Qing, 2018).

In Mauritius, renewable electricity production is mainly through the combustion of sugarcane bagasse (18.6%) and through hydropower (4.3%) (Surroop and Raghoo, 2017, 2018; EIA, 2018). Sugarcane bagasse, as a bioenergy source, has mostly reached saturation point (Surroop and Raghoo, 2017) but other sources of biomass and wastes materials are estimated to supply up to 12 PJ/year of energy for the island (Bundhoo, 2018). Cane tops and leaves as a fuel are currently under test in some power plants and hopefully, to be under full operation soon (Bundhoo, 2018). Hydropower in Mauritius has reached technical exploitation capacity and no further large–scale hydropower potential exist (Elahee, 2013). However, some 10 MW can be expected from micro and pico hydropower plants which can still be exploited (Elahee, 2013). As at 2015, solar and wind energy constitute less than 1% but both sources are expected to increase in the future as more investment flows in the country (Bundhoo, 2018). Mauritius has a target of 35% electricity generation from renewable energy by 2025 (biomass and wastes: 21%; hydropower: 2%; solar and geothermal: 4% and wind: 8%) (MREPU, 2009) but right now, it is still unclear how far this objective can be achieved. Recently, the Mauritius government is also seeking to invest in liquefied natural gas (LNG) but a study by Raghoo et al. (2017a,b) shows that such investment might not be financially viable and other mode of transporting the natural gas is required. However, any attempt to invest in petroleum products do not solve Mauritius (and SIDS in general) issue of energy security (Raghoo et al., 2018).

Singapore is another AIMS SIDS utilising biomass and wastes for electricity production. From the 3.1% of electricity production from biomass and wastes materials in 2015, a major fraction is attributed to the processing of municipal wastes through anaerobic digestion and incineration plants (Energy Market Authority, 2017).

In Comoros and São Tomé and Príncipe (STP), most of the electricity is produced from diesel engines and the remaining by hydropower (see Fig. 5). However, it is seen that increasing electricity demand is met mostly by oil rather than renewable energy (Surroop and Raghoo, 2018). According to Surroop and Raghoo (2018), Comoros has a solar

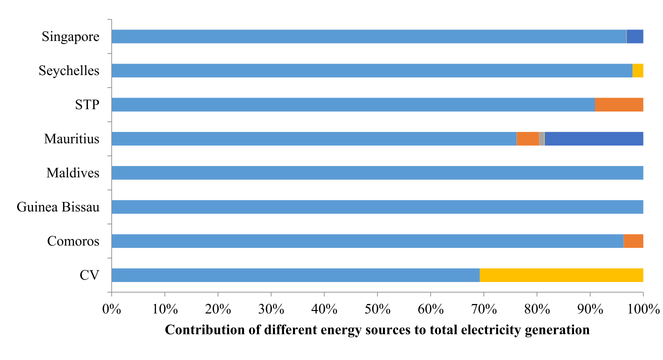

Fig. 5. – Energy sources for electricity generation in AIMS SIDS in 2015 (Drawn based on data from EIA, 2018).

energy potential of 5000 W/h/m^2, but little solar is exploited. STP is said to have good solar, wind and hydropower potential but with a lack of resource assessment studies, the exact potential is still unknown (Surroop and Raghoo, 2018).

Maldives and Guinea–Bissau are entirely dependent on fossil fuels for electricity production. The reason for Maldives' high dependence on fossil fuels is due to the fact that standalone renewable energy technologies may not be economically feasible on the island (Van Alphen et al., 2007) while the lack of finance, skill and know-how in the field of renewable energy further hinder its development (Ministry of Housing and Environment, 2010). Nonetheless, there have been some attempts to implement renewable energy systems in Maldives for those whose potential has been assessed (Van Alphen et al., 2007, 2008) Likewise, as part of its National Energy Policy and Strategy, the Maldives are encouraging the use of renewable energies such as solar, wind and biomass (Ministry of Housing and Environment, 2010). As a solution to the high costs of standalone renewable energy systems in the Maldives, several studies have proposed coupled energy-water systems or hybrid renewable energy-diesel systems which eventually lowers the cost of renewable energy and increases its economic viability in the Maldives (Liu et al., 2017; Wijayatunga et al., 2016).

It seems that policymakers have become very active these last years to uplift the energy sector in Guinea–Bissau. The Government has set up a renewable energy centre for the promotion of solar, wind and biomass energy (Guinea Bissau Republic, 2012) and seek to launch a framework for renewable energy development in the country. In the same line, an expression of interest was launched in 2013 for the recruitment of a consultant for assisting in the preparation of a framework for developing the renewable energy sector in Guinea Bissau (ECREEE, 2013). Moreover, Surroop and Raghoo (2018) reported that Guinea–Bissau has good solar wind and hydro resources.

Despite the AIMS SIDS being surrounded by sea, ocean-based renewable energy is not currently harnessed in any of these islands. A previous study by Hammar et al. (2012) revealed that there is a high potential for ocean thermal energy conversion (OTEC) in Mauritius, Seychelles and Comoros while the potential for harnessing wave energy is also high in Mauritius (Hammar et al., 2012). In the same line, wave data were previously collected in south coast of Mauritius with a view of tapping wave energy (Carnegie Wave Energy, 2016).

3.2.2. Caribbean SIDS

Similar to AIMS SIDS, electricity production from renewable energy in Caribbean SIDS is predominantly through the utilisation of fossil fuels although Belize and Suriname are two exceptions. In Belize, nearly 28% of electricity is imported from Mexico while the remaining electricity is generated on the island through hydropower (45.9%), biomass and wastes (14.1%) and fossil fuels (12.1%) (Government of Belize, 2012). Considering only electricity generated in Belize, hydropower thus constitutes the main source of renewable electricity production (63.7%) followed by energy from biomass and waste materials (19.6%) (Government of Belize, 2012). In Suriname, hydropower contributes 53.8% of total electricity generation (IRENA, 2015). These two SIDS are followed by Haiti, Dominica and St. Vincent and the Grenadines with hydropower contributing 28.7%, 24.5% and 16.1% of total electricity generation respectively (IRENA, 2012; EIA, 2018).

With respect to other sources of renewable energy in Caribbean SIDS, electricity from wind energy amounts to 4.6% in DR, 3.8% in SKN and 3.2% in Jamaica while energy from biomass (mainly sugarcane bagasse) amounts to 4.3% in Jamaica and 3.7% in Cuba (EIA, 2018). Nonetheless, the potential for electricity production from sugarcane agricultural residues, energy cane and marabu (a type of bush tree) is much higher in Cuba with a study previously reporting that 48–99% of electricity demand in Cuba in 2030 could be supplied through biomass (Gutiérrez et al., 2018).

Ocean-based renewable energies such as offshore wind, OTEC or wave energy is not currently tapped in Caribbean SIDS despite the potential reported in previous studies (Henry et al., 2015; Singh and Ephraim, 2016). Nonetheless, a policy adopted in 2014 is planning on exploiting ocean resources in the Caribbean region, with ocean-based renewable energy among one of the potential benefits (Singh and Ephraim, 2016). Surprisingly, solar energy is only harnessed to a relatively low extent in many Caribbean SIDS (as observed in Fig. 6) despite a solar irradiation rate reaching 7 kWh/m^2/day in dry seasons (Headley, 1997).

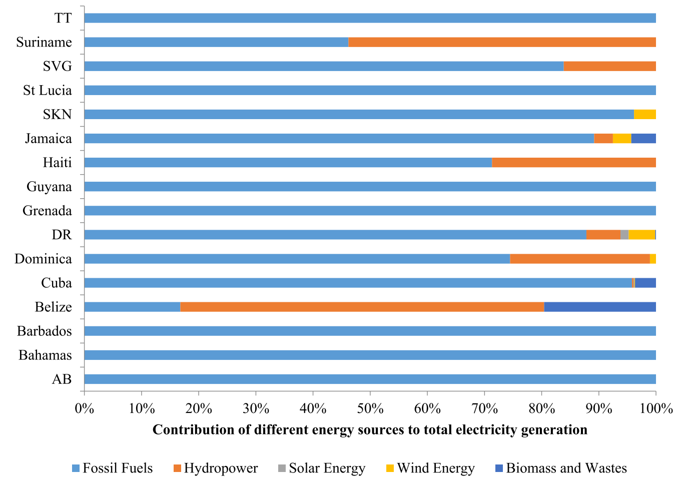

Fig. 6. – Energy sources for electricity generation in Caribbean SIDS in 2015 (Drawn based on data from EIA (2018); data for Belize (2010), Haiti (2009) and Suriname (2011) have been obtained from Government of Belize (2012), IRENA (2012) and IRENA (2015) respectively).

As observed in Fig. 6, seven of the 16 Caribbean SIDS are fully dependent on fossil fuels for electricity generation which is surprising considering the high potential for solar and wind energy exploitation in many of these SIDS (NREL, 2015). The possible reasons for this high dependence on fossil fuels remain the lack of finance for implementation of renewable energy technologies, lack of capacity development in the field of renewable energy and a lack of technology transfer to these small developing economies (CARICOM, 2009; Ince et al., 2016). However, the development of the Caribbean Centre for Renewable Energy and Energy Efficiency (CCREEE) will promote the implementation of renewable energy in the Caribbean SIDS by alleviating the aforementioned barriers to renewable energy in these small islands (United Nations, 2018).

3.2.3. Pacific SIDS

Nearly half of the Pacific SIDS are fully reliant on fossil fuels for electricity production while renewable electricity production is only discernible in three islands namely Fiji (46.2%), PNG (38.0%) and Samoa (33.1%) as observed in Fig. 7. In all these three Pacific SIDS, renewable electricity production is predominantly through hydropower. Wind energy has a small contribution in renewable electricity production in Vanuatu (9.1%) while solar energy is harnessed to some extent (3.1%) in Tuvalu for electricity generation (EIA, 2018; IRENA, 2012). Electricity production from biomass and wastes is only noticeable in the Federated States of Micronesia and contribute to 3.2% of total electricity generation (EIA, 2018). This contribution is attributed to biofuel in the form of coconut oil that is mixed with diesel for electricity production (Nachmany et al., 2015). PNG is the only SIDS with geothermal energy contributing to electricity production (11.0% of total electricity production) (APEC, 2013).

The current observation from Fig. 7 is in line with a previous study by Dornan (2015) whereby the author reported that only 3 Pacific SIDS (Fiji, Samoa and PNG) had good hydropower resources while the other Pacific islands had no potential for hydroelectricity generation (except Solomon Island with moderate potential). Nonetheless, the same study

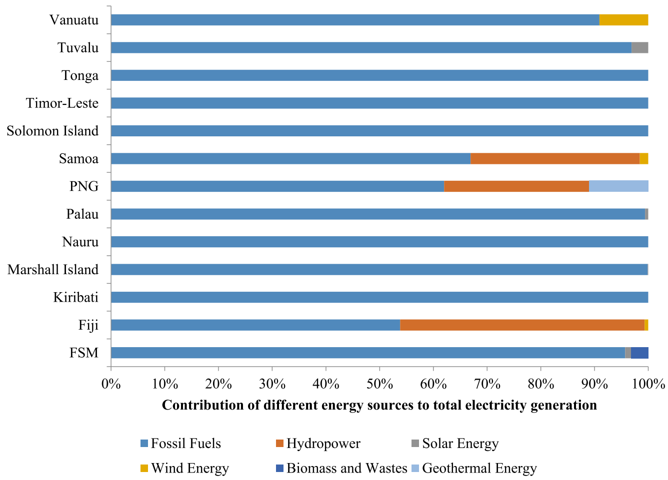

Fig. 7. – Energy sources for electricity generation in Pacific SIDS in 2015 (Drawn based on data from EIA (2018); data for Federated States of Micronesia, Marshall Island, Palau, Timor-Leste and Tuvalu are for the year 2009 and have been obtained from IRENA (2012); data for Papua New Guinea is for the year 2010 and has been obtained from APEC (2013)).

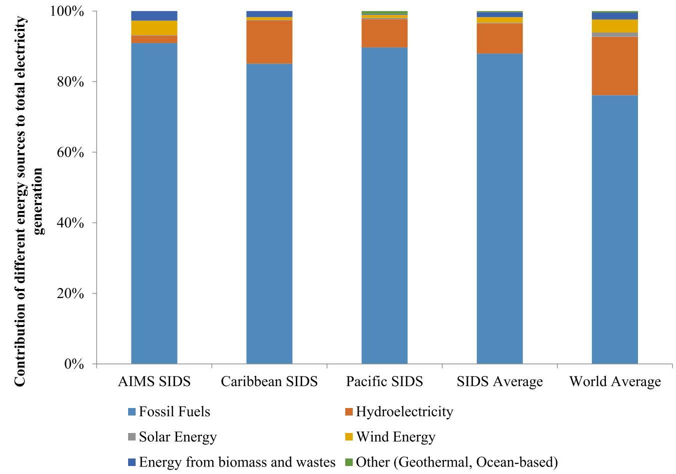

Fig. 8. – Comparison of electricity generation from different energy sources between SIDS regions in 2015 and the world (Drawn based on data from: EIA, 2018; IRENA, 2012; IRENA, 2015; APEC, 2013; Government of Belize, 2012 and Ren21 Steering Committee, 2016).

also reported that the Pacific SIDS have good resources in terms of solar energy and moderate wind energy resources while Fiji and Vanuatu also possess good potential in terms of geothermal energy exploitation (Dornan, 2015). The reasons for the lack of implementation of renewable energy technologies (particularly solar, wind) in Pacific SIDS are similar to those of AIMS and Caribbean SIDS and are generally classified as economic, institutional and technical barriers that hamper the development of such energy systems (Dornan, 2015; IRENA, 2013; Singh, 2012).

3.2.4. *Comparison between SIDS regions*

On average, 88.0% of the total electricity demand in SIDS is met through fossil fuels while the remaining 12.0% is supplied through primarily hydropower followed by wind energy and energy from biomass. As opposed, 76.3% of worldwide electricity generated in 2015 was produced from fossil fuels with 23.7% being contributed from renewable energy (mainly hydropower: 16.6% and wind energy: 3.7%) (REN21 Steering Committee, 2016).

As previously mentioned, the low deployment of renewable energy systems in SIDS is attributed to several barriers including lack of finance, lack of capacity development in the field of renewable energy, lack of technology transfer while the small-scale nature of renewable energy systems in SIDS often create a lack of economies of scale, increasing the cost of renewable electricity produced (Ince et al., 2016; Dornan, 2015; IRENA, 2013; Singh, 2012). Comparing the SIDS regions (Fig. 8), Caribbean SIDS depend the least on fossil fuels for its electricity requirements although it is not significantly lower compared to the other SIDS regions. Electricity production from hydropower is also highest in Caribbean SIDS and these are mainly attributed to the contributions of Belize and Suriname in the hydroelectricity sector. Wind energy and energy from biomass are highest in AIMS SIDS owing to the contributions from CV and Mauritius respectively while there is no major difference between the SIDS regions with respect to solar energy exploitation. Ocean-based energies are not currently harnessed in any SIDS region and geothermal energy is only exploited in PNG.

The heavy reliance on fossil fuels for electricity production makes SIDS vulnerable to the highly fluctuating prices of fossils on the international market, potentially impacting on their economies. As such, many SIDS are feeling the necessity to shift towards renewable energies. Besides, the international assistance obtained for renewable energy development is another factor driving this shift towards renewable energies in SIDS as observed by the high renewable energy targets set by many SIDS (Dornan and Shah, 2016). While these ambitious targets are laudable, many of these are not often realistic and achievable in these SIDS since the renewable energy resource is poor. In Mauritius, for instance, it is targeted that electricity production from geothermal sources will reach 2% by 2025 (MREPU, 2009) but geothermal potential for Mauritius is very low and not viable (ELC-Electroconsult, 2015). As such, these targets must be set based on studies conducted on the potential of the renewable energy resource in each SIDS while also considering the feasibility aspects of the renewable energy technology being deployed.

3.3. *Cost of electricity in SIDS*

It is also interesting to look at the price of electricity in the different SIDS. The cost of electricity varies significantly for different countries irrespective of their regions as shown in Fig. 9. The cost of electricity in the AIMS region varies from 0.1 to 0.434 USD/kWh. Electricity is cheapest in Singapore at a rate of 0.1 USD/kWh followed by STP at 0.179 USD/kWh. The cost of electricity is most expensive in Maldives at 0.434 USD/kWh followed by Seychelles at 0.31 USD/kWh. The costs of electricity in the other AIMS SIDS are in the range of 0.23–0.28 USD/kWh.

The Caribbean region is similar to the AIMS region whereby the cost

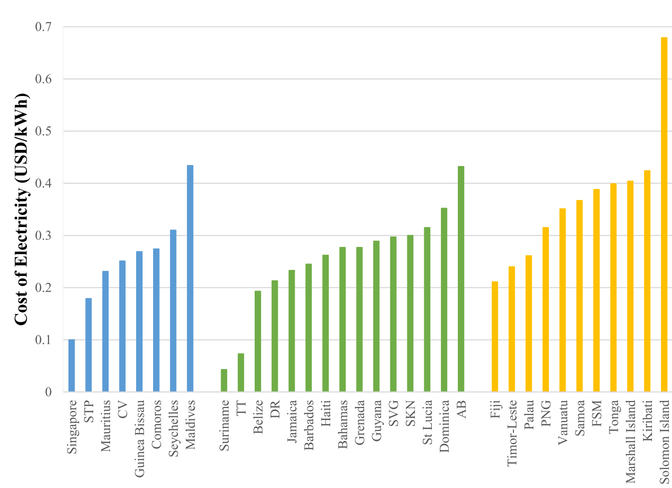

Fig. 9. Price of Electricity in SIDS (Authors' compilation; data from World Bank, 2017b).

varies from 0.043 to 0.423 USD/kWh. Surinam and TT produce electricity at the lowest cost at 0.043 USD/kWh and 0.073 USD/kWh respectively. Electricity is most expensive in AB at a rate of 0.432 USD/kWh followed by Dominica and St. Lucia at a rate of 0.352 and 0.315 USD/kWh respectively. The cost of electricity in the other islands is in the range of 0.2–0.3 USD/kWh.

The Pacific region is slightly different from the other two regions in the sense that the cost of electricity varies over a bigger range. Electricity is most expensive in Solomon Island at a rate of 0.679 USD/kWh and the cheapest is in Fiji at a rate of 0.211 USD/kWh. It should be highlighted that although PNG has gas reserves, the level of energy access is low and the cost of electricity is relatively high at a rate of 0.315 USD/kWh.

Comparing the cost of electricity in all the SIDS, it is noted that electricity is most expensive in Solomon Island and cheapest in Surinam and TT. TT is also an oil-producing country which explains the low cost of electricity. The costs of electricity are generally high in SIDS compared with other countries mainly due the transportation cost.

4. Recommendations for renewable energy development

Renewable energy development in SIDS has been hampered by several barriers namely institutional, technical and financial as previously mentioned. In order to promote the implementation of renewable energy in SIDS, these barriers need to be overcome while other key aspects of renewable energy deployment need to be considered. The following lists some of the recommendations for renewable energy development in SIDS.

4.1. Institutional framework

The absence of an institutional framework is regarded as a major bottleneck for overseeing the development of renewable energy. Consequently, the first recommendation for SIDS that do not have a dedicated centre for renewable energy is to set up such an institution that will supervise and promote the development and deployment of renewable energy in these small islands. A public-private partnership must be created between these institutions (which are generally public entities) and the private sector (which are potential investors in renewable energy projects). These dedicated renewable energy organizations must also be in constant liaison with their respective renewable energy centres for each SIDS region such as CCREEE in the Caribbean region, Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE) and the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) for African SIDS (United Nations, 2018b). The collaboration of the regional centres with the International Renewable Energy Agency (IRENA) will also act as a bridge between the local and international centre that may further promote renewable energy development.

4.2. Research on resources availability

As reported by Dornan (2015), many SIDS have set very high renewable energy targets. However, in many of these SIDS, these targets are not realisable owing to the lack of renewable energy resources. It is therefore recommended that prior to devising any energy strategy (particularly long-term), appropriate studies need to be carried out to determine the potential of each renewable energy resource in each SIDS. The studies must consider, amongst others, the intermittency of the renewable energy resource and must be carried out over a time period long enough to account for seasonal variations as well as long-term climate variability. These studies could be carried out by local universities in collaboration with the local, regional and international centres for renewable energy. The results of these studies could also be reported in the same formats for all SIDS and must be available to all stakeholders (Tao and Finenko, 2016).

In parallel, research on optimisation techniques for renewable energy deployment in a particular SIDS could also be carried out so as to determine the renewable energy system most appropriate for that island. Common aspects that are considered during the optimisation are the choice of renewable energy (hydropower, solar, wind, etc.), the type of energy system (standalone or hybrid), design or sizing of the renewable energy technology, the cost of the renewable energy system, the location more suitable for implementation of the renewable energy system, the availability and cost of land for deployment of the renewable energy system, amongst others (Bundhoo, 2018; Iqbal et al., 2014; Baños et al., 2011; Erdinc and Uzunoglu, 2012). Optimisation is thus necessary so as to ensure that the energy system deployed is the most suitable to the chosen location while also being efficient, reliable and cost-effective (Bundhoo, 2018; Iqbal et al., 2014; Erdinc and Uzunoglu, 2012; Ab. Razak et al., 2007).

4.3. Capacity building

Lack of local technical know-how and skills in the field of renewable energy is often seen as a major stumbling block to the development of renewable energy in SIDS. It is therefore important that capacity building is carried out at basic, intermediate and advanced levels (IRENA, 2013; Timilsina and Shah, 2016). This capacity building process could be carried out by local centres for renewable energy in collaboration with local universities as well as the regional and international centres for renewable energy. Furthermore, general awareness campaigns must also be carried out by the local renewable energy centres to promote the efficient use of renewable energy.

4.4. Financing mechanisms

Funding is particularly regarded as a major barrier that hinders the development of renewable energy in SIDS. The local renewable energy centres must work in partnership with the regional centres to source funding from international funding agencies while also disseminating the potential of renewable energy exploitation in their respective SIDS and its economic benefits to attract external investors (Timilsina and Shah, 2016). Financing mechanisms such as grants or loans must be properly formulated and well controlled. Financial incentives must be provided by governments for renewable energy projects either on small- or large-scales (Timilsina and Shah, 2016). Grants or subsidies may be provided for purchase of photovoltatic cells at household level and net-metering or feed-in-tariffs schemes must be properly devised and promoted. Public-private partnerships must be encouraged whereby governments share the financial risk of the project as this will attract investments from the private sector.

4.5. Policy and regulatory frameworks

For any system to be properly effective, a proper policy coupled with applicable regulations is fundamental. Similarly, any renewable energy system is subject to failure if there is no policy or regulation in place to frame and oversee its development. A policy may be devised for the whole energy sector in a particular SIDS but must cater for the development of renewable energy. More importantly, appropriate regulatory frameworks must be set up for renewable energy so that there is no monopoly which ultimately impact on the cost of renewable electricity produced.

5. Summary and conclusions

A detailed review of the SIDS energy sector is a necessary pre-requisite to good energy policy-making for these nations. This paper addresses this need by presenting the current state of energy affairs in SIDS.

SIDS high dependence on fossil fuels and little resilience against climate change has attracted international interest from researchers from all around the world. However, some fields still appear to lack consideration. This paper shows that some areas of SIDS remain understudied and without clearing these grey areas, sustainable development is less likely. In the second part of the paper, the overview that is presented dictates to what extent SIDS is dependent on fossil fuels. Despite having exploitable renewable energy, the development pace of these sustainable energies is slow and undesirable.

Lastly, four potential solutions were elaborated that may possibly speed up renewable energy development in SIDS context. It should be noted that these solutions are not necessarily applicable to Singapore which is the most developed country in this group of states. These solutions can be grouped as research, training and capacity-building, institutional solutions and fiscal policies. Research and more accurate data can lead to more accurate and reliable resource assessment which will boost confidence of any interested party in renewable energy. Equally, the availability of well-trained manpower and energy practitioners can promote renewable energy as investors can spend less on training. Policy, regulatory and institutional frameworks will assist in simplifying bureaucratic procedures and speed up licensing of any renewable energy project. This is highly incentivizing to investors as they reduce costs and time for project implementation along the renewable energy development chain.

Lastly, considering relatively high costs of renewable energy technologies, financial mechanisms can attract project developers and reduce risks associated with the development of renewable energy project. Cumulatively, these solutions can provide a better investment climate for private participation and ensure the sustainability of renewable energy projects.

References

Ab Razak, J., Sopian, K., Ali, Y., 2007. Optimization of renewable energy hybrid system by minimizing excess capacity. Int. J. Energy 1, 77–81.
APEC, 2013. Energy Demand and Supply Outlook. Asian Pacific Energy Research Centre.
Baños, R., Manzano-Agugliaro, F., Montoya, F.G., Gil, C., Alcayde, A., Gómez, J., 2011. Optimization methods applied to renewable and sustainable energy: a review. Renew. Sustain. Energy Rev. 15, 1753–1766.
Briguglio, L., 1995. Small island developing states and their economic vulnerabilities. World Dev. 23, 1615–1632.
Bundhoo, M.A.Z., 2018. Renewable energy exploitation in the small island developing state of Mauritius: current practice and future potential. Renew. Sustain. Energy Rev. 82, 2029–2038.
Cabeólica, 2016. Annual Report. . http://www.cabeolica.com/site1/annual-report-2016/, Accessed date: 13 February 2018.
CARICOM, 2009. Small Island Developing States (SIDS) Sustainable Energy Initiative SIDS DOCK. https://caricom.org/projects/detail/small-island-developing-states-sids-sustainable-energy-initiative-sids-dock/P135, Accessed date: 15 February 2018.
Carnegie Wave Energy, 2016. ASX Announcement: Wave Monitoring Buoy Deployed off Mauritius.
Chandra, V.V., Hemstock, S.L., N'Yeurt, A.R., Surroop, D., 2017. Environmental and economic study for a prospective ethanol industry in Fiji. Prog. Ind. Ecol. 2, 146–163.
Dornan, M., 2014. Access to electricity in small island developing states of the Pacific: issues and challenges. Renew. Sustain. Energy Rev. 31, 726–735.
Dornan, M., 2015. Renewable energy development in small island developing states of the Pacific. Resources 4, 490–506. https://doi.org/10.3390/resources4030490.
Dornan, M., Shah, K.U., 2016. Energy policy aid, and the development of renewable energy resources in small island developing states. Energy Pol. 98, 759–767.
ECREEE, 2013. Call for Expressions of Interest-national Sustainable Energy Expert for Guinea Bissau. http://www.ecreee.org/fr/node/18658, Accessed date: 14 February 2018.
EIA, 2018. International Energy Statistics: Electricity Generation. U.S. Energy Information Administration. https://www.eia.gov, Accessed date: 13 February 2018.
Elahee, M.K., 2013. Potential of hydropower in Mauritius: myth or Reality? Energy sources, Part A: recovery. Util. Environ. Eff. 35, 921–925.
ELC-Electroconsult, 2015. Opportunity Assessment for the Development of Geothermal Energy in Mauritius: Final Report.
Energy Market Authority, 2017. Singapore Energy Statistics. https://www.ema.gov.sg/Singapore_Energy_Statistics.aspx, Accessed date: 14 February 2018.
Erdinc, O., Uzunoglu, M., 2012. Optimum design of hybrid renewable energy systems: overview of different approaches. Renew. Sustain. Energy Rev. 16, 1412–1425.
Government of Belize, 2012. Strategic Plan 2012-2017: Integrating Energy, Science and Technology into National Development Planning and Decision Making to Catalyze Sustainable Development.
Guinea Bissau Republic, 2012. The energy sector electricity. LPG Renew. Energy. http://www.guinebissaurepublic.com/energy.html, Accessed date: 14 February 2018.
Gutiérrez, A.S., Eras, J.J.C., Huisingh, D., Vandecasteele, C., Hens, L., 2018. The current potential of low-carbon economy and biomass-based electricity in Cuba. The case of sugarcane, energy cane and marabu (Dichrostachys cinerea) as biomass sources. J. Clean. Prod. 172, 2108–2122.
Hammar, L., Ehnberg, J., Mavume, A., Cuamba, B.C., Molander, S., 2012. Renewable ocean energy in the western Indian Ocean. Renew. Sustain. Energy Rev. 16, 4938–4950.
Headley, O., 1997. Renewable energy technologies in the Caribbean. Sol. Energy 59 (1–3), 1–9.
Henry, L., Bridge, J., Henderson, M., Keleher, K., Barry, M., Goodwin, G., Namugayi, D., Morris, M., Oaks, B., Dalrymple, O., Shrake, S., Ota, A., Azevedo, L., Blue, B., Boucher, Z., Boege, S., Hager, L., Mack, T., Thompson, K., Rodak, D., Harding, B., Liu, B., Zhu, S., Loveall, J., Chavez, M., 2015. Key factors around ocean-based power in the Caribbean region, via Trinidad and Tobago. Renew. Sustain. Energy Rev. 50, 160–175.
Hsu, C.T., Korimara, R., Cheng, T.J., 2014. Cost-effectiveness analysis of PVGS on the electrical power supply of a small island. Int. J. Photoenergy 264802, 1–9.
Ince, D., Vredenburg, H., Liu, X., 2016. Drivers and inhibitors of renewable energy: a qualitative and quantitative study of the Caribbean. Energy Pol. 98, 700–712.
Iqbal, M., Azam, M., Naeem, M., Khwaja, A.S., Anpalagan, A., 2014. Optimization classification, algorithms and tools for renewable energy: a review. Renew. Sustain. Energy Rev. 39, 640–654.
IRENA, 2012. Renewable Energy Country Profiles: special Edition on the Occasion of the Renewables and Islands Global Summit. International Renewable Energy Agency.
IRENA, 2013. Pacific Lighthouses: Renewable Energy Road-mapping for Islands.
IRENA, 2015. Renewable Energy Policy Brief: Suriname.
Kelman, I., West, J.J., 2009. Climate change and small island developing states: a critical review. Ecological and Environmental Anthropology 5 (1).
Kumar, A., Nair, K., 2013. Wind power potential in Benau, Savusavu, Vanua Levu, Fiji. Int. J. Energy Inf. Commun. 4, 51–62.
Lal, S., Raturi, A., 2012. Techno – economic analysis of a hybrid mini-grid system in Fiji Islands. J. Energy Environ. Eng. 3, 1–10.
Legros, G., Havet, I., Bruce, N., Bonjour, S., 2009. The Energy Access Situation in Developing Countries. United Nations Development Programme (UNDP) and World Health Organisation (WHO), New York.
Liu, J., Mei, C., Wang, H., Shao, W., Xiang, C., 2017. Powering an island system by renewable energy-A feasibility analysis in the Maldives. Appl. Energy In Press, Corrected Proof. https://doi.org/10.1016/j.apenergy.2017.10.019.
Ministry of Housing and Environment, 2010. Maldives National Energy Policy & Strategy, Maldives.
MREPU, 2009. Long-term Energy Strategy 2009-2025. Ministry of Renewable Energy and Public Utilities, Republic of Mauritius.
Nachmany, M., Fankhauser, S., Davidová, J., Kingsmill, N., Landesman, T., Roppongi, H., Schleifer, P., Setzer, J., Sharman, A., Singleton, C.S., Sundaresan, J., Townshend, T., 2015. Climate Change Legislation in Federated States of Micronesia: an Excerpt from the 2015 Global Climate Change Legislation Study-a Review of Climate Change Legislation in 99 Countries.
NREL, 2015. Energy Transition Initiative: Islands Energy Snapshot. National Renewable Energy Laboratory, US Department of Energy. https://energy.gov/eere/island-energy-snapshots, Accessed date: 15 February 2018.
Qing, X., 2018. Statistical analysis of wind energy characteristics in Santiago island, Cape Verde. Renew. Energy 115, 448–461.
Ranaboldo, M., Lega, B.D., Ferrenbach, D.V., Ferrer-Marti, L., Moreno, R.P., Garcia-Villoria, A., 2014. Renewable energy projects to electrify rural communities in Cape Verde. Appl. Energy 118, 280–291.
Raghoo, P., Jeetah, P., Surroop, D., 2017a. Lifelong learning (LLL) for energy practitioners in small island developing states (SIDS): the pivotal role of education in energy efficiency and demand side management. In: Leal Filho, W. (Ed.), Climate Change Adaptation in Pacific Countries, Climate Change Management. Springer.
Raghoo, P., Surroop, D., Wolf, F., 2017b. Natural gas to improve energy security in Small Island Developing States: a techno-economic analysis. Develop. Eng. 2, 92–98.
Raghoo, P., Surroop, D., Wolf, F., Leal Filho, W., Jeetah, P., Delakowitz, B., 2018. Dimensions of energy security in small island developing states. Util. Pol. 53, 94–101.
REN21 Steering Committee, 2016. Renewable 2016: Global Status Report.
Segurado, R., Krajacic, G., Duic, N., Alves, L., 2011. Increasing the penetration of renewable energy resources in S. Vicente, Cape Verde. Appl. Energy 88, 466–472.
Singh, A., 2012. Renewable energy in the Pacific Island countries: resources, policies and issues. Manag. Environ. Qual. Int. J. 23 (3), 254–263.
Singh, A., Ephraim, J., 2016. Ocean energy: the new energy frontier for the eastern Caribbean small island developing states. Energy Pol. 99, 1–3.
Sovacool, B.K., D'Agostino, A.L., Bambawale, M.J., 2011. The socio-technical barriers to Solar Home Systems (SHS) in Papua New Guinea: “Choosing pigs, prostitutes and poker chips over panels”. Energy Pol. 39 1552–1542.
Surroop, D., Raghoo, P., 2017. Energy landscape in Mauritius. Renew. Sustain. Energy Rev. 73, 688–694.
Surroop, D., Raghoo, P., 2018. Renewable energy to improve energy situation in African island states. Renew. Sustain. Energy Rev. 88, 176–183.
Surroop, D., Raghoo, P., Wolf, F., Shah, K.U., Jeetah, P., 2018. Energy access in small island developing states: status, barriers and policy measures. Environ. Develop. https://doi.org/10.1016/j.envdev.2018.07.003.
Tao, J.Y., Finenko, A., 2016. Moving beyond LCOE: impact of various financing methods on PV profitability for SIDS. Energy Pol. 98, 749–758.
The World Bank Group, 2018a. Access to Electricity (% of Population). https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS, Accessed date: 16 February 2018.
The World Bank Group, 2018b. Population, Total. https://data.worldbank.org/indicator/SP.POP.TOTL?end=2014&start=1960, Accessed date: 16 February 2018.

Timilsina, G.R., Shah, K.U., 2016. Filling the gaps: policy supports and interventions for scaling up renewable energy development in Small Island Developing States. Energy Pol. 98, 653–662.
Tung, O.J.L., 2017. Towards a regional energy framework for African SIDS: prospects and challenges. J. World Energy Law Bus. 10, 220–234.
UN, 1994. Report of the Global Conference on the Sustainable Development of Small Island Developing States, Bridgetown, Barbados. United Nations, NY.
UN, 2005. Report of the International Meeting to Review the Implementation of the Program of Action for the Sustainable Development of Small Island Developing States, Port–louis, Mauritius. United Nations, NY.
UN, 2014. Report on the Third International Conference on Small Island Developing States, Apia, Samoa. United Nations, NY.
UNEP, 2014. Global Environmental Outlook Small Island Developing States. United Natins Environment Program, Kenya.
United Nations, 2018. Partnerships for the SDGs: Caribbean Centre for Renewable Energy and Energy Efficiency. https://sustainabledevelopment.un.org/partnership/?p=7504, Accessed date: 15 February 2018.
United Nations, 2018b. Network of Regional Sustainable Energy Centres for SIDS. https://sustainabledevelopment.un.org/partnership/?p=7639, Accessed date: 17 February 2018.
Urmee, T., Harries, D., 2012. The solar home PV program in Fiji – a successful RESCO approach? Renew. Energy 48, 499–506.
Van Alphen, K., Hekkert, M.P., van Sark, W.G.J.H.M., 2008. Renewable energy technologies in the Maldives-Realizing the potential. Renew. Sustain. Energy Rev. 12, 162–180.
Van Alphen, K., van Sark, W.G.J.H.M., Hekkert, M.P., 2007. Renewable energy technologies in the Maldives-Determining the potential. Renew. Sustain. Energy Rev. 11, 1650–1674.
Wijayatunga, P., George, L., Lopez, A., Aguado, J.A., 2016. Integrating clean energy in small island power systems: Maldives experience. Energy Procedia 103, 274–279.
Wolf, F., Surroop, D., Singh, A., Leal, W., 2016. Energy access and security in small island developing states. Energy Pol. 98, 663–673.
Wong, P.P., 2011. Small Island Developing States. WIREs Clim. Change 2, 1–6.
World Bank, 2017a. The Little Green Data Book 2017. Work Bank, Washington D.C.
World Bank, 2017b. Doing Business: Measuring Business Regulations - Getting Electricity. http://www.doingbusiness.org/data/exploretopics/getting-electricity, Accessed date: 16 February 2018.
Wright, R.M., 2001. Wind energy development in the Caribbean. Renew. Energy 24, 439–444.
Yaqoot, M., Diwan, P., Kandpal, T.C., 2016. Review of barriers to the dissemination of centralized renewable energy systems. Renew. Sustain. Energy Rev. 58, 477–490.
Yuan, S., Kocaman, A.S., Modi, V., 2017. Benefits of forecasting and energy storage in isolated grids with large wind penetration - the case of Sao Vicente. Renew. Energy 105, 167–174.