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Feasibility analysis of offshore renewables penetrating local energy systems in remote oceanic areas – A case study of emissions from an electricity system with tidal power in Southern Alaska

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HIGHLIGHTS

- A numerical model was developed to simulate energy systems in remote oceanic areas.
- The reduction of negative environmental impacts by introducing offshore renewable energy sources was presented.
- Introducing 56 kW of tidal power results in an annual emissions reduction of almost 244,000 lb of CO_2.
- The analysis also suggested that storage systems have the potential to provide additional system benefits.

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ABSTRACT

In many remote areas, expensive fossil fuels such as diesel are used to meet local electricity demand. However, their environmental impact is significant. Consequently, some of these areas have started to use hybrid systems that combine renewable energy sources and fossil fuel generation, such as wind-diesel systems, although wind is not feasible in some remote locations and fossil fuels remain the only resource in these areas. Fortunately, offshore renewable energy sources are available in many remote areas close to the ocean. In order to understand the feasibility of using offshore renewables in remote oceanic areas, we recently conducted a systematic study by developing an integrated model. This model includes a supply module, demand module, environmental impact module, and integrating module. Using this model, we mainly study the reduction in emissions resulting from offshore renewable energy penetration in local energy systems. In this article, we present this integrated model and an example study of tidal energy in the Southern Alaska community of Elfin Cove, which relies on diesel fuel for all of its electricity requirements. With 56 kW of tidal power penetrating the energy system, we found that almost 12,000 gallons of diesel fuel are displaced per year. This results in an annual emissions reduction of almost 244,000 lb CO_2 and about 1400 lb CO, as well as considerable reductions of PM-10, NO_x, and SO_x. The newly developed integrated model is expected to be used to analyze other aspects of tidal energy (and offshore renewable energy in general) in remote areas. For example, since the electricity demand in some remote areas varies significantly throughout the year, we recommend that tidal power should be used with a storage system.

1. Introduction

With the ever-increasing negative environmental impacts from traditional fossil fuel energy sources and the foreseen depletion of the fuel reserves, many countries and regions have started to integrate renewable energy resources and develop their own renewable portfolio standards (RPSs) [1,2]. Furthermore, international and intergovernmental agencies such as the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC) are heavily facilitating this process.

From a cost-effective point of view, it is understood that optimally expanding the transmission system is very important for lowering the cost of integrating renewable energy resources [3]. However, it is not feasible to build transmission lines between existing renewable power plants and remote areas such as islands, highlands, high altitude locations, or areas with minimum population. Many of these remote locations have to use expensive energy

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sources such as diesel fuel while they are considering integrating renewable sources at the same time. For example, the Scottish government shows that about 35% of the electricity demand in Scotland is supported by renewable energy sources, primarily wind [4]. Lund and Matheson [5] presented wind-dominant 100% renewable energy scenarios for Denmark in 2030 and 2050. Suomalainen et al. [6] studied the wind penetration impact in Portugal. However, wind resources are not dominant or their utilization is not feasible in many of the remote oceanic areas. Fortunately, another energy resource, offshore renewable energy (mainly offshore wind, wave, and tidal energy), is often very easy to access in these areas. In this research, we use tidal energy as an example, and the popular technology that converts the energy in tidal currents to electric power is the tidal current turbine, which is similar to a wind turbine in working principle. Readers who are interested in offshore wind energy technology can refer to Musial et al. [7] and those who are interested in wave energy technology can refer to Falcao [8] and Li and Yu [9].

1.1. Relevant studies

During the past couple decades, several researchers have studied tidal current energy systems. Peter Fraenkel gave an early outlook of tidal current energy in 2002 when Marine Current Turbines deployed their first large-scale system [10]. Then, many resource assessment efforts started. For example, Myers and Bahaj [11] estimated the electric power potential of tidal current turbines. Garrett and Cummins [12] developed an analytical approach. Hagerman et al. [13] developed a practical method. Li and Calisal [14] developed an engineering perturbation approach that can be used for optimization. Recently, researchers began to conduct integrated analyses on tidal current energy systems. Douglas et al. [15] presented a life cycle assessment of the turbine produced by Marine Current Turbines. Particularly, Li et al. [16] developed a systematic approach to estimate and optimize the cost of electricity of a tidal current turbine farm. In short, most of the above approaches can be used to develop integrated energy system models. Since part of the integrated model in this paper is developed based on Li et al. [16], from here, we cite Li et al. [16] as LLC11.

Regional integrated energy system models are often used for renewable energy system analyses [17]. There are a number of popular models, such as the National Energy Modeling System (NEMS), developed by the US Energy Information Administration (EIA) [18], and the Regional Energy Deployment System (ReEDS), developed by the National Renewable Energy Laboratory (NREL) [19]. They focus on relatively large areas such that no remote area study is reported. Nonetheless, there are other models or analyses studying hybrid renewable energy and fossil fuel systems for rural communities and remote areas [20–22]. However, few have evaluated offshore energy penetration into energy systems in remote areas.

1.2. Objective of this study

In order to understand the feasibility of utilizing offshore energy to support the local electricity demand in remote oceanic areas, we conducted a comprehensive analysis by developing an integrated model. This model is expected to analyze various aspects of ocean energy penetrating local energy systems in remote areas. Specifically, after presenting the framework of the integrated model, we detail key modules, i.e., *Supply Module*, *Demand Module* and *Environmental Impact Module*. With this model, we show a simulation result of tidal energy penetrating a local energy system in a remote region of the US: Elfin Cove, Alaska, which currently relies on diesel fuel for 100% of its electricity requirements. We also show how to use this model to study energy policy with offshore renewables, and suggest that they should be strategically integrated with storage systems.

2. Framework of the analysis

Similar to our previous study about cost in LLC11, the analysis in this article integrates sub-level analyses in the disciplines of engineering, economics, and the environment, and an integrating module connects all the sub-level analyses. Specifically, this regional offshore energy analysis (ROEA) includes a *Supply Module*, a *Demand Module*, an *Environmental Impact Module*, and an *Integrating Module* (Fig. 1). It should be noted that for a more complicated region, a *Macroeconomics Module* and an *Electricity Market Module* are very necessary. In this article, since we focus on a remote region in Alaska, the economics and electricity market calculations are conducted in the *Integrating Module*. We shall discuss them as individual modules in future papers.

The *Supply Module* consists of two sub-modules, the *Tidal Power Module* and the *Other Power Source Module*. These modules calculate the annual energy output from tidal power and other energy sources by cost-effectiveness-based optimization approaches. The *Tidal Power Module* optimizes the utilization of tidal power with various tidal power penetration strategies. The *Demand Module* consists of a *Regional Electricity Demand Module* which provides the regional electricity demand from the residential, transportation, industrial, and commercial sectors. The *Environmental Impact Module* estimates the emissions under different scenarios. The *Integrating Module* integrates each module and conducts the final calculation. To formulate this integrated model, the following assumptions are made:

- All assumptions in LLC11 apply, unless specified otherwise (e.g. Section 3.1).
- There is no failure of the power generation system to affect the electricity distribution; failure of power generation system results into cost of the electricity.
- No power is generated when the flow velocity is slower than the cut-in speed.
- No permitting or other issues delay or prevent using ocean energy.
- *Demand Module* treats all consuming sectors as one for the purpose of simplifying the optimization.
- The electricity market is assumed to be regulated.
- No international trading activity is included.
- Tidal power can be curtailed when necessary.

2.1. Simulation process

We use scenario-based analysis to conduct the simulation. During the past decade, many researchers have used scenario-based

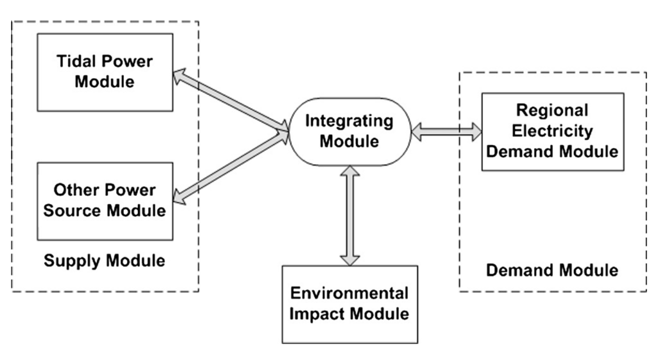

Fig. 1. Main structure of regional offshore energy analysis model.