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Technological Innovation System for Energy Transition in Small Island Developing States: Adaptive Capacity, Market Formation and Policy Direction in the Maldives

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Abstract By analyzing the adaptive capacity, market formation and policy direction as functional areas of Technological Innovation System (TIS), the article evaluates the progress of renewable energy transition in the Maldives, with the inclusion of ideas from Mauritius and Cabo Verde. On the policy direction in the Maldives, technology roadmaps produced with assistance from International Renewable Energy Agency (IRENA) and Asian Development Bank (ADB) are evaluated. Although there are inducing factors such as the Solar Risk Management Initiative, the progress of energy transition is hindered by the lack of technical capacity and local value chain. The findings indicate the importance of facilitating and establishing industry and knowledge networks, incorporating innovation policies, greater involvement of the local private sector along with international investors, and taking water-energy nexus to achieve complementary targets. The study adds value to knowledge by offering a simplified TIS framework, with a current insight of the energy transition in Small Island Developing States with a focus on the Maldives.

Keywords Renewable Energy, Technological Innovation System, Small Island Developing States

I. Introduction

Achieving the 17 Sustainable Development Goals (SDGs) requires technological transformations, and policy-makers are confronting the challenge of restructuring energy systems into more sustainable forms (Kern & Smith, 2008). However, limited information is available on the characteristics and factors that affect sustainable energy transitions in developing countries, including specific Small Island Developing States (SIDS) that are dependent on

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the importation of technologies. The available few studies on SIDS have focused collectively on the Pacific and Caribbean, resulting in a lack of thorough understanding of the particularities of SIDS from the Atlantic, Indian Ocean and South China Sea (AIS) region. In this research, the situation of the Maldives is discussed, and ideas from Mauritius and Cabo Verde are utilized.

The Maldives is one of the few SIDS that have been able to provide 24-hour electricity access to 100% of the population. However, there are challenges in the energy transition to renewable energy as the Maldives does not have a diversity of resources such as hydroelectricity or strong wind patterns. Seizing energy transition opportunities through increased investments in renewables can contribute to post-COVID-19 economic recovery (Florian & Yoong, 2020).

The sections below provide an introduction to the Technological Innovation System by focusing on the adaptive capacity, market formation and policy direction. It is followed by an assessment of the experience of the Maldives and providing good examples from Mauritius and Cabo Verde on areas for improvement as a way for peer learning and action amongst SIDS. The findings of the article are relevant globally as there are common objectives for the transition to renewable energy around the world. The article adds value to the literature by offering a simplified framework for Technological Innovation System, and an insight into the progress of energy transition in SIDS, with a focus on the Maldives.

II. Technological Innovation System in SIDS

Islands and remote communities represent a niche market for the application of renewable energy technologies and are very important for promoting renewable energy worldwide (Nayar, 2010). Improvement and innovation require that new products meet market needs by learning from past experiences (Kline & Rosenberg, 2010). The dynamics of a technological system are considered a consequence of the interactive functions that lead to innovation (Johnson & Jacobsson, 2000: 625). The functional approach of the Technological Innovation System (TIS) can generate essential lessons concerning inducing, hindering and prospective factors for sustainable energy development (Edsand, 2019; Hekkert et al., 2007).

Over the last two decades, several authors have tested, adopted, and further developed TIS approaches, resulting in numerous lists of system functions. Most functions were developed and applied for developed country contexts (Johnson & Johnson, 2001; Hekkert et al., 2007). There is a lack of discussion on the conditions for technology adoption in SIDS (Sawulski et al., 2019). One of the first studies on TIS on SIDS was about the Maldives by Van Alphen et al. (2008), which proposed the need to include adaptive capacity for developing countries dependent on imported technologies.

In order to derive an analytical framework that is suitable for reviewing and analyzing the progress of renewable energy in the Maldives, a combination of the approaches of Bergek & Jacobsson (2003, 11), Hekkert et al. (2007, 426), Van Alphen et al. (2008, 166-167), International Renewable Energy Agency (IRENA) (2014, 4), and Asian Development Bank (ADB) (2020, 17) is conceptualized. Due to the interactive nature of the functions, the model is simplified to three functions: adaptive capacity, market formation, and policy direction (table 1).

Table 1. Technological Innovation System

	Bergek, & Jacobsson, (2003)	Hekkert et al. (2007)	Van Alphen, et al. (2008)	IRENA (2014)	ADB (2020)	Proposed conceptual elements
Creating adaptive capacity			✓			Adaptive capacity
Knowledge Diffusion	✓	✓	✓			
Knowledge Development		✓			✓	
Technical planning				✓		
Positive externalities	✓					
Market formation	✓	✓		✓	✓	Market formation
Demand articulation			✓			
Entrepreneurial activities and experimentation		✓	✓			
Resource mobilization	✓		✓			
Guidance of the search/ policy direction	✓	✓		✓	✓	Policy direction
Creation of legitimacy/ counteract resistance		✓	✓			

Developing countries often import ready-to-use and mature technologies from developed countries, and with experience, it is possible to incorporate adaptation based on the local environment. Adaptive expertise requires field-specific and place-specific knowledge for innovation (Ramakumar et al., 1992). Regional energy planning and adaptation approaches can help identify issues that have not been focused in national-level plans and orient goals suitable for localities (Shah et al., 2020). Economic opportunities increasingly depend on the flow of knowledge in specific regions (Zhao, 2011). Knowledge is one of the important factors that impact on the formation of new firms. As per the knowledge spillover theory of entrepreneurship, new environmental knowledge is a significant source for new investments in renewable energy technologies (Cojoinanu et al., 2020).

Markets for renewable energy are formed as a result of demand-pull and supply-push factors (Bento & Fontes, 2015). On the demand side, information gaps on renewable energy technologies increase barriers to adoption (Masini, 2013). On the supply side, the processes of a market formation may be affected by the efforts of the firms and by government policies, as well as international donors (Van Alphen et al., 2008). Entrepreneurial activities in an economy can further drive the adoption and development of renewable energy, including the growth of local value chains and collaborations (Azwar, 2019; Hoggett, 2014). However, for individual organizations, investing in renewable energy may be challenging due to high transaction costs and uncertainty (Painuly, 2001). These barriers can be reduced through market facilitation and stakeholder networking (Chen et al., 2005). As stated by Van Alphen et al. (2008), efforts are needed to establish a domestic market and create employment opportunities in the renewable energy sector in the Maldives. With regard to the water heater industry in Barbados, Rogers (2016) indicates the need for government support for technologies, with incentives and long-term commitment.

Government intervention is needed as markets do not always work in favor of new technologies (Ayoub & Yuji, 2012). The existence of an official renewable energy target and emphasis on renewable energy in the National Development Plans (NDP) can demonstrate the political will of the government to deploy renewable energy (Keeley, 2017). As a complementary tool to support NDPs, technology roadmapping is a growing technique widely used for strategic planning and aligning technology with overall business objectives for market development, product, and technology integration (Amer & Daim, 2010). It is used by both government and industry to identify and prioritize key technology areas, establish clear targets and coordinate the efforts of different stakeholders (Yasunaga et al., 2009).

Targets can be exclusive to specific technologies and sectors to match resource availability and peak demand. Targets can vary from a single technology or sector to an economy-wide focus (IRENA et al., 2018). Alternatively, targets can be made exclusively for markets (Sovacool, 2013). A domestic market can help achieve technology transfer to develop sustainable markets (Van Alphen et al., 2008). In planning, policymakers can also have targets for technologies targeted at particular regions, in addition to national targets (Couture & Leidreiter, 2014). This can help minimize the urban and rural divide in infrastructure for sustainable energy development. In doing so, institutional structures targeted at rural areas can be designed. This can be related to demand analysis and cost estimates for investments in such regions. Targets can also be made towards employment and training needs (MEPU, 2019).

III. Methodology

To analyze the adaptive capacity, market formation and policy direction on renewable energy in the Maldives, 54 semi-structured interviews were conducted. These include representatives from the Ministry of Environment[1]; the Ministry of Economic Development; academia; utilities; regulatory agencies; local councils; and Non-Governmental Organizations (NGOs) in the Maldives. Further, to understand policies in other SIDS, interviews were done with representatives from ADB, the Mauritius Renewable Energy Agency (MARENA) and the Cabo Verde Ministério da Indústria, Comércio e Energia (MICE) (or Ministry of Industry, Trade and Energy).

The review on TIS in section II provides key points on adaptive capacity, market formation, and policy direction. The collected data from the interviews are analyzed in relation to key points from the literature with a recognition that the functions of a TIS framework have inter-linkage, as presented in Figure 1. Therefore, important factors are included when analyzing the separate functions in the discussion section.

1 Ministry of Environment, Climate Change and Technology (2018 onwards)

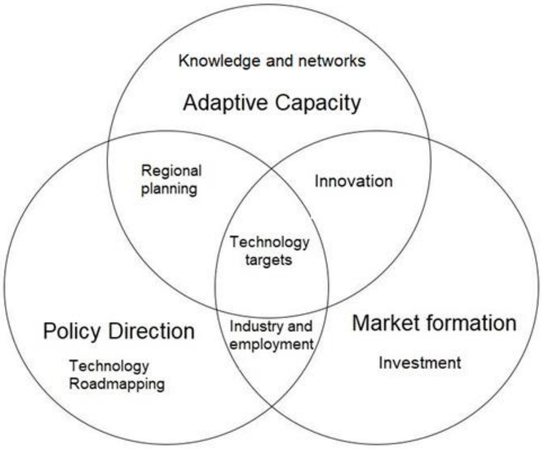

Figure 1. Conceptual diagram with functional interlinks of Technological Innovation System
Source: The author

IV. Discussion

In this section, the situation of renewable energy transition in the Maldives is analyzed by drawing upon examples from Mauritius and Cabo Verde. These two countries, have demonstrated successful experiences in the progress of the renewable energy transition. Similar to the Maldives, Mauritius has achieved electricity coverage for 100% of the population, and Cabo Verde has set a goal to reach this target by 2023. As with many SIDS located in tropical and equatorial regions, these three countries possess a significant potential for enhancing the use of solar photovoltaic (PV) technologies (Nordman et al., 2019). The discussion in this section centers on adaptive capacity, market formation, and policy direction as key considerations in the context of the TIS for renewable energy.

1. Adaptive Capacity

One of the hindering factors for renewable energy deployment is the limited capacity of SIDS in terms of knowledge. For developing adaptive capacity in the Maldives, strengthening human and institutional capacity is needed for innovative and efficient ways for energy transitions (Van Alphen et al., 2008). Many technical experts continue to be brought in from outside the country (ADB, 2011). For professional work, dependence on international consultants to support project implementation has mainly resulted in capacity substitution.

Although it is an opportunity for short-term needs, it is a hindrance that there is a lack of emphasis on investment on human resources and sustaining capacity in local institutions for long-term sustainability. Among the respondents that were interviewed, 71% of them consider the importance of building technical capacity for the development of renewable energy in the Maldives. A respondent from Fenaka utility mentions that “although solar PV for electricity and reverse osmosis (RO) plants for water projects are implemented, local experts in the two areas are limited.”

Both solar PV and reverse osmosis (RO) for water have linkages, as RO plants are being implemented with solar PV used for water production. However, there have been limited local training opportunities in a continuous manner. While the Maldives National University has no course on renewable energy, only a certificate course on renewable energy is available at the Maldives Polytechnic.

Figure 2 shows a scatter plot of renewable energy capacity (watts) per capita (ESMAP, 2021) and the Technology Readiness Index (TRI) (UNCTAD, 2022). It considers technological capacities related to physical investment; human capital and technological effort; and capacities to utilize, adopt and adapt technologies. There is a trend that higher TRI values are associated with higher renewable energy capacity. When compared, the Maldives appears to be weaker.

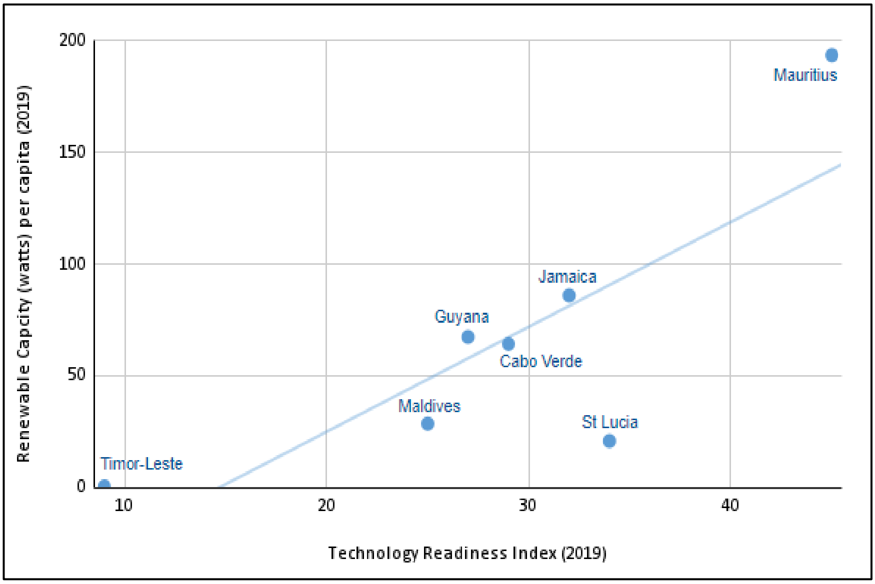

Figure 2. Renewable Energy Capacity per capita and Technology Readiness
Source: The author, based on data from ESMAP (2021) and UNCTAD (2022)

Compared to the Maldives, an aspect of Cabo Verde's relative success can be attributed to the awareness-raising efforts of the government and the reinforcement provided by local media coverage of renewable energy development in the country. This helped in forming public support for renewable energy in Cabo Verde and a broader awareness of the issues related to high dependency on fossil fuel imports (Couture and Leidreiter, 2014). Cabo Verde also has support facilities such as the Center for Training and Certification, Clean Energy Business Incubator, Clean Energy and Energy Efficiency Technology Park (Costa, 2015) and Centro de Energías Renováveis e Manutenção Industrial (CERMI) (or The Centre for Renewable Energy and Industrial Maintenance of Cabo Verde). These facilities help to make networks of experts in Cabo Verde and the neighboring West African countries. For example, with the assistance of LuxAid from Luxembourg, networking and training have been organized by CERMI for renewable energy practitioners from West Africa. This gives CERMI an opportunity to develop experience and enhance human resource capacity.

Mauritius has a relatively higher level of TRI and renewable energy capacity per capita among the SIDS. One of the reasons for this is the emphasis on innovation. In Mauritius, the National Innovation Framework (2018-2030) was introduced to facilitate innovation by encouraging efforts between the industry and academia. An open data policy was formulated, and an open data portal was set up to encourage data-driven initiatives in research and business (Dkan, 2021). In recent years, Mauritius has set aside a national innovation fund of about 125 million to 150 million Mauritian Rupees annually (Madhou et al., 2022). A funding scheme is also set up in the name of the National Scheme for Emerging and Innovation Renewable Energy Technologies to encourage local companies to partner with international partners to carry out collaborative projects (MRIC, 2021). As one of the respondents from the utility sector indicates, "the growth of renewable energy is hindered by lack of collaboration and research and development."

Between 2000 and 2022, there were 49 research papers[2] published on renewable energy in the Maldives. Most of the papers were published by academia outside of the Maldives. Only 19% of the papers have involvement with an institute in the Maldives, while 23% of the papers have Maldivians as one of the authors. Only 14% of the papers have collaborations with Maldivian and international researchers. Research published by institutes from only Italy, New Zealand, Finland, the Netherlands, France, Sweden, India and South Korea have involvement of Maldivians as authors. None of the papers have a Maldivian as a co-author together with an author from another SIDS. However,

2 From accessible papers published in English, based on searches on Google Scholar and Sciencedirect.

in various research papers on renewable energy that include the Maldives, authors from 32 other countries have been involved between 2006 and 2022, including Mauritius and Singapore as SIDS.

Most of the research is based on solar PV (figure 3). Technical feasibility is the focus of most of the research. However, there are very few studies on post-project evaluations and on resource assessments (see table 2). According to Azwar (2019), a lack of understanding about the economic feasibility of renewable energy technologies (RETs) in the Maldives, including investment requirements and payback periods, is a barrier to the adoption of renewable energy.

Although, as part of projects implemented by the Ministry of Environment, external consultants have collected baseline data on different regions of the Maldives, only a limited amount of data have been published or are available at the Ministry of Environment. According to a private sector professional, "both local and international networking and collaboration opportunities are lacking, and it hinders sharing data, improvement of technical capacity and renewable energy growth."

Currently, there is no association or network for renewable energy in the Maldives, or for SIDS in the Indian Ocean, unlike in the Pacific and Caribbean. One of the good models from SIDS is the Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE). Another good example is the Caribbean Renewable Energy Community (CAREC).

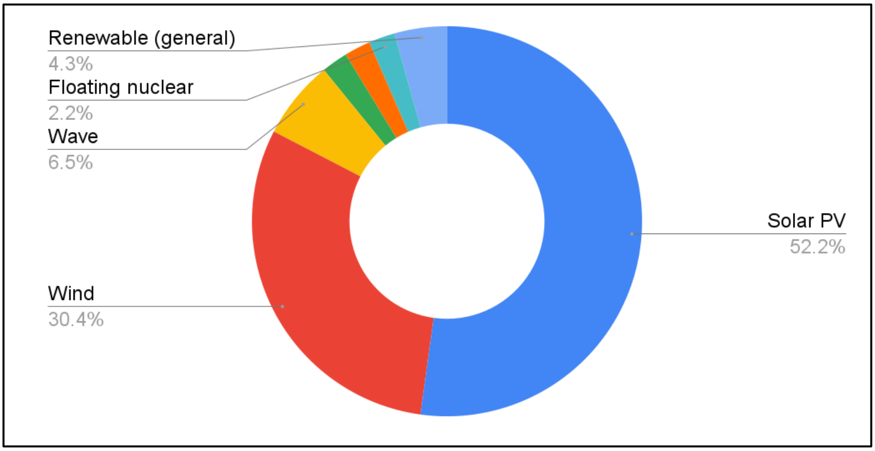

Figure 3. Types of technologies focused on research

Source: The author, based on the survey of publications.

Table 2. Focus of the studies

Area	Number of papers
Technical feasibility	18
Socio economic	6
Techno economic	6
Resource assessment	4
Technical review	3
Policy	2
Technical evaluation	2
Trade	2
Innovation system	1

Source: The author, based on the survey of publications.

2. Market Formation

Although financing is a crucial factor for renewable energy development, getting finance is one of the challenges for smaller local companies and thus hinders investment and renewable energy growth. According to a banking expert, "getting finance for small businesses for renewable energy is not easy, and there is a lack of awareness in the banking sector on the technicalities of renewable energy."

In 2016, the Bank of Maldives (BML) launched the "BML Green Loan," a concessional loan scheme to finance environmental technologies such as solar PV systems for power generation or energy-efficient equipment and appliances. Customers could borrow between 50,000 and 20 million Maldivian Rufiyaa (MVR), for a maximum tenure of 20 years, with the condition that collateral had to be kept, such as a vessel, property, land, or other assets (Waheed, 2016). In 2020, BML announced changes to the scheme for customers to borrow between MVR50,000 and MVR500,000 without a collateral for a five-year tenure. However, the interest rate continues to be high at 12% (AbdulHadi, 2020; BML, 2020). In contrast, in Mauritius, 5% interest is charged in the "Green Loan" scheme for climate change mitigation projects, while 2% interest is charged in the "Lokal is Beautiful" scheme for digital and smart island projects (PAGE, 2021: 41-42).

Figure 4 shows a scatter plot of the renewable energy capacity (watts) per capita (ESMAP, 2021) with domestic credit to the private sector as a percentage of GDP (World Bank, 2022a) in some of the SIDS. It shows that Mauritius and Cabo Verde have higher amounts of credit to the private sector. The Maldives, St Kitts and Nevis, Jamaica and Antigua and Barbuda have similar amounts in credit as a percentage of the GDP. However, renewable energy capacity of the Maldives is lower than these three countries. It is also likely that the firms in the renewable energy industry themselves have difficulties in getting credit. In Cabo Verde, training has been aimed to inform professionals in the banking sector and encourage them to explore new financing products for the energy market (Vaz, 2020).

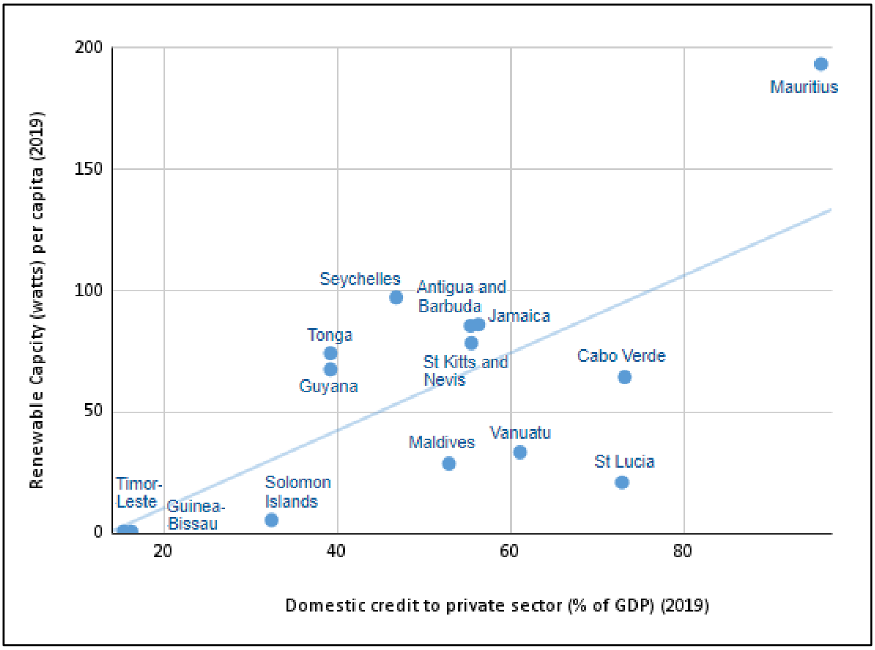

Figure 4. Renewable Energy Capacity per capita and Domestic Credit to Private Sector
Source: The author, based on data from ESMAP (2021) and World Bank (2022a)

Encouraging private sector joint ventures can be considered as one possible solution to address the lack of domestic credit facilities by bringing in private investment and financing to support development projects. One of the successful international investments in the Maldives is from Swimsol, which is an organization that was formed by an Austrian and Maldivian partnership. In 2014, Swimsol launched the world's first floating solar solution for the sea called SolarSea. With this innovation, the company has successfully installed the technology in the Maldives, Indonesia, Chile, and a demonstration project is planned for Seychelles. In the Maldives, the tourism industry has been particularly receptive of technology.

To overcome the lack of domestic credit facilities in the Maldives, attracting investment through public-private partnerships is an alternative approach. One strategy for achieving this is to encourage private sector involvement through power purchase agreements. Private sector investors would be using their funds to develop the infrastructure needed for these projects and then produce energy. The advantage of this method is that the government will not have to spend on infrastructure. A disadvantage is that the payments will be outflows from the foreign currency reserves. However, the amount of outflows are expected to be lower in currency conversion compared to outflows due to spending on oil imports, and there is no certainty on the costs due to fluctuations in oil prices in the world market.

A model followed in the Maldives to reduce financial risks for international investors is the Solar Risk Mitigation Initiative (SRMI). It was launched in 2018 by the World Bank's Energy Sector Management Assistance Program (ESMAP), the Agence Française de Développement (AFD) (the French Development Agency), IRENA, and the International Solar Alliance (ISA) at the 24th Conference of the Parties to the (UNFCCC) (COP24). SRMI is an integrated way that leverages private sector investments, bilateral and multilateral development finance, and concessional climate finance for solar deployment, designed to induce renewable energy investments by reducing risks of reliance on public finances (World Bank, 2019). SRMI provides guarantees to cover risks of termination of PPAs; a payment security mechanism through an established escrow account to cover PPA payment delays; a tariff buydown mechanism to decrease the capital cost of solar PV; and a clause that allows currency convertibility to reduce the foreign exchange risk by allowing the private sector to bid in US dollars.

Implementation of SRMI in the Maldives is the first initiation in South Asia to extend a series of World Bank guarantees to small solar PV installations. Its success will have a demonstrative impact on other developing countries. According to Amit Jain, the team leader of the World Bank projects in the Maldives, the bankability of renewable energy projects is crucial to unlocking private sector investment, and the reduction of risks by SRMI was significant for attracting investment starting from an 11MW renewable energy project in 2022 (World Bank, 2022b). With this experience, it is possible to have standard documents, and it can facilitate multiple transactions and contribute to reducing transaction costs (World Bank, 2014).

Another approach is to provide relevant information on the site characteristics. According to the Ministry of Environment, if adequate information is not provided, it becomes a risk for investors, and higher risks are translated into higher tariff rates. Providing updated and relevant information is necessary for bankable projects. Therefore, the Ministry of Environment of the Maldives does assessments on potential locations to provide more information on renewable energy resources.

In addition, calls for proposals are advertised for clusters of islands bundled together. The clustering of islands is an approach that was used in the Maldives in the 1990s for poverty alleviation programs to provide more equitable development by focusing on regions (ADB, 2002). According to a representative from ADB, "targeting clusters of communities in projects is a good concept in Maldives that ADB has applied in designing projects in some other countries." In the Maldives, clustering of islands is now used in renewable energy projects as it can also help in reducing transaction costs. As an official from the Ministry of Environment mentions, "if projects are tendered separately for each location, there is a disadvantage due to small-scale of operation. On the other hand, regional cluster projects can be more attractive for developers, suppliers and financiers." Therefore, the provision of site-specific information and clustering of islands in particular regions both help to reduce transaction costs.

Moreover, import duties were waived to induce renewable energy investments as early as 2011. However, the duty exemptions specifically for renewable energy comprised only 0.6% of the total duty exemptions in 2019 (MoF, 2021). On the other hand, the companies still incur Goods and Service Tax (GST) for the purchase of renewable energy equipment in the Maldives. In this case, costs get increased in the supply chain and increases the cost for the final consumer. In Mauritius, a complete tax exemption applicable to renewable energy equipment has been introduced (IRENA, 2014). An alternative is a phased approach as done by Cabo Verde where there is a complete tax exemption for the initial five years of each renewable energy project's operational life, with a 50% reduction offered for the following five years, and subsidies to encourage banking institutions to open up new banking products for the renewable energy projection sector (Couture & Leidreiter, 2014; Vaz, 2020).

In the Maldives, the few companies operating in the renewable energy sector may find it hard to compete with international companies. However, there are also examples of smaller local companies that operate in the solar industry by finding niches. If fiscal incentives are provided, it can help smaller companies grow in the Maldives. For example, Avi technologies have targeted the household sector for rooftop solar PV. This is done by using the finance program of the Maldives Finance Leasing Company and Maldives Islamic Bank (MIB). According to them, by installing solar PV on the roofs of households and by using net metering, it is possible for customers to reduce costs by 100%, and the cost can be spread up to three years for payment. In the case of financing from Maldives Islamic Bank, instead of interest rates[3] for financing, a concept called

3 According to Islamic teachings, riba or interest is forbidden, and thus, many people in Muslim societies avoid earning income from interest, or take loans that require paying interest (Musthaq & Siddiqui, 2016).

Murabaha is used, in which both the cost price and profit are disclosed and agreed by both parties. The bank purchases the desired goods from a third party and sells to the customer on a deferred payment basis. Using this facility, a renewable energy community cooperative was formed in Addu by targeting the sale of spare parts of renewable energy equipment.

In order to promote local youth investors, entrepreneurship and innovation, the Ministry of Economic Development (MED) has a scheme for the development of entrepreneurs called "GetSet". According to MED, the proposals from youth that were interested in technological investments were limited. However, this could be a reflection of the way the scheme is designed. One of the things that are evaluated is the profitability of investment in a short term. Another reason is that the youth or the applicants are not familiar with renewable energy technologies, and thus limits relevant, innovative entrepreneurship activities. In Mauritius, various training programs have been held by segmenting different groups. For example, activities have been organized for women to increase awareness on shifting to renewable energy sources, with particular emphasis on solar energy. Additionally, training sessions on the installation, operation and maintenance of solar PV systems have been held to empower women to understand how they can utilize renewable energy technologies in potential businesses.

3. Policy Direction

The Maldives has a technology roadmap for the energy sector that was produced with the help of IRENA in 2015. A new road map for the energy sector was produced by ADB in 2020. In the new roadmap for 2020-2030 (2020), the base case scenario is proposed with a steady and moderate shift in the national electricity sector to increase the share of renewable energy by 21% by 20230. It also proposes a paradigm shift scenario with a business-oriented model targeted to increase the share of renewable energy by 44% for the electricity sector by 2020 (ADB, 2020).

There have been no published evaluation or progress reports on the achievements on the roadmaps in the Maldives. The roadmap (2020) did not make any reference to the previous roadmap. In Mauritius, rather than making a new roadmap, the approach was to review the roadmap to align with the government's agenda to phase out the use of coal and to achieve 60% of energy needs from renewable energy sources by 2030 (PU, 2022; MEPU, 2022).

In the Maldives, in the initial roadmap (2015), there were no targets for regions and no targets for industries. However, according to the new roadmap (2020), there is a target to increase renewable energy by 38% in Malé region (the capital and nearby islands), 48% in other islands, and 50% in resorts and industrial islands. Technologies have been indicated as solar PV over bridges and rooftops, floating solar PV, onshore wind, micro rooftop wind, waste-to-energy, and ocean energy. However, no consideration was given to identifying strengths and weaknesses of how particular regions can potentially benefit from specific technologies. For example, all inhabited islands except Malé are taken as a broad category, although there are differences in the renewable energy resources available in different regions and in every island on sizes and other features. One solution can be for the government to identify special development zones in collaboration with local stakeholders where projects could be located.

In the case of Cabo Verde, there is no formal renewable energy roadmap (Nordman et al., 2019). However, targets are established for generation (GWh) and capacity (MW) for each renewable energy technology, by site, for every island. In addition, cost estimates have been produced for the growth in demand, the current and future costs of renewable technologies, and the future costs of imported fuels (Couture & Leidreiter, 2014).

In the Maldives, the roadmap (2020) does recommend arranging training opportunities on electricity pricing mechanisms, power purchase agreements, and particularly on innovative auctioning systems to facilitate further involvement of the private sector (ADB, 2020: 71). However, both roadmaps (2015 and 2020) have no targets for increasing employment opportunities. Having targets for employment can help in planning technical capacity for different types of renewable energy. If employment targets are linked together with planning for technologies for specific regions, then training can be targeted to communities accordingly. In Mauritius, the roadmap includes targets for an estimated number of additional jobs, targeted for years and technologies (solar PV, wind and biomass). The target in Mauritius is to increase employment by 40% by 2030, compared to the level of 2018 (MEPU, 2019).

As a long-term arrangement to incorporate the private sector into the electricity sector, power purchase agreements have been established to a limited extent in the Maldives. Since 2012 there has been a reduction in the bid costs from USD 0.25 to USD 0.09 per kWh between 2015 and 2022 for solar PV projects (table 3). Power generation from diesel generators costs USD 0.30 per kWh at the lowest, and costs go up to USD 0.70 per kWh in some islands (MEE, 2013). Therefore, there is evidence that electricity costs could be reduced through the use of renewable energy.

Table 3. Rates per kWh in Power Purchase Agreements

Company	Capacity	Year	Rate
Renewable Energy Maldives	0.652 MW in 6 islands Kaashidhoo, Thulusdhoo, Himmafushi, Guraidhoo, Maafushi	2012	USD 0.25 per kWh
China Machinery Engineering Corporation (CMEC) and Grass Solartek Schweiz SA of Switzerland	1.5MW Hulhumale	2015	USD 0.21 per kWh
Ensys Thailand	5 MW Between Hulhule and Hulhumale	2020	USD 0.109 per kWh
Mega First Power Industries, Malaysia and Power China Huadong Engineering Corporation, China.	11 MW in 6 islands	2022	USD 0.098 per kWh

Source: MFR (2022), Zahir (2014), Rehan (2022) Mi (2015)

The largest PPA contract was signed in March 2022 with a Malaysian and Chinese joint venture to establish solar energy systems in islands in six different regions in the Maldives. The bid of USD 0.098 for this project is the lowest bid in the Maldives for a PPA by 2022. In the project islands, plans are in place to upgrade power grids and install battery energy storage systems by 2023. According to an official from the Ministry of Environment, the low bid is likely due to lower solar costs, the proposed security package, the project design, and the use of the tariff buydown. According to the World Bank (2022b), SRMI increases investor confidence. Thus, it is an inducing factor as the Maldives can attract international investors. However, in large PPA agreements signed between 2020 and 2022, no Maldivian company was included in consortiums. According to a respondent from the private sector, "the conditions of the international tenders are very high, in terms of asset value and years of operation. Due to strict conditions, it is not easy for local companies to put a proposal as a joint venture." Two other respondents from the private sector indicated that currently, there are no facilities for small-scale Independent Power Producers (IPPs), and it could be a model suitable for some islands. If it is permitted, new opportunities could be available for small-scale IPPs from the private sector that can enter into an agreement with the councils and then sell to the utility companies.

In the internationally funded projects, the focus has been on attracting foreign companies and utilities for relatively larger projects in the Maldives, without a mechanism for ensuring Maldivian private sector is getting opportunities to participate. Maldivian entrepreneurs have the disadvantage of being trapped in what Pacheco et al. (2010, 465) call the "green prison" because of the competitive disadvantage relative to larger international companies, and thus lose the potential benefit of investment incentives (Cojoianu et al., 2020). The experience is crucial for technological learning (Wright, 1936), as the activities can improve over time due to learning by doing (Fischer & Newell, 2008). It enables potential cost reduction in developing various technologies in different regional settings.

As for other constraints for Maldivian organizations, according to an island councilor, "government and utility companies are not very conducive for community initiated projects." The council of Dharavandhoo island cooperated with the Swimsol to experiment with floating solar PV, and a 96kW solar PV floating system was set up in the island harbor. The island needed 240kw for the whole island. Therefore the solar PV floating system could contribute to the needed power in the island during the daytime without batteries. Although the utility company was initially receptive, they refused to integrate the PV system. This was one of the first experiences of Swimsol in the Maldives, and it appears that for the private sector when it has to deal with the public sector, the environment is not very conducive for investments. Swimsol was however able to successfully exhibit the floating technologies by liaising with tourist resort islands operated by the private sector.

In 2009, the government announced a goal to be the world's first carbon-neutral country. To respond to that, the United Nations Development Program (UNDP) facilitated a project in Laamu atoll by installing solar panels in 11 schools. The idea was that the project would benefit schools with revenue or a reduction in electricity costs by feeding into the utility company's grid. However, feed-in tariff payment was discontinued after one month with the notion that the roofs of public schools are public property. According to one interviewee from the Ministry of Education, "if the public roofs are used, then the public must see a benefit or get an incentive."

Therefore, none of the solar PV panels installed in schools has been utilized. Although the Maldives energy roadmap (2020) was prepared ten years after the project in Laamu atoll, there are still no targets for the public utility companies to improve efficiency in production and also to adopt renewable energy. The public utility companies have mainly operated diesel-powered plants. However, according to a respondent from the Ministry of Environment, "in most of the islands, to relieve the demand for day peak, utilization of solar PV can be a good strategy." Therefore, one of the ways to persuade utilities to expand the renewable energy mix is to have Renewable Portfolio Standards (RPS)." It is a law that mandates utilities to produce a specific percentage of electricity from renewable energy sources (Hadush and Bhagwat, 2019, 13). There are also indications that utility companies have shown more interest in renewable energy. In 2019, prior to the COVID-19 pandemic, utility companies expressed a target of generating 50% to 70% of electricity from renewable energy sources by 2024 and collaborated with foreign partners to carry out more projects (Ziyau, 2019; Zalif, 2019). Although it is unlikely that these targets will be achieved by 2024, it is an indication of a positive shift in perspectives.

While the utilities serve 189 inhabited islands, there are also 166 tourist resort islands, which are operated by the private sector. Several resorts in the Maldives have invested significantly in renewable energy. For example, the Club Med Finolhu Villas Resort opened in 2015, has a 67,000 square feet solar PV and battery system that has been sustained to provide electricity for the guests and tourists in the island with the use of a 900kw generator. There are also other feasibility case studies that have been published on renewable energy in resort islands (see Jung & Kim, 2017; Jung et al., 2018; Reillies et al., 2019; Jung et al., 2019). This is one of the major differences from the study of Van Alphen et al. (2008), as by then, there was no notable involvement from the tourist sector in renewable energy. In recent years, the tourism sector has collaborated with Maldivian companies and has formed market opportunities for niche projects. For example, Swimsol has installed floating solar PV or rooftop solar PV systems in more than 25 tourist resorts and has established power purchase agreements with some resorts. However, the adoption of renewables and energy efficiency measures across the tourism industry is still not well documented. For example, in 2019, when there were 145 resorts, only 26% of the resorts provided electricity data, only and 4% of the resorts provided data on renewable energy to the Ministry of Environment (ME, 2020). The roadmap (2020) recommends the government mandate resorts to collect and submit information and enforce transparency (ADB, 2020: 70). However, no new data on electricity has been published on any inhabited island or resorts since 2020. Therefore, data collection and dissemination have become weaker.

Figure 5 shows a scatter plot of renewable energy capacity (watts) per capita (ESMAP, 2021) and government effectiveness (World Bank, 2021). In countries with higher government effectiveness value, renewable energy capacity has also increased. According to this data, the government effectiveness of the Maldives is in the middle range. This indicates that there is a need for improvement. In the Maldives, currently, there is no agency that specifically focuses on renewable energy projects. Maldives Energy Authority (MEA) was responsible for regulating the generation, distribution, and tariff setting on electricity. However, it did not have clear powers to enforce standards or ensure compliance (Siyambalapitiya, 2018). After dissolving the MEA, the Utility Regulatory Authority (URA) was formed as mandated under Article 3 (a) of the Utility Regulatory Authority Act (2020). Similar to MEA, the URA continues to be a part of the Ministry of Environment and thus does not have the legitimacy to review and establish standards as an independent institution. In Mauritius, with regard to institutional and regulatory changes, the Mauritius government formed the Mauritius Renewable Energy Agency (MARENA) under the MARENA Act 2015. This was to further assist in transforming the local energy sector into a clean energy economy (Shea, 2016) and to play an important role in achieving the Mauritian government's vision to increase the share of renewable energy to 35% of the energy mix and maintain it at this target by 2030 (IEA, 2021). An advantage of having a specific organization is that focus can be given to monitoring and evaluation of past projects, and work can be implemented in a programmatic way on the promotion of investments.

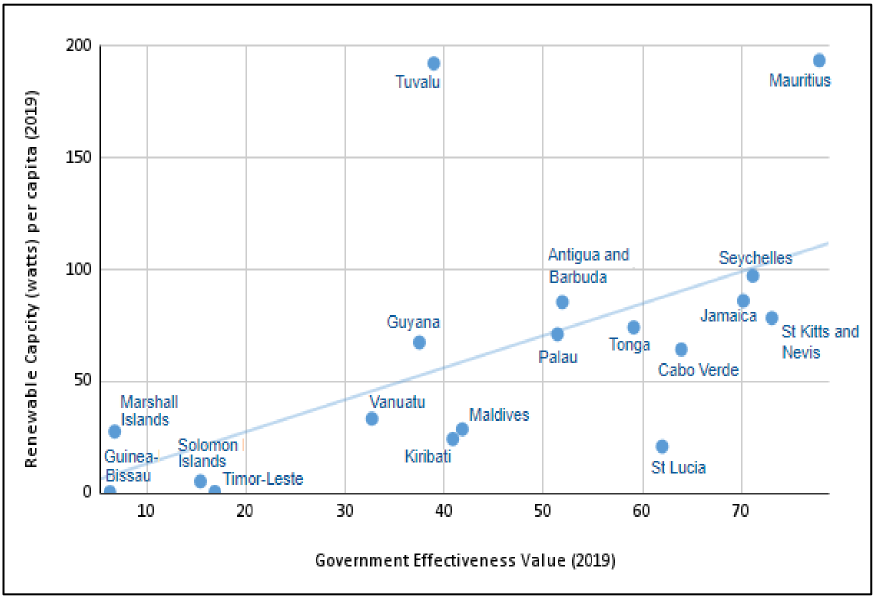

Figure 5. Renewable Energy Capacity per capita and Government Effectiveness

Source: The author, based on data from ESMAP (2021) and World Bank (2021)

According to an engineer, in the context of the Maldives, "one problem with forming more organizations is devolution of activities and experts, because often experts are moved from one department to another, and it may weaken one department at the expense of the other." With the formation of URA, the MEA, which functioned under the Ministry of Environment, was dissolved, and more than 50% of the staff from the Environmental Protection Agency (EPA) under the Ministry of Environment were moved to URA, resulting in a shortage of staff in EPA. One of the reasons for setting up URA is that in the Maldives, water and electricity production are both connected. Electricity is needed for water production through reverse osmosis, and excess electricity can be stored in batteries or fed into the grid. Therefore, it is expected that in the future, URA will play a greater role in energy efficiency and renewable energy in a water-energy nexus approach to achieve water security and energy security objectives. Taking a water-energy nexus approach is vital because the Maldives has a relatively high energy intensity.

Currently, there is no data available on the total amount of electricity produced in the Maldives. However, based on data from the overall energy sector (World Bank, 2022c), it appears that the Maldives has an increasing trend in energy intensity (figure 6). In contrast, Cabo Verde and Mauritius have decreasing trends in energy intensity. Singapore, the most industrialized country among SIDS, also has a decreasing trend in energy intensity. It is worth noting that although the Maldives is showing an increasing trend in energy intensity, the rate of increase is slowing down, which can be considered a positive sign.

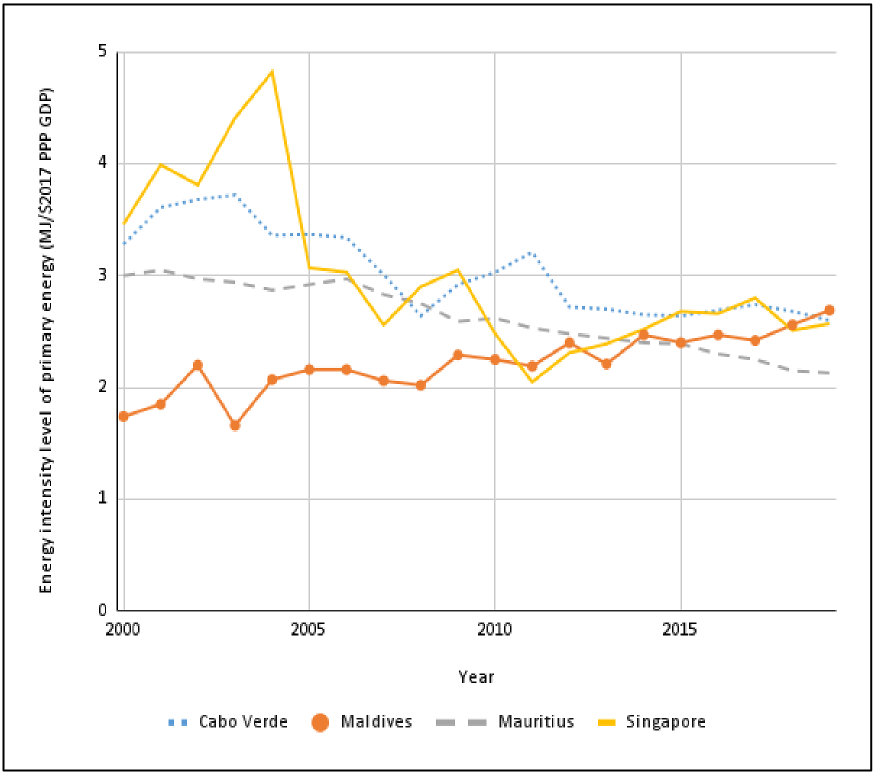

Figure 6. Energy intensity level of primary energy

Source: The author, based on data from World Bank (2022c)

The roadmap (2020) calls for developing a “zero fossil fuel” program to channel incentives to private sector investments, but there are no targets for the electricity sector for reducing emissions (ADB, 2020, 56). However, it was included in the 2020 update of the Nationally Determined Contribution of the Maldives by setting a target of 15% emission reduction in the electricity sector by 2030 (ME, 2020). In contrast, in the Mauritius roadmap, there is a target of reducing emissions from the electricity sector by 20% by 2030. Although renewable energy comprises up to only 4% in the Maldives, between 2019 and 2021, emission reduction was achieved by 72,178 tonnes in the electricity sector and saved up to MVR 147.80 million (about USD 9.60 million) in oil imports for power generation (President's Office, 2022).

V. Conclusion

The Technological Innovation System approach adopted here has allowed a structured approach to analyzing the progress of the energy transition in the Maldives. The study indicates that Small Island Developing States (SIDS), such as the Maldives, offer a niche opportunity for collaboration between local and international partners. There are a number of inducing factors for renewable energy in the Maldives. For example, Swimsol developed the world’s first floating solar PV system suitable for the sea. In the last decade, the tourism industry in the Maldives has been particularly receptive to the adoption of such technologies.

To attract investment in renewable energy, the government has established a Solar Risk Mitigation Initiative with support from the World Bank to cater to the risks and reduce transaction costs. Additionally, the government's approach of clustering a group of islands together for projects and providing site-specific data has also helped to reduce transaction costs for potential investors, resulting in competitive bids. Thus, Maldives has been able to attract international investors and establish power purchase agreements.

However, there are some hindering factors that impede progress. One such obstacle is the lack of technical capacity and unavailability of training programs, which are essential for developing and sustaining human resource expertise. Additionally, there is a lack of collaboration and networking between Maldivian organizations, as well as between Maldivian and foreign organizations. Furthermore, power generation characteristics in all the islands are not evaluated adequately, and there is a lack of published data. Best practices are not widely disseminated, and poor practices are not effectively monitored.

Fostering collaboration at various levels can increase performance and innovation. Establishing an industry networking association could facilitate the exchange of data and knowledge in the Maldives. Additionally, an international association for promoting renewable energy in the Atlantic, Indian Ocean and South China Sea (AIS) or for the Indian Ocean region could be established, as there are no such organizations for SIDS in these regions, unlike in the Pacific and the Caribbean. Furthermore, an innovation policy similar to that of Mauritius can be implemented by focusing on renewable energy planning and implementation, as well as smart technologies. Moreover, there is a need to raise awareness of business aspects of renewable energy among entrepreneurs and banking professionals, as done in Mauritius and Cabo Verde. Tax exemptions with a phased approach can be used as an incentive for renewable energy development. Similarly, small-scale Independent Power Producers can be given the opportunity if they have a cost-effective model and can contribute to renewable energy growth in different regions.

It is important to also consider targets for investment, training, and employment, with a focus on regions. Special development zones can be established with amenities for the private sector, as in Cabo Verde. Renewable Portfolio Standards can be implemented to motivate the utility sector to generate renewable energy through partnerships with the private sector, as in Mauritius, where the private sector produces about 60% of the power. With the current establishment of the Utility Regulatory Authority, which deals with both electricity and water, the Maldives could further explore opportunities in the water-energy nexus approach. Periodically reviewing and revising the renewable energy roadmaps can help to adjust policy direction by identifying areas of progress and areas where additional efforts are needed to achieve renewable energy targets.

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