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Modeling, planning, application and management of energy systems for isolated areas: A review

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ABSTRACT

The energy systems of isolated areas are different from the stable energy systems of mainland areas. The particularity of isolated areas creates more risks for their energy systems planning, and the isolated areas can be considered to be a more specific analysis target than mainland areas. Various energy models and systems have been developed and applied in isolated areas. The major objective of this study is to provide a comprehensive literature review to identify, classify, evaluate and analyze the performance of different methodologies, models and energy systems for isolated areas. Therefore, effective information could be provided to support decision-making toward to appropriate energy models and systems for isolated areas with different scales and demands. This paper reviewed the forecasting techniques of energy demand and renewable energy (RE) resources, energy models, application of hybrid RE systems (HRESs), and management of energy planning for two most representative isolated areas: islands and remote villages. The uncertainty analysis of energy systems of isolated areas is also discussed. It is evident that the indigenous RE resources show great potentials for the energy system of isolated areas, especially the solar and wind resources. The various combinations of photovoltaic (PV), wind, diesel and batteries have been proven more competitive. Also, it is necessary to develop sophisticated models that are more applicable to isolated areas and that consider the distinctive characteristics, practical needs and uncertainties of isolated areas.

1. Introduction

Isolated areas, such as isolated islands and remote villages, are areas that are set away from other regions. Currently, large numbers of people live in isolated areas, and energy supply is an essential issue for these areas. However, millions of occupied islands and remote villages worldwide are beyond the reach of energy systems [1], or are highly dependent on the imported fossil fuels. To improve the energy system and environmental performance of isolated areas, much effort would be required when considering the particularity of isolated areas.

Compared with national or regional energy planning, the planning of isolated areas is distinctive because of typical characteristics that can be classified as: (i) enormous distances from the large population centers, (ii) limitation of access to the utility grids, (iii) high dependence on imported energy, and (iv) inconvenient transportation. Some isolated areas such as remote islands, present all these characteristics, whereas some isolated areas, such as off-grid communities and villages, display only partial characteristics. However, these features lead to more acute risks for energy systems planning for all isolated areas, such as the shortage of energy sources, the security problems, the limitation of technologies and capital costs, therefore, the isolated areas could be considered as a more specific analysis target than the mainland areas. It is difficult for isolated areas with relatively poor financial conditions to be grid-connected [2], stand-alone systems could be more cost-effective for such areas [3].

Many isolated islands and remote areas are highly reliant on imported fossil fuels for energy supply, for example for diesel generators [4–8]. Considering the shortages of fossil fuel, environmental pollution, transportation problems and price fluctuations, the penetration of local RE resources has attracted extensive attention for the supply of energy to isolated areas worldwide, with the main advantages of inexhaustible resources, pollution reduction, no long-term transport requirements and usually local abundance. However, compared with the stable energy supply of mainland areas, the instability of stand-alone energy systems with high RE penetration is a risk for isolated areas. Therefore, the hybrid energy systems provide an option for isolated areas.

Many literature sources have reported studies associated with energy planning issues for isolated areas. Oyama et al., [9] divided generation planning cases into isolated area and wide area planning from the perspective of facility siting. In some studies, the optimal designs of

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energy systems were obtained by using software tools [10,11]. Some researchers paid their attentions to islands [7,12–15] whereas others focus on remote villages or communities [16–19]. However, these studies have not been sufficiently systematic, and some have overlapped. Isolated areas were not proposed as a category of research targets, islands, remote villages or communities were only considered as case studies. Moreover, some of these studies were very broad, whereas others provided analysis from limited aspects without reflecting the specific characteristics of isolated areas.

This paper aims to provide a comprehensive literature review to identify, classify, evaluate and analyze the performance of different methodologies, models and energy systems for isolated areas. The main tasks of this paper are described as follows:

- Various forecasting techniques for both energy demand and RE were identified and classified. The developed approaches suitable for isolated areas based on conventional forecasting techniques were surveyed.
- The evolution of modeling approaches was explored, and the applicability of these models for isolated areas was analyzed.
- The roles of RE and HRES in isolated areas were evaluated, and the application of various configuration of HRESs for different isolated areas were investigated.
- The management including policy effect on energy planning of isolated areas were discussed with two typical representatives: islands and remote villages.

The results of this review can provide effective information to support decision-making toward to appropriate energy models and systems for isolated areas with different scales and demand. The review methodology is presented in Fig. 1.

2. Modeling of energy systems planning in isolated area

Since a simple model was proposed by Landsberg in 1977 [20], many scholars have conducted the researches on modeling which served as a tool for energy planning issues and have played a part in the development of many countries and regions. Various energy models have been applied to aid the decision makers by describing, simulating and analyzing the entire energy systems. However, for isolated areas with unique characteristics, the feasibility of models during the process of demand forecasting and model construction involving RE deployment require further discussion.

2.1. Energy demand forecasting

Reliable energy demand forecasting can provide effective support for decision-making for energy planning [21]. Many demand forecasting techniques have been developed and adopted. Ma et al. [22] provided a comprehensive overview of methodologies for short-term electric load forecasting for three categories: statistical methods, expert systems and artificial neural networks (ANN). Sisworahardjo et al. [23] divided the forecasting models into three categories as well: statistic analytical-based, knowledge-based and hybrid approaches. Suganthi and Samuel [24] reviewed 12 categories of models for energy demand forecasting. These models were classified as traditional methods, new techniques and bottom-up models. Traditional methods include time series, regression, econometric methods, auto regressive integrated moving average (ARIMA), fuzzy logic (FL), genetic algorithm (GA) and neural networks. New techniques include support vector regression, particle swarm optimization (PSO) and ant colony optimization (ACO). MARKAL and LEAP are bottom-up models. According to Ardakani and Ardehali [25], parametric methods and Artificial Intelligence (AI)-Based Methods are two categories for long-term electrical energy consumption forecasting. Compared with AI-Based Methods, the parametric methods would result in less accuracy in forecasting. Raza and Khosravi [26] reviewed the performance of AI techniques on load forecasting and observed that ANN techniques show superior performance than statistical and time series methods on forecasting. Daut et al., [27] summarized two categories of electrical energy consumption forecasting methods: conventional methods and AI-based methods. The conventional methods covered stochastic time series and regression based method has been widely used, however, AI-based methods such as ANN and support vector machine (SVM) were found to perform better than conventional methods because of their ability to handle nonlinear problems. Fig. 2 shows the taxonomy of major forecasting methods.

Energy demand can be influenced by many factors, such as local climate, weather, geographical features, economy, culture, type of consumer, living habits, applied algorithm and quality of input data. The development of combined methods of two or more techniques has the potential to optimize the forecasting accuracy by taking advantages of all methods.

Isolated areas have unique characteristics that could challenge demand forecasting; such as the unavailability of the past data and the high impact of local consumers' behaviors. Many literature sources have developed approaches suitable for isolated areas based on

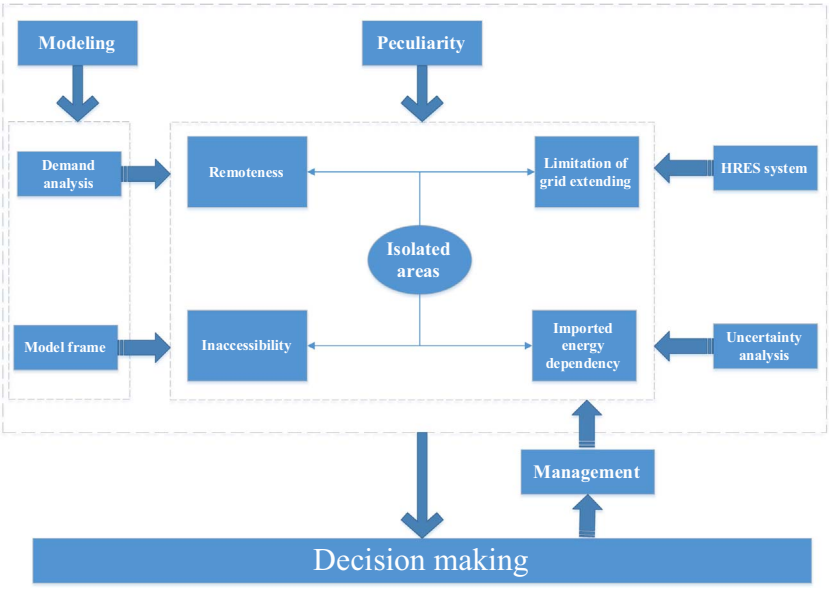

Fig. 1. The review methodology for energy systems of isolated areas.