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A preliminary feasibility of roof-mounted solar PV systems in the Maldives

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ABSTRACT

The small economy and the fragile environment of the Maldives necessitate the use of indigenous and clean resources for electricity generation. The country is mostly dependent on imported fossil fuels for electricity generation, which makes the cost of energy generation high and lowers energy security. Therefore, to reduce the energy costs, limit energy crisis problems, and minimise global warming, a techno-economic feasibility study has been undertaken to investigate the prospects of roof-mounted PV systems on the islands of the Maldives. This study estimated the gross roof area and total PV potential for Hulhumalé Island, and investigated the economic and environmental prospects of roof-top PV systems on the island considering total production cost, cost of energy, the level of contributions from PV and the resulting impact on GHG emissions. The research found that, depending on the available roof area, there is potential for generating 4.8 GWh to 8.0 GWh of electricity from rooftop PV systems on Hulhumalé Island in a year. From the economic analysis, it is evident that roof-mounted PV systems have significant potential for reducing diesel generator use and diesel fuel imports, minimising energy generation costs, helping to ameliorate the energy crisis and contributing to the reduction of global warming.

1. Introduction

Electric power plants are one of the primary consumers of imported fossil fuels, however there has been growing public awareness that increasing the share of electricity generated by renewable energy (RE) resources is an invaluable way to increase energy security and supply while reducing environmental risks associated with the growing demand for electricity [1]. RE resources are typically inexhaustible, environmentally benign, reusable and available domestically. For underdeveloped countries, these advantages are pivotal to maintain their development in a sustainable manner [2].

Solar energy is one of the most reliable, mature, and common forms of RE for electricity production. Recent economic and technical advances have made solar technologies increasingly attractive. The installed price of solar energy has dropped by as much as 50% since 2010 [3]. Despite substantial economic progress and anticipated cost parity with fossil fuels, renewable energy technologies have often been criticised for their low power densities, making them inappropriate for integrating into urban applications. The solar resource is highly region-dependent, and annual direct solar irradiation in some regions is more than 100 W/m^2 [4].

Generating electricity by incorporating photovoltaics (PV) modules in new buildings or retrofitting them into existing buildings have emerged as feasible options, especially in the developed countries [5]. One of the biggest advantages of solar PV is its capability for distributed power generation [6], and therefore offers a huge potential when scarcity of land is one of the limiting factors. This enables solar PV to be deployed on individual rooftops, which are described by [7] as "large resources of the area for the conversion of solar energy". For example, over 14% of the total electricity consumed in Hong Kong in 2011 could be generated by rooftop solar modules [7] while for Ontario, Canada, this figure is as high as 30% [8].

Being a lowland island country, the Maldives is facing a lot of challenges in the context of climate change like all other similar island nations. The geography of the Maldives also makes communication difficult and transport expensive. It has one of the highest levels of fuel imports, which poses a number of challenges. The energy demand of the Maldives is entirely met by imported fossil fuel and it is therefore imperative that the Maldives explores, develops and deploys indigenous, clean and renewable sources to meet the growing energy demand and ensure energy security. The Maldives aims to achieve a low emissions development future and ensure energy security, and intends to reduce 10% of its Greenhouse Gases (below BAU) unconditionally by the year 2030 [9].

For small island nations like the Maldives, integrating RE into the generation mix is one of the options to increase energy security and reduce fossil fuel dependency [10]. The technical feasibility of integrating RE systems into the grid proved that applying hybrid

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renewable energy systems in such applications is cost-effective, saves energy resources and is climate-friendly [11–15]. Literature indicates that the feasibility of these systems is dependent on geographical and climatic conditions [11,12,16,17]. Some studies have considered large-scale RE integration while others considered only small-scale RE integration such as roof-top PV systems [11,15,18–20]. The potentialities of hybrid renewable energy systems for electricity generation have been investigated for both developing and developed countries as well as for sub-tropical, tropical and hot-arid climatic conditions.

Moreover, having solar panels installed on roofs can create more self-sufficient users and reduce the need for additional power generating capacity in the future [21]. In a study by Arif H. and Zeyad A. [22] it has shown that a PV/diesel hybrid system compris of a 2.5 MWp PV system with 4.5 MW diesel system and a battery of 60 min of autonomy generates 27% energy from PV with a cost of energy (COE) of 0.170US$/kWh assuming a diesel fuel price of 0.1$/L. The study has proved that increase of PV capacity increases PV generation and reduces the number of diesel generators operational hours [22]. However, the actual potential in the Maldives will always be somewhat limited due to its geography. Around 99% of the territory of the Maldives is made up of water, and the remaining 1% is fragmented and widely dispersed. This leaves a very limited amount of land space for PV panels, and researchers have not adequately explored this constraint. One possible option would be to move the panels offshore, as many islands are surrounded by shallow lagoons. In fact, this solution has been proposed by Eierstock (2012) [24]. However, the additional costs of the strong support structures, specialised materials, and subsea cabling put its viability into question. Therefore, to increase RE penetration by PV without sacrificing land space, it is necessary to deploy them on rooftops. Studies have shown that rooftop PV is an encouraging possibility and should, therefore, be researched further in the Maldives. Several authors also advocate for more comprehensive RE assessments, which are crucial for formulating future utility plans [7,8,25–27].

According to the World Bank, the islands of the Maldives are capable of producing between 30 to 80% of their electricity through rooftop PV systems [10]. Since electricity is currently generated by individual power systems, specific assessments need to be carried out for each island. In 2009, the Japan International Cooperation Agency conducted a comprehensive study on the feasibility of commercial rooftop PV systems for Malé - the capital city [28]. Researchers have shown that the Maldives has the potential to achieve a large share of its electricity generation from roof mounted PV systems [10,29,30]. One of the main reasons for this is the low population and low demand for electricity on many of its islands.

Several methodologies are being developed by researchers to estimate the potential of electricity generation by retrofitting solar panels on roofs [31]. Using a GIS database is one of the recent research breakthroughs for calculating rooftop PV potential [18,26,32,33]. Strzalka *et al.* (2012) used geo-information systems in a 3D city model to quantify potential rooftop solar photovoltaic deployment at an urban level [34,35]. However, to use this method requires sophisticated tools and data, and remote sensing data to assess the PV production from actual roof space. These are expensive and /or hard to obtain, and unfortunately such high quality and expensive data for the islands of the Maldives is currently not available. Therefore, these methods are not practical for a country like the Maldives [36].

There is little or no research available that has considered both the estimation of rooftop PV potential and a techno-economic evaluation to facilitate the integration of large-scale PV into the energy mix, in particular for the Maldives. Therefore, this research aims to investigate the prospects of electricity generation from rooftop solar PV on Hulhumalé Island (one of the 188 inhabited islands in the Maldives) and conduct a techno-economic feasibility analysis of rooftop PV systems for this location. Outcomes of this study will be helpful for the power utilities and government in the Maldives to plan for a climate-friendly sustainable power system to meet current and future energy demands. The approach of this study could be used for any islands to estimate the feasibility of large-scale roof mounted PV systems considering unique values such as the potential roof area, total load profiles, and available solar radiation for the individual island.

2. Overview of electricity generation and renewable energy resources in the Maldives

The Maldives is a collection of 1190 geographically fragmented islands in the Indian Ocean and stretches in a chain of approximately 860 km long. The country lies between the latitudes of 7° 6′ 35" N and 0° 42′ 24" S and longitudes of 72° 33' 19" E and 73° 46' 13". Out of 1190 islands, only 188 are inhabited, while 112 have been developed as private resort islands [37]. The rest of the islands are uninhabited, except for a few dedicated to industrial activities. More than half of the inhabited islands are smaller than half a square kilometre and are dispersed within an area of 115,300 square kilometres forming very small pockets of land in the middle of the ocean [37].

The country has no known reserves of fossil fuels like coal, oil or natural gas. Hence, the whole economy of the nation relies on imported fuels. A major portion of the imported petroleum goes towards electricity generation, which is almost entirely composed of diesel generators. Due to this over dependence on imported fuel, the already fragile economy of the Maldives is at the mercy of global fuel prices. According to the statistics, 35% of country's GDP in 2012 was spent for purchasing petroleum products, of which 70% was diesel and half of that was used in diesel generators throughout the country [38]. Therefore, an increase in fuel price will substantially impact the country's economy.

The seemingly unique geographical characteristics of the Maldives pose many challenges in regard to building comprehensive electric power infrastructure. It is extremely difficult or perhaps impossible to develop regional or national electricity distribution networks [28]. Consequently, electricity is generated by small and independent power systems installed on each island. In 2013, the total installed generation capacity of the Maldives was 268.8 MW of which around 141 MW was installed on inhabited islands [39] and rest was scattered among other tourist resort island. The majority of this installation (61 MW) was in Malé and the remaining 80 MW was divided among 186 power stations on the other inhabited islands [29].

One of the prevailing issues affecting the country's power generation sector is low fuel efficiency and this can be directly attributed to the sub-optimal operating conditions of generator sets. Fig. 1 shows the energy consumption by fuel type in the Maldives [37,39]. Around 81% of the total consumption is met by diesel.

Certainly, there is a degree of mismatch between the demand and the installed capacity of power plants. In some cases, installed capacity on an island can be five times as high as the peak demand. On one island, a 50 kW gen-set was running to meet a peak demand of only 20 kW [39]. Although such examples are extreme cases, many other

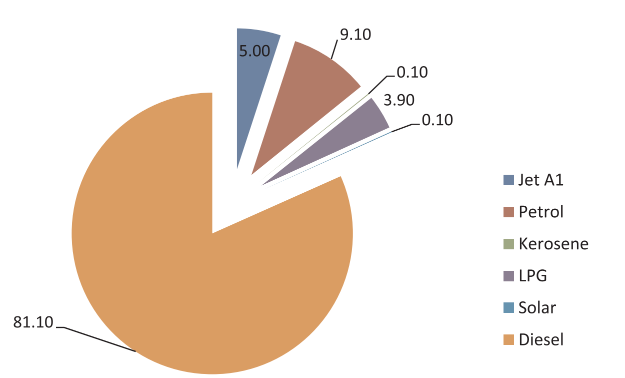

Fig. 1. Energy Consumption by Source in the Maldives (2011), Data Source: [28].