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DIMENSIONS OF ENERGY INSECURITY ON SMALL ISLANDS: THE CASE OF THE MALDIVES

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Abstract

The study explores the dimensions of energy insecurity on small islands in terms of heavy dependence on fossil fuels and the challenges involved in improving efficiency and renewable energy capacity to enhance energy security in the electricity system. Although all inhabited islands in the Maldives have made progress in electrification, the goal of achieving a secure, reliable supply of energy while changing to a low-carbon energy system has been challenging. However, every country faces a distinctive energy security outlook. Although the Maldives is the first and only country in South Asia with 100% access to electricity, the geographic spread necessitates the electrification of each island with its own diesel-powered mini-grid system, resulting in an expensive and inconsistent supply. The power sector continues to depend on fossil fuels, although the transformation to renewable energy has begun, particularly through solar photovoltaic hybrid systems. An evaluation in the context of the targets of SDG 7 for the Maldives offers insights into the distinctive energy security issues that small islands face, suggesting how they could develop their policies and priorities.

Keywords: small island developing states, Maldives, energy insecurity, renewable energy, electricity, sustainable development goals

JEL Classification: Q01, Q42, Q48, Q56, L94

Contents

1. INTRODUCTION

The term energy insecurity has evolved over the years. Until the oil crisis in the 1970s, energy insecurity was mostly linked to the geo-political risks connected with securing energy supplies. Environmental considerations became important after the Rio Summit in 1992, and a focus on the Small Island Developing States (SIDS) first recognized them as a distinct group at the United Nations Conference on Environment and Development in June 1992. Among SIDS, there are variations in the size of the population, number of islands, and diversity of energy resources available. Therefore, it is important to study the different positions of countries in relation to energy insecurity. This will help to identify the challenges and solutions and facilitate the understanding and areas of mutual cooperation between SIDS and with other countries. The United Nations declared 2014 as the International Year for SIDS, and Samoa hosted the UN International Conference on SIDS. The recommendation from the Conference called SIDS Accelerated Modalities of Action (S.A.M.O.A.) Pathway emphasized the important role of cooperation between countries for capacity building in relation to renewable energy (Lucas et al. 2017). Thus, there is a wider need for SIDS as well as advanced countries to cooperate. Accordingly, there is a need for Maldivians to be involved in different capacities of renewable energy. This could also include research related to renewable energy in the context of the Maldives. There is a dearth of research on the energy insecurity in the Maldives, which consist of over 1,190 islands of a relatively small land area dispersed over 90,000km^2. Identifying the energy insecurities and finding strategies can contribute to the achievement of sustainable development in the Maldives and could offer lessons for other SIDS.

Case studies are a suitable method to explore how SIDS respond to the challenges in formulating energy policies to improve the status of energy security (Wolf et al. 2016). As there is limited literature on the energy insecurity of the Maldives and its electricity system, a descriptive approach has the advantage of identifying factors that might influence the energy insecurity and warrant attention. Therefore, the aim of this paper is to provide a descriptive overview of the energy insecurity issues in the Maldives. This includes the perspective of an energy system as an object exposed to security threats, such as disasters and fires, and the perspective of an energy system as a subject facilitating security to enhance living standards by taking the Sustainable Development Goals as a guide. The paper provides a brief discussion on the concept of energy insecurity, based on an analysis of energy insecurity in the Maldives with reference to the energy targets from the Sustainable Development Goals (SDGs), namely access to affordable, reliable, and modern energy services; increasing conservation and efficient use of energy; and enhancing the use of renewable energy (United Nations [UN] 2015). Conclusions with suggestions follow this discussion.

2. ENERGY INSECURITY IN SIDS

Energy insecurity relates to the concept of security. It implies a condition of being without threat; a state of being protected; and a form of avoidance through non-exposure to danger (Zedner 2003). From the perspective of an energy system as an object, the focus is on securing the functionality, enabling it to facilitate the provision of energy services to the society without significant interruptions or extreme price effects. These factors include resource availability, diversity in energy resources, supplier reliability, import dependency, secure and safe transit routes, infrastructure reliability, and so on (Johansson 2013). Energy security includes supply and demand side factors.

The supply side of energy security includes the ability of a country to generate and produce energy efficiently from diverse sources, requiring the development of new and renewable energy sources and effective management of the energy sources available within and outside the country. The demand side of energy security requires accessible energy services at an affordable price. Thus, efficient and equitable distribution as well as minimization of loss in the distribution and conversion of energy into final uses through energy conservation practices and end-use technologies are important (Elkind 2009). Renewable energy can contribute to the security of the supply of energy as well as reducing greenhouse gas (GHG) emissions. It can also enable the reduction of geopolitical security risks through the diversification of the fuel mix and increased use of locally available renewable energy sources (Ölz, Sims, and Kirchner 2007). Thus, renewable energy systems can improve some aspects of security. However, they will not automatically result in the removal of all types of energy insecurity problems. Solutions to many issues related to energy security also rely on energy resource management and on the existence of good governance and effectively functioning institutions (Johansson 2013). In terms of energy, this implies the importance of conserving limited energy resources to reduce overconsumption and taking precautionary actions, particularly when faced with challenges in achieving economies of scale in small operations on small islands. People have conventionally generated energy from limited resources: wood for cooking, imported fossil fuels, or renewable energy technologies. Consequently, the management of energy resources to ensure energy security is essential. It is necessary to protect the energy infrastructure and build the capacity within communities.

Energy security is important for facilitating economic growth, because it enhances the productivity of capital, labor, and other factors of production (Ministry of Environment and Energy [MEE] and Asian Development Bank [ADB] 2017). However, the world market prices of fossil oil fluctuate sharply and continue to be a risk for SIDS. Moreover, climate change alters disaster risks for electricity generation. Research and policies on energy insecurity often overlook these considerations (Urban and Mitchell 2011). This is particularly relevant to the Maldives as one of the lowest-lying SIDS, vulnerable to the effects of climate change due to rising sea levels. Extreme weather conditions could cause damage to the critical infrastructure on the islands (Hanaif 2012). Moreover, fires in electric power-generating plants can cause risky incidents and costly consequences (Ali 2017b; Dieken 2019).

The SDGs provide guidance on a sustainable approach and evaluation. This includes a pathway for sustainable energy by 2030: (1) ensuring universal access to affordable, reliable, and modern energy services; (2) increasing substantially the share of renewable energy in the global energy mix; and (3) doubling the global rate of improvement in energy efficiency (UN 2015). As in the case of building resilient infrastructure, the strategies to achieve the energy goal require the enhancement of the resilience of new and existing critical infrastructures to ensure that they remain safe, effective, and operational during and after disasters to facilitate life-saving and essential services (United Nations Office for Disaster Risk Reduction [UNISDR] 2015).

3. ACCESS TO AFFORDABLE, RELIABLE, AND MODERN ENERGY SERVICES

The Maldives Energy Policy and Strategy (2016) states that its main objective is the provision of reliable and sustainable energy services for social and economic development for all the people of the Maldives at the lowest possible cost. This relates to the SDG objective to ensure universal access to affordable, reliable, and modern energy services (UN 2015). The Maldives Constitution of 2008 enshrines that access to essential services is a right. However, the dispersed nature of the islands and the scattered nature of the population over many islands pose major challenges to the provision of essential services. For instance, achieving economies of scale and increased unit costs in building and maintaining the infrastructure and provision of public services are a major challenge (World Bank 2016). As electricity generation requires management at the island level, it involves high costs for each island, making all the costs relatively higher overall than those in other parts of South Asia. There are 186 powerhouses on inhabited islands, excluding the islands used exclusively as resorts or for industrial purposes.

Fuels such as diesel, petrol, aviation gas, and kerosene are the major types of petroleum products that the Maldives imports. Among these, diesel is the major import and accounts for 72% of the total fuel imports. Electricity generation consumes the largest proportion of imported fuel, and the outer islands, excluding the capital, account for 39% of the total electricity generated (MEE 2015a). Oil imports accounted for 31.2% of merchandise imports in 2012, which reduced by 13.3% in 2017. The world fuel prices fluctuate and affect the small countries that are dependent on fossil fuel imports. The Maldives addresses such fluctuation through government controls, subsidies, and direct importation of oil through state-owned companies, such as the State Trading Organization (STO). The provision of subsidies is not always an economically efficient policy, as it can encourage the continuation of inefficient industries and the use of government resources that could be spent more efficiently for other purposes (Jakob et al. 2015).

Various issues of insecurity are linked to the importing of fossil fuels. SIDS must rely on sea transportation for fuel imports. Among the challenges, Maldivian importers do not obtain favorable credit terms from most suppliers. Major suppliers, such as the Singapore Petroleum Oil Company (SPC) and Petronas Malaysia, allow 45 days’ credit, while the Emirates National Company (ENOC) is the only company to provide 90 days’ credit. In addition, the relatively small tenders do not facilitate a lower price. Similarly, the oil tanker size of a maximum of 24,000 metric tons used by Maldivian companies is too small to bring down the freight rates. Moreover, due to their smaller size, Maldivian companies are not able to use the ports and berthing facilities in the neighboring South Asian region, as they lack berthing facilities for the smaller tankers that Maldivian companies operate. The nearest port is Cochin in India, and the smallest clean petroleum products (CPP) tanker size that it caters for is 30,000 deadweight tonnage (DWT). Therefore, Maldivian companies have to make special arrangements through the UAE, Singapore, or Malaysia. Ships have to steam one way with cargo and make the return voyage with ballast. Consequently, to cover the voyage cost, shipowners increase the freight rate, adding extra costs.

The limited storage capacity on the islands is also a major drawback. By 2015, about 64% of the diesel bunkering capacity of the country was on one small island, Funadhoo, near Malé. There are three other small bunkering facilities in the south of the Maldives but none in the north (MEE 2015b). The Maldives Energy Policy and Strategy (MEE 2016) recommended building regional oil bunkers in four locations in the northern parts to store oil in times when the world oil prices drop.

The limited number of small delivery vessels, especially for long distances, incurs frequent voyages, which inflate the delivery and operational costs mainly for bunkers and for steaming and maintenance. Table 1 shows the average monthly consumption based on 2017 data on the monthly average consumption of a similar approximate level and 2019 data on the capacity of the storage tanks on sample islands. The capacity of the storage tanks entails filling them twelve times a month in Gemanafushi and six times in Nolhivaram compared with twice a month in Makunudhoo.

Table 1: Capacity of Oil Storage and Estimated Number of Times Required to Fill the Tanks

Island	**Atoll**	**Monthly Average Diesel Consumption** (Liters)	**Capacity of Storage Tank** (Liters)	**Number of Times Required to Fill the Tank per Month**
Nolhivaram	Haa Dhaal	34,937.67	6,100	6
Makunudhoo	Haa Dhaal	35,895.92	15,000	2
Maduvvari	Raa	38,966.75	19,300	2
Kurendhoo	Lhaviyani	40,274.00	20,000	2
Meedhoo	Dhaal	35,851.08	15,000	2
Gemanafushi	Gaaf Alif	37,420.17	3,000	12

Source: Authors' calculation based on data from Fuel Supplies Maldives (FSM) (2019) and MEE (2018a).

The results indicate that, in the past, the islands had different tariff structures, although the government supervised them. These differences were reflections of the production scale due to the population size, efficiency, and cost of transportation of fuel. The electricity tariff structures varied across the Maldives, but, in 2016, the government introduced a single tariff band for all the islands other than Malé. In 2018, the government eliminated the differences in the tariff rate and made it the same as in Malé. The following Table 2 shows the change in the tariff levels for the domestic sector. It was an important step in promoting equity for all consumers, although it may not be a cost-reflective tariff system.

Table 2: Electricity Tariffs (in Maldivian Rufiya) in the Maldives in 2016 and 2018

Band (30 Days)	**Malé (2016)**	**Other Islands (2016)**	**All Islands (2018)**
1–100	2.10	3.00	1.50
101–200	2.20	3.30	1.70
201–300	2.35	3.40	2.15
301–400	2.70	3.50	2.50

Source: Fathih (2016), Rasheed (2018)

The Government of Maldives has a constitutional obligation to ensure the provision of a reasonable standard of electricity to every inhabited island. Therefore, to reduce the burden on electricity-producing companies, the government decided to reduce the import duty of diesel between 10% and 15% in 2017. This was followed in 2018 by a complete exemption of import duty on diesel. The government expected the import duty reduction to result in a reduction of the production cost.

However, as the population on most islands is small, it requires less fuel. Therefore, instead of buying in bulk from Malé at a lower rate, the powerhouses purchase small quantities from nearby suppliers. However, people consider this to be malpractice, as the Auditor General's Office (AGA) refutes such sales. For instance, there are reports of some cases in which utilities are involved in corruption. Normally power companies must obtain three quotations before purchasing. However, if there are not many suppliers in a particular location, then the operator buys from the nearest location. In some instances, powerhouses have even purchased diesel from fishing boats due to a shortage of fuel to ensure an uninterrupted electricity service. According to the Auditor General's report, one of the electricity companies bought fuel at higher rates with a value up to about $1,414,887 between 2014 and 2015 (AGA 2018). Although it is possible to buy larger quantities of fuel from the suppliers in Malé, the powerhouses on the islands do not have adequate fuel storage capacity. One way to overcome this problem is to increase the capacity to store fuel safely. Regulations and standards are necessary for the transportation and storage of fuel. The storage facility on Funadhoo island is also a high-risk area, being constrained by space and risks of tidal surges or fire. Despite it being adjacent to Malé's international airport, the government has no plans to shift the facility to a safer place, with room for expansion.

The UN Sendai Framework for Disaster Risk Reduction for 2015–2030 appealed to governments to prioritize the protection and resilience of critical infrastructure. It included such aspects as transport systems, air- and seaports, electricity, water and communications systems, hospitals and health clinics, and centers for fire, police, and public administration services (National Disaster Management Centre [NDMC], 2014). Thus, the vulnerability and insecurity of the electricity infrastructure are also a concern on the government's national security agenda. The ability to manage and address these risks and ensure the resilience of the energy infrastructure thus needs an integrated approach for mainstreaming disaster risks, which include natural disasters or fire-related incidents. Such mainstreaming will also enhance the capacity to assess risks in preparing plans to enhance the resilience of the existing energy infrastructure and retrofit the existing infrastructure to minimize energy insecurity. This includes preparing and implementing design guidelines as well as policies and regulatory mechanisms to ensure the enforcement of the standards and policies while taking precautionary measures.

The islands of the Maldives are not especially prone to tropical cyclones and therefore do not experience direct impacts from and damage due to cyclones (Risk Management Solutions Inc. [RMSI] 2006). However, historical records indicate occurrences of incidents and damage due to extreme weather resulting from cyclone-driven storms in the Indian Ocean, a few hundred kilometers away from the Maldives. People have abandoned a number of islands due to such storms. For instance, about 18 islands from the northern atolls are uninhabited due to storm damage (Maniku 1990 as cited in Jameel 2007) and people abandoned 3 islands after the 2004 Indian Ocean tsunami.

For a robust electricity infrastructure, the power plant system, distribution boxes, and distribution lines must be able to withstand extreme weather conditions while other electrical equipment, such as transformers, must remain operational. This will ensure that the electricity service is uninterrupted. However, the energy infrastructure on the islands lacks robustness, resourcefulness, and recovery to varying degrees. In the Maldives, the transmission lines are underground, although laying them underground is often costlier. In the past, when the transmission lines were above ground, many incidents occurred, including loss of life. Incidents of heavy rainfall affecting powerhouses and loss of electricity are common on many islands. For instance, a lightning strike in Mandhoo damaged the first solar PV panels that were installed in the Maldives in 2005, before their official commissioning (Van Sark et al. 2006). This is an important lesson on precautionary measures and transformative adaptation for the future. There are no records on damage to powerhouses in relation to weather events except in the case of the 2004 Indian Ocean tsunami.

The tsunami that hit the Maldives on 26 December 2004 was a nationwide disaster that caused severe damage to the physical infrastructure of many islands. Estimates indicated that the total damage was $470 million or 62% of the gross domestic product (GDP). The tsunami caused damage to the electric power supply system on 95 islands (about 48% of the islands with electricity then) and deprived them of electricity for several days (World Bank, ADB, and UN System 2005). On almost all the affected islands, the damage occurred to the distribution network, that is, cables, distribution boxes, and household connections. The strong waves pulled out the cables and tore them out of the ground. On some islands, the powerhouses, generators, and switchboards were also damaged to varying degrees; some of the generators needed repairs and others replacement. This damage amounted to $4.65 million of asset losses. The damaged facilities included 24 powerhouses, 104 generators, 652 streetlights, 34 switchboards, 632 distribution boxes, and more than 121 kilometers of cable (World Bank, ADB, and UN System 2005). The damage incurred was still less than in some other sectors, such as housing ($64.8 million), transport ($20.3 million), health ($5.6 million), education ($15.5 million), and water and sanitation ($13.1 million). However, electricity is critical for the operation of all those sectors; thus, the real value of a reliable electricity service is much higher than the value of the physical infrastructure.

The islands could not rebuild the powerhouses that were destroyed in the 2004 tsunami for a long time. Until then, the powerhouses were run in a temporary manner. Communities themselves ran most powerhouses, and islands did not have a network of manpower and equipment to assist them contingently. For example, in Isdhoo Kalaidhoo, two members of staff ran the powerhouse every day. There were no trained electricians or engineers, and there were frequent disruptions in the supply of electricity, risking the operation of the health center. Even after the tsunami, the powerhouse was not relocated to a safer area, and most streetlights remained defective for 3 years.

The assessments of the tsunami also revealed that there were households that did not have electricity before or after the tsunami, as they were not subscribers to electricity due to its affordability. However, there are no recent assessments to understand energy poverty, while all the islands have an electricity service. To protect them from extreme events, such as tidal waves and flooding, islands must locate powerhouses at a particular height. Power interruptions have been common in times of heavy rain. Recent examples in 2019 include power cuts in Dhigurah and Maamendhoo.

Incidents of fire at power plants in SIDS are an area that has received little attention in the literature. The energy policy documents of the Maldives also do not recognize such incidents. However, in the Maldives, fire incidents have destroyed the electricity generation infrastructure on many islands, causing a huge loss in terms of machinery, buildings, and even human life on a number of islands. To learn about fire incidents, Table 3 contains some reported cases.

Unlike other countries, powerhouses in the Maldives are situated very close to residential areas. Consequently, the impact of smoke and noise on residents is critical (Ali 2007b). The smoke and radiation cause a risk of cancer and asthma for children residing in the area (Usama as cited in Ali 2017a). For instance, a children’s park is located next to the powerhouse in Malé, and many other islands have imitated this.

Both residential houses and powerhouses are prone to incidents, as a fire in one building may affect another. For instance, people have alleged that the fire in Thinadhoo powerhouse in 2016 started in a neighboring warehouse. While powerhouses are small, oil tanks and other parts of the engines are not kept safe. In addition, they are not kept at an appropriate distance, increasing the vulnerability to such hazards (Ali 2017a). Many powerhouses also lack fire extinguishers, while existing ones have often expired. When the fire started in Narudhoo, there were no fire extinguishers (Anwar 2017).

Table 3: Some Fire Incidents in the Maldives between 2016 and 2017

Year	Island	Reason for Fire	Response	Loss
2016	Thinadhoo	Fire at a neighboring warehouse	A generator was brought from a nearby island	MVR22 million: 100,700 kW and 600 kW generators and 22 kW solar PV panel
2017	Bilehfahi	Fire in turbo	Temporary generator 120 kw and panel board brought from neighboring Feydhoo	MVR2.27 million
2017	Narudhoo	Unidentified		50 kW, 80 kw generator
2017	Ukulhas	Fire at fuel shed	Using the unburnt 300 kw generator	200 kW generator
2017	Fiyori	Battery fault	180 kW generator brought from Dhevvaddhoo	250 kW generator Death of 1 employee

Sources: Ali (2016, 2017a), Anwar (2017), Jameel (2017), and Samah (2017).

Following disasters and fire incidents, building powerhouses usually takes a long time. Even for an island with a small population, it takes more than a year to rebuild using local contractors. Currently, Bilehfahi power generation is in a temporary building. This temporary facility is not appropriate for electricity generation. The power company considered a prefabricated powerhouse to be cheaper and faster to build (Samah 2017). Although it completed the bidding, the construction has not taken place and the powerhouses in Thinadhoo and Bilehfahi islands remain in temporary facilities.

Lessons on fire incidents at powerhouses are important to minimize and take precautionary measures to avoid risks for energy security. Fire incidents are also a reflection of the poor maintenance and occupational safety in the powerhouses. On some islands, the power systems are unreliable and poorly maintained, leading to frequent power outages due to technical failures or the price and availability of diesel fuel. There is also a possibility that the design of the older powerhouses has contributed to inflated damage during fire incidents. Some powerhouses contained timber roof rafters. Many powerhouses have now changed to steel structures. The outer islands projects that the ADB funded between 2011 and 2013 began with powerhouses on 19 islands.

4. IMPROVEMENT IN ENERGY EFFICIENCY

Energy efficiency refers to a reduction in the energy used to provide a given level of energy services to a household, building, or facility. The optimization of end-user energy consumption is usually associated with technological changes but is also achievable by improving energy management processes or by adjusting operational procedures. Energy efficiency is first a matter of societal or individual choice and reflects the response of the government, utilities, and energy consumers to energy costs and their derivation in the energy demand and energy prices.

With economic growth and an increase in the expectation of living standards, there is a rise in the demand for electrical appliances and thus an increase in the demand for energy. One of the key changes has been a drastic rise in the use of air conditioners in recent years. Estimates indicate that the entire stock of air conditioners in the Maldives (excluding resorts) in 2012 was 76,000 units, of which around two-thirds were low-efficiency units. Hameed (2014) provided a set of data on electricity costs on the campuses of the Maldives National University from 2004 to 2013. Comparing the data before and after the installation of air conditioners on the university campuses on the outer islands, a drastic change in electric consumption is observable compared with 2012, with an increase of 113% from $133,132 to $283,631.

An energy audit revealed that air conditioning accounts for 60% to 70% of electricity consumption in households and offices (MEE 2014). Many developed countries are now experiencing economic growth with decoupling of emissions, owing to energy conservation and renewable energy. This is not the case in the Maldives yet, as the demand for energy is increasing without emphasis on conservation or sustainable lifestyles. Additionally, the lack of enforcement of building codes and green building concepts, compounded by urban sprawl and internal migration, poses further challenges. Since the tsunami of 2004, more people have been migrating to the capital area, and, as they live in rented small spaces with poor ventilation in urban areas with less greenery, the usage of air conditioning increases the demand for energy. On the other hand, on the rural islands, a decrease in population due to migration results in diseconomies of scale in electricity production.

According to the Ministry of Environment and Energy (2014), 65% of the air conditioners in the Maldives are not energy efficient. To reduce the energy consumption and to take advantage of the latest technology, the Ministry suggested replacing the existing air conditioners with energy-efficient ones. Such air conditioners are 10% more efficient than standard models. Replacing the existing stock with more energy-efficient air conditioners would cost $9.6 million in the Maldives, but, over the lifespan of the new air-conditioning units, there would be yearly savings of $27.7 million by reducing the electricity demand by 97 GWh up to 2020 (Marcu et al. 2015). Moreover, a survey that the MEE (2017) conducted found that 85% of people were not aware of the energy efficiency labels or ratings often depicted on consumer appliances. However, 48% of households have air conditioning in their homes, and this figure is continuing to increase. Imports of air-conditioning units increased by 166% from 2012 to 2017 (see Table 4). Customs data, however, are not available with energy ratings.

Table 4: Imports of Air Conditioners

Year	Quantity	CIF Value (MVR)	CIF Value (USD)
2012	13,836	79,218,810.26	5,137,406.63
2013	19,565	123,602,728.18	8,015,741.13
2014	26,361	153,919,142.08	9,981,786.13
2015	28,414	163,100,990.52	10,577,236.74
2016	149,158	210,914,855.59	13,678,006.20
2017	36,841	220,556,015.62	14,303,243.56

Source: Maldives Customs (2018).

The promotion of energy conservation and energy efficiency was one of the key policies that the Strategic Action Plan (2008) highlighted, and the National Strategy on Sustainable Development (2009) set a target of a 7.5% reduction in the final energy demand by 2020. Further to this, the Maldives Energy Policy and Strategy (MEE 2016) recommended facilitating the provision of energy-saving equipment to promote energy conservation and efficiency. With regard to institutional arrangements, initiatives of the Ministry of Environment have conducted energy audits in some of the public and local buildings. The Ministry of Housing and Infrastructure has developed a building code but lacks compliance documents, causing gaps in implementation. Similarly, the Maldives Energy Authority is working on labeling regulations for energy efficiency products. However, no obligatory or mandatory requirements regarding energy efficiency are yet in place, although there is a clear policy vision (IEA 2014). This is an important point to take into account to be resilient to energy insecurity and save energy.

Existing policies are already attempting to address many of the constraints that the country faces in improving energy efficiency, but progress in some key areas is slow. Electricity savings are not nearly fully utilized despite their financial and economic benefits. Therefore, there is an expectation that the electricity demand in the Maldives will grow by more than 10% per annum unless the current scenario changes. Not only will the electricity requirements increase but also the load curves will become peakier, in particular for island grids in which the connected cooling loads from air conditioners are likely to increase. For some islands, the peak loads may grow at an even higher rate than the electricity requirement growth rate. For instance, after the government allowed guesthouses in locally inhabited islands in 2009, the room capacity increased by 2090 rooms by 2018. After a domestic airport became operational on Dharavandhoo island of Baa Atoll, the tourist arrivals to the island increased. However, power generation relied on the old generators with capacities of 200 kw, 250 kw, and 10 kw. Since the peak load is high, power interruption has become frequent on the island. As a result, the air conditioning and water heating in the guesthouses are inconsistent, resulting in tourists' dissatisfaction. Hence, the community either has to adopt a type of tourism that requires less energy and target a market of tourists who require less energy-consuming services or has to increase the electricity capacity. This further reiterates the importance of energy insecurity and its link to livelihoods.

Energy consumption levels are a reflection of households' and institutions' choice of equipment to purchase and infrastructure to build and use in the long run. Hence, an early emphasis on energy efficiency is crucial (Elkind 2009). The Ministry of Environment and Energy, with the aid of the ADB, is developing a road map for the low-carbon development of the Maldives Energy Sector. According to MEE (2018b) the objective of the Roadmap for Low Carbon Development of Energy Sector in the Maldives (2018–2025) is to reduce the fuel dependency by 70% using clean energies and implementing energy efficiency measures. The road map will also help the Maldives to implement the changes required to provide sustainable clean energy to the communities by using suitable modern renewable technologies.

One of the successful environmental cooperations around the world was the implementation of the Montreal Protocol to phase out chlorofluorocarbon (CFC) gases, identified contributors to ozone layer depletion. Currently work is also underway to phase out hydrochlorofluorocarbons (HCFCs), which are an ozone-depleting substance (ODS) and a contributor to global warming. One way to deal with the reduction of such gases is to phase out the dependency on high global warming potential (GWP) alternatives and promote the usage of low GWP, energy-efficient technologies (Barton 2014). As air-conditioning equipment uses HCFCs as a refrigerant, prospective strategies can explore different interventions in environmental management that have co-benefits.

On the supply side of electricity generation, the Maldives Energy Policy and Strategy (MEE 2016) implies that measures are necessary to improve the operational performance of electricity service providers to manage the electric power infrastructure and to provide a quality energy service. However, the distribution losses that poorly designed and maintained networks cause are high. Currently, network losses account for 20% to 30%. On many islands, the design of the cable networks did not allow for overloading. There are some regulations in place, such as the banning of aluminum cables owing to incompatibility with the environmental conditions of the Maldives. For instance, aluminum cables are more prone to corrosion and susceptible to heat than copper cables. Reducing these variations through regulatory intervention will conserve more energy and reduce energy insecurity. Additional measures are necessary to improve efficiency and secureness. It is important for energy policies to include measures to increase efficiency in the production and distribution.

Improvements in efficiency can reduce the operational cost of electricity generation. Many islands are operating powerhouses above capacity. The installed capacity is often two to three times higher than the peak load. On some islands, oversizing leads to generators running with inefficient part loads. The size of diesel-powered electric generators typically intends to meet the peak demand, but the low load at other times results in poor fuel efficiency and increased maintenance (Nayar 2010). The following Table 5 indicates the installed capacity and maximum load for a few islands. As Table 6 shows, there is a large discrepancy between the installed capacity and the maximum peak load. Therefore, the government has to devise a structured system optimization program to make the current systems more efficient and sustainable (MEE and ADB 2017).

Table 5: Installed Capacity of Diesel Generators and Peak Load

Island	Atoll	Installed Capacity (kW)	Maximum Peak Load (kW)
Thinadhoo	Gaaf Dhaal	3,920	1,462
Ukulhas	Alif	737	286
Hulhumeedhoo and Meedhoo	Seenu	1,495	760
Maafushi	Kaafu	4,079	1,389

Source: MEE (2018a).

One solution to save fuel in a diesel generator is to enable the engine to operate at variable speeds in relation to the electrical load demand (Nayar 2010). Hybrid diesel application requires increased flexibility of the diesel generator, with variable potential speed configurations. This could be a transitional technology for use with renewable energy and diesel hybrid models (Hamilton et al. 2019). Such solutions require further research to determine whether there are constraints to leapfrogging directly to a complete transformation to renewable energy.

People generally consider energy efficiency as the lowest-cost option to deal with the current and future constraints in energy insecurity and to achieve the necessary reductions in GHG emissions (Econoler International 2011). While the Maldives is vulnerable to the effects of climate change, their own contribution to GHG emissions is relatively small. The Maldives pledged to reduce greenhouse gas (GHG) emissions by 10% of the level that it would reach in 2030 if it continued under a business-as-usual (BAU) scenario. The 10% target falls far short of the plans that the Maldivian President announced in early 2009 to become carbon neutral by 2020. The government has lowered the target due to the difficulty in generating finance and accessing technology. Nonetheless, with international assistance, it will operationalize a mitigation target to reduce this by 27%. According to MEE (2015b), to facilitate further renewable energy installations, the Maldives Climate Change Policy Framework (2015) highlighted sustainable financing, low emission development and ensuring energy security, adaptation actions or opportunities, and building a climate-resilient infrastructure and communities as well as fostering local capacity.

5. RENEWABLE ENERGY IN SIDS

Renewable energy has the potential to play a key role in enhancing energy security in SIDS and assisting them to achieve their sustainable development goals. Recently there has been an increase in familiarity with renewable energy, particularly solar and wind, as a few projects have taken place as pilot projects. The Maldives Energy Policy Strategy recommends the introduction of hybrid systems that use renewable energy, the conducting of projects to install solar PV panels in government and large private buildings, and the facilitating of research in wind, solar, ocean currents, and wave energy as ways to minimize electricity expenses.

Compared with solar PV, the prices of most other technologies have not yet decreased to a suitable extent for SIDS. The initial cost of investing in solar PV is still high, but the prices have fallen to a feasible level for small countries, and it is a simpler technology with the potential for saving fuel. The Maldives also has an abundance of sunshine, and investing in solar PV is highly significant from the perspective of energy security. In fact, adding the social costs of fossil fuel, the costs are higher than in the conventional understanding. However, the lack of land on the islands and lagoons in coastal marine areas is a challenge. Hence, the Maldives could try to incorporate diverse types of technologies and explore further development of technologies. By 2017, it had installed 11 MW of renewable energy (MEE 2018a) with projects in the pipeline to increase this by December 2019. Renewable electricity could range between 5% and 10% of the total electricity generating capacity by 2019 (Marcu et al. 2015). Most of these projects are solar PV installations, while there are proposals for wind and waste to energy projects. For example, the incineration plant on Vandhoo island of Raa Atoll now incorporates waste to energy.

Considering the empirical studies, van Alphen, van Sark, and Hekkert (2007) indicated the solar and wind power potential in the Maldives. While solar power sources are widely spread across the country's islands, wind potential is confined to a few locations, mainly in some northern areas. Wijayatunga et al. (2016) discussed the design of hybrid diesel–solar photovoltaic systems with energy storage in the Maldives and indicated that diesel–solar PV hybrid power generation systems with storage systems can increase energy security in terms of economic and environmental factors. Jung et al. (2018) investigated whether renewable systems are feasible options in SIDS based on the case of Kuda Bandos Island. They suggested that, if the project uses solar PV and a diesel generator, it will be possible to achieve grid parity in 5.77 years, and the renewable system is an effective solution for replacing the existing diesel generator and reducing the diesel consumption.

As the islands are small, one of the challenges is to find appropriate spaces to install solar panels, because they require uninterrupted sunshine. There are cases in which trees removal has taken place over a relatively large area for the installation of solar panels. Where possible, it is necessary to minimize this, as the conservation of trees is important. An alternative is to install floating solar PV panels on lagoons, close to the shore. However, very few clusters of islands are situated on particular reefs. According to estimates, the electricity generation costs are below the diesel generation costs but higher than the costs of rooftop systems (Journeay-Kaler and Taibi 2015). The Ministry of Environment and Energy estimated that, by utilizing the rooftop space of individual households and public buildings, the country could fulfill as much as 30 to 80% of the electricity demand on islands (World Bank 2015).

In the case of some resorts, there are a few successful examples of solar PV installation and storage. In peak loads, some of the resorts can shut down their generator. For efficient use of solar PV, storage batteries are necessary and require further investment. However, caution is essential regarding the disposal of lithium–ion batteries after their lifetime. In the case of lead–acid batteries, their lifespan is even shorter. As there is no facility to dispose of batteries, it is necessary to send them abroad for proper disposal. However, this would lead to further issues, as there are regulations in other countries on accepting hazardous waste for disposal.

The Climate Trust Fund project installed a solar PV diesel hybrid project with a capacity of 558 kWp on Thinadhoo island as a pilot program, which the European Union and Australian Aid funded. The project involved the installation of rooftop solar PV on a range of public buildings in addition to the powerhouse. This project helped the island to generate about 50% of its electricity through solar PV during the daytime. Demonstration projects in Thinadhoo and Ukulhas contributed to building the confidence of the key stakeholders of the Maldives in the applicability of island grids.

However, a fire in 2016 destroyed half of the solar panels installed on the roof of the powerhouse in Thinadhoo. The remaining solar PV panels are not in regular use because of certain technical issues that have not received attention for a long time. According to a key informant, there is a lack of technical expertise, as some of those who had received trained left their jobs and the regular monitoring of the technical issues was inconsistent. As a result, only diesel generators currently generate electricity on the island. Therefore, the case of Thinadhoo offers important lessons on developing renewable energy as well as emphasizing the precautionary aspect for energy insecurity in disaster management. Another lesson learned from these projects is the lack of availability of qualified and trained Maldivians on most islands. The utility companies have also faced challenges in maintaining trained staff on rural islands, as many of them move to work in resorts where the pay is higher. To improve the energy security situation sustainably, there is a need to enhance the human resource capacity and provide continuous training as a programmed approach. This is crucial as more islands are joining and more projects are installing solar PV hybrid systems. Without development of the human resource capacity, the Maldives will continue to depend on foreign sources for technical capacity as well as technologies with a high cost of dependence (Cole and Banks 2017). The Maldives Energy Authority divides power engineering licenses into five categories.

Table 6: Power Engineering Licensees

Categories	2003	2018
A. General House Wiring	47	311
B. Control Logic Design and Installation	4	17
C. 400V Distribution Switchboard Design and Installation	4	10
D. Installation of Generating Units Less than 1 MW	4	8
E. Design and Installation of 400 V Distribution Networks	4	10
F. Design and Installation of MV Systems, Installation of Power Transformers	0	2
G. Installation of Generating Units of Capacity 1 MW or more	0	2

Source: Author's calculation based on MEE power engineering licensee lists (1997–2019); Maldives Energy Authority (MEA) (2019).

As Table 6 illustrates, in 2003, a year before the tsunami devastated a large portion of the electricity infrastructure, there were only four licensees issued for the design and installation of distribution networks, and by 2018 the number of licenses issued had only increased to 10. Moreover, it is notable that there were no female licensees in 2018, though there was one female licensee in 2003. For the design and installation of power transformers and the installation of generating units of capacity of 1 MW or more, there were only two registered personnel. This implies that the emphasis on the technical skills that the Maldives's economy needs is low, including the encouragement of women to participate in the power-generating sector and expertise on renewable energy as new categories.

Other experiences learned from the Thinadhoo project indicate that the intermittency of solar energy poses limits on the grid's ability to absorb and rely on the electricity that such sources generate and that the peak load time of the island was not during the daytime, as expected. The peak times vary on different islands of the Maldives, and, in the case of Thinadhoo, the peak load time was at 20:30, as Table 7 shows. As Blum, Wakeling, and Schmidt (2013) noted, a crucial factor concerning the use of an intermittent power generation source such as solar PV is its dependence on battery storage. However, there was no battery bank in Thinadhoo.

Table 7: Peak Times

Island	Atoll	Peak Time
Thinadhoo	Gaaf Dhaal	20:30
Ukulhas	Alif	12:30
Hulhumeedhoo and Meedhoo	Seenu	21:00
Maafushi	Kaafu	19:00

Source: MEE (2018a).

It is necessary to supply electricity generated from renewable energy to consumers instantly. If the generated output is greater than the electrical load, then it must use distributed electric energy storage. It can supply electricity when the generated output is insufficient or in an emergency. However, as there are technical constraints on storing huge amounts of electricity, one solution could be to produce desalinated water (Liu et al. 2017). Groundwater has increasingly become salinized on many islands in the Maldives, and a desalination system is crucial.

With the development of guesthouse tourism, the issue is becoming critical for islands. In the past, even if the water was salty, many Maldivian families continued to use groundwater for bathing and depended on fresh rainwater for potable use and only minimal water for showers. To maintain island water security, desalination plants supply fresh water. A demonstration project in Ukulhas employed roof-top rainwater harvesting along with desalination of the groundwater using solar energy. The use of solar energy for pumping and other processes is a special feature of this scheme, as it meets the objective of harnessing renewable sources of energy, thereby avoiding carbon dioxide (CO_2)-emitting options.

One of the positive externalities of these demonstration projects is private parties' installations of solar PV, as the project has showcased the benefits of solar PV. For instance, several small businesses, such as restaurants and guesthouses, have begun to install rooftop solar PV in Thinadhoo and Ukulhas. In Nellaidhoo, a nongovernment organization (NGO) facilitated the installation of a solar PV system at a mosque as a way of reducing the increasing expenditure on electricity as a result of air conditioning. After installing solar PV, the electricity bills fell significantly (Fareeha 2019). This resulted in the reduction of expenses that the government would otherwise have incurred, as the government funds the utility charges of mosques. The government should encourage co-production by civil society groups following these examples.

Other initiatives include a joint credit mechanism program that the Japanese government facilitated; it is a Japanese initiative aiming to facilitate the diffusion of climate-friendly technology to developing countries. An advantage of participating in the JCM is that the monitoring and assurances of technical experts help to ascertain that the implementation of projects is appropriate and standard. This project installed a 186 kW grid-connected rooftop solar PV system on the roofs of Villa College, which is one of the private educational institutes. Through this project, Villa College was able to reduce its electricity expenses by 42% by taking advantage of the opportunity for net metering. The structure of the JCM process requires project completion before it confirms a financial incentive or a grant. There are very limited opportunities in the Maldives to finance such projects through bank loans. The collateral on these loans makes it impossible for small businesses to undertake such projects relating to renewable energy (Manik 2019). Currently the Bank of Maldives has a green loan scheme, but this is not attractive to small firms or the household sector, because the interest rates are staggeringly high. Therefore, alternative financing schemes are essential. The government could introduce an alternative special revolving trust fund or subsidies to facilitate installation.

6. CONCLUSION

Energy insecurity related to fossil fuel availability, prices, and emissions will continue to exist for a long period, as diesel-based power systems continue to function in the Maldives. As Surroop et al. (2018) suggested, a committed and forward-looking government is the key to driving the improvement of energy security. Moreover, a long-term commitment to resource efficiency is a critical component to overcome economic, financial, technical, institutional, and social challenges.

Energy insecurity also arises due to disasters related to weather as well as from manmade incidents, such as fires. To sustain the infrastructure in a usable manner, safety precautions regarding natural and manmade disasters are necessary, especially when climate change risks are exacerbating. As Ang, Choong, and Ng (2015) indicated, good infrastructure is a prerequisite for stable energy supplies and a significant factor of energy security. Adequate investments in these facilities are vital to ensure that sufficient energy is available in the short and long terms.

On the demand side, air conditioning is one category that consumes a large portion of energy costs. Many consumers do not know how to interpret labels and identify energy-efficient appliances and are unaware of the costs and benefits of such appliances. Increasing awareness can increase energy conservation. The customs statistics on imports do not differentiate energy-efficient appliances, and this needs due consideration. These data are important, as renewable energy installation continues to increase and it is necessary to utilize energy more efficiently.

On the supply side of electricity generation, the powerhouses need to plan the procurement of fuel supplies in advance, as this could minimize the cost burden incurred in fuel purchases. Instead of depending on the government for subsidies, they must increase their efficiency and identify areas in which they can reduce costs. As the Maldives consists of many islands, it is necessary to build the energy infrastructure separately on the islands on a small scale, and this increases the costs. Therefore, efficiency in resource usage is important. Measures are necessary to improve efficiency and secureness. The policy must include a clear focus on measures to increase efficiency, particularly in the production and distribution, as it is lacking in the Energy Policy and Strategy of 2016, executed currently.

One of the lessons learned in the implementation of renewable energy projects in the Maldives is the importance of monitoring the usability and appropriateness of renewable energy. Regular monitoring can help to identify technical faults and areas in which technical expertise is lacking. In addition, monitoring of projects would help sustainability even after the end of their funding period. The publication of data and case studies will enable communities and professionals to learn from experiences, both negative and positive. This is important, as small-scale projects enable the testing of new technologies and communities are able to become familiar with them. As Kohli and Braud (2016) agreed, small-scale pilot projects can reduce the technology risk and build confidence among stakeholders in renewable energy development in developing countries.

The prospect of installing more solar PV hybrid systems in the future is high. The Maldives will be able to learn through experiences or through a learning curve approach about more effective and efficient ways of installing renewable energy and thus reducing energy insecurity related to fossil fuels. Research is important in the Maldives to learn from experiences and to conduct experimentation on the newer available technologies in use in other SIDS. It is noteworthy that initiatives that the government has undertaken have inspired civil society and the private sector to implement renewable energy projects. The examples from Nellaidhoo, where a civil society group installed solar PV on a mosque roof to reduce the electricity expenditure of the government, and Villa College, which implemented a project that the Japanese Joint Crediting Mechanism considered for carbon credit, offer critical learning opportunities. These are examples of co-production and net metering that countries elsewhere can replicate. Net metering allows owners of grid-connected renewable electricity systems to receive credit for the electricity that they input to the grid, and thus the meter offsets the electricity consumed from the grid (Blazek 2011; Jacobs and Sovacool 2012).

The study identifies the challenges of raising finance as a major obstacle. This requires attention at the policy level to determine how financial institutes could introduce innovative and convenient models for promoting energy efficiency and renewable energy. Alternatively, a revolving trust fund could finance renewable energy projects sustainably. The Maldives is currently establishing a Green Fund and is embarking on using it.

The article falls short of analyzing the challenge of human resource capacity adequately. It is a major challenge and, to be resilient to energy insecurity, the sector requires detailed analysis and actions. The article recommends further studies on human resource capacities in SIDS in relation to improving energy security and on how countries and academic institutes could cooperate on sustainable development, especially to leap into an energy-secure future through transformative thinking.

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