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Powering an island system by renewable energy—A feasibility analysis in the Maldives

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HIGHLIGHTS

- A new framework of energy and water systems on island has been proposed.
- Water demand and renewable energy potential of the Maldives are estimated.
- Feasibility analysis of renewable energy-driven island was done in the Maldives.
- It is possible for the Maldives to be a "zero input" system as to energy & water.

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ABSTRACT

Water and energy supply systems are essential parts of the infrastructure on islands. For small islands that are far from continents, water shortage is usually the main constraint on economic and social development. In order to maintain island water security, desalination plants are built to supply fresh water. The plants need a great deal of energy, which increases demand for energy and the cost of transportation. Thus, it is necessary to design a new island system driven by renewable energy. This study investigated the existing type of water and energy supply systems in some typical islands of the world, and analyzed their advantages and disadvantages. The energy supply systems can be classified into three categories: imported conventional energy supply system (ICESS); imported conventional energy & renewable energy supply system (ICE & RESS); and integrated energy supply system (IESS). Water supply systems can also be classified into three categories: imported water supply system (ImWSS); imported water and unconventional water supply system (IW & UWSS); and integrated water supply system (InWSS). The nexus of energy and water is very complicated on islands. This paper presents a framework for an interconnected energy and water system on an island. The new framework reveals a roadmap from "full input of energy & water (FIEW)" through "semi-input of energy & water (SIEW)" to "zero input of energy & water (ZIEW)", which leads an island's energy and water resources to become gradually independent from the mainland. The new framework also reduces transportation costs and carbon emissions. The proposed framework is applied to the Maldives to aid design of a renewable energy-driven water supply system. The characteristics and mutual adaptability of three types of renewable energy (solar, wind, and biomass energy) and water supply systems is discussed. The results show that a ZIEW system can be realized in the Maldives with a reduction in the cost of renewable energy. ZIEW system has great potential for application in island regions in the future.

1. Introduction

There are more than 50 000 islands across the world, which account for 17% of the global land area, and more than 700 million people, or about 10% of the global population, live on islands [1]. Island areas enjoy many unique advantages, such as beautiful scenery, fishing resources, ports, and other economic function, which have become an indispensable part of the global economy [2]. Energy and water are important strategic resources for islands, which are the basic resources that drive industrialization, technological advancement, engineering transformation and economic growth. The energy and fresh water and are usually sparsely available in island regions due in part to the special natural and geographical aspects of island environments [3]. The lack of energy and fresh water severely restrict

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Nomenclature

SIDS	island developing states
GHG	greenhouse gases
ED_T	total energy demand, kWh
ED_d	daily energy demand excluding energy used for desalination, kWh
ED_w	energy used for desalination, kWh
P_n	native population
P_t	tourist population
D_t	average number of days that tourists stay, d
η	coefficient of energy consumption to obtain 1 m^3 fresh water by desalination
WD_T	total water demand, m^3
WD_n	water demand of natives, m^3
WD_t	water demand of tourists, m^3
RES_{Tre}	total renewable energy power generation, kWh
RES_{se}	solar power generation, kWh
RES_{we}	wind power generation, kWh
RES_{be}	biomass power generation, kWh
λ	area ratio that can be installed in a solar power plant
θ	conversion efficiency of solar energy into electricity
DR	daily solar radiation intensity, $kWh/m^2/d$
A	land area, m^2
CI	clear index
b	average quantity of waste generated per person per year
P	total population
BE	energy produced per kilogram of waste, kWh/kg
ε	conversion efficiency of biomass energy into electricity

the economic and social development of islands [4].

Most of the small island developing states (SIDS) or small islands are suffering from high costs of electricity and also threatened by the impacts of greenhouse gases (GHG) emissions, which indicates that a promotion of large scale of renewable energy is necessary [5]. Blechinger et al. [6] made an assessment of the global potential for renewable energy storage systems on small islands. It is estimated that about 71% of the energy demand could be supplied by renewable energy on small islands in the world, which reveals the enormous market potential for high share renewable energy solutions. Due to various economic and technical constraints, there will be a long way before 100% Renewable Energy (RE), which makes the researches on combination of renewable energy and conventional power generation technologies, energy storage technologies and demand side management are among the hot issues [7,8]. Various technological solutions to supply islands by renewable energy based power systems aroused wide concerns [9], such as barriers to the dissemination of decentralized renewable energy systems [10]. On the other hand, the cost-effectiveness of renewable energy is widely discussed [11], and the techno-economic potential of renewable energy hybrid system on small island is analyzed all over the world [12]. The feasibility of stand-alone hybrid solar–wind–battery systems for remote islands is studied, and it is confirmed to be feasible in some remote islands [3].

Water supply and energy systems are closely coupled [13]. Schallenberg-Rodríguez et al. [14] described the relationship between energy and desalinated water and its evolution in Canary Islands. Gils and Simon [15] presented a pathway to a 100% renewable energy supply for the Canary Islands, which was the innovative research in this field. With the development of the technology of renewable energy production and desalination [16,17], it is high time to link the two systems to consider and resolve the bottleneck problem of islands [18,19]. Despite the lack of conventional energy and freshwater resources in island areas, there are usually abundant sea water and renewable energy [20,21]. Kuang et al. [8] summarized and reviewed the renewable energy of island areas, noting that the construction of efficient, reliable, and affordable energy systems will be the future direction of development in island areas. Many islands, such as Sicily's outlying islands, have attempted to create renewable energy-driven water supply systems. Solar power was introduced as a primary energy supply, and some solar power was used for desalination [22]. Sakaguchi and Tabata [23] presented a scenario analysis of solar, wind, ocean (tide) energy, and other renewable energy in Awaji Island in Japan and estimated that by 2050, the island could achieve 100% of its energy supply from renewable energy sources. In this regard, there are a number of precedents set by applications of mature technology [24].

There is still a long way to go before achieving a comprehensive coupling of renewable energy and desalination systems. SIDS enjoy considerable and diverse renewable energy sources, and desalination is intensively used as a mean to reduce current or future water scarcity for islands. The integration of renewable resources in desalination and water purification is becoming increasingly attractive in recent years. Ma and Lu [25] reviewed the wind energy technologies integrated with desalination system. It is concluded that overcoming the intermittent characteristic and improving the energy utilizing efficiency of wind energy are two important technological problems. Ghaffour et al. [26] presented an innovative and sustainable desalination processes, which is suitable for integrated renewable energy systems. They also discussed the benefits of various technologies and their limitations. Ismail et al. [27] made a theoretical investigation of the performance of integrated seawater desalination plants that utilize renewable energy. The results show that site location, solar intensity, wind speed, ambient temperature, and water salinity are the most dominant factors in the performance. Eltawil et al. [28] points out that the real problems in renewable energy technologies integrated with desalination systems are the optimum economic design and evaluation of the combined plants in order to be economically viable for remote or arid regions. Most of the recent researches are optimistic about the prospects for renewable energy driven desalination systems in the future. It is a fundamental solution for energy and water supply on islands [28,29].

This study undertook a preliminary coupled analysis of island energy system and water system, and proposed the strategy of coupled management of water and energy system on islands, based on which a new framework of energy and water system on islands was proposed. This article is organized into three parts: the first part summarizes the categories of energy and water supply on islands; the second part makes a case study of the Maldives, the potential of renewable energy and