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Assessment of renewable energy systems combining techno-economic optimization with energy scenario analysis

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ABSTRACT

Energy system modeling offers helpful insights for exploring the potential use of renewable energy technologies in various applications. Different software tools are extensively used to model and design the renewable energy systems having different features. The choice of software tools used is highly dependent on the specific objective of the respective study. Among the software tools used, *HOMER* and *RETScreen* are two most popular modeling software used for designing renewable energy systems. In this paper, a modeling framework utilizing HOMER and RETScreen has been proposed for assessing renewable energy systems focusing on power systems providing electricity. HOMER has been employed to obtain the optimization of energy system components, cost and electricity share for the system. The results from HOMER were subsequently used as input in RETScreen along with other appropriate inputs for detailed project analysis with energy scenario for the systems. As a case study, this framework has been utilized for assessing Solar PV-Diesel energy system and Wind-Diesel energy system in Kutubdia Island, Bangladesh. This modeling framework employing unique features of two different popular software tools, HOMER and RETScreen, can be beneficial for the researchers and policy makers to better assess renewable energy systems utilizing techno-economic optimization with energy analysis.

1. Introduction

Due to its environment friendly nature, renewable energy technologies have drawn significant attention from the researchers, scientists and policy makers. The conventional energy systems utilize fossil fuel as primary energy source which is also causing greenhouse gas emission and global warming. For the deployment and development of renewable energy systems, national and international organizations are proposing novel policies such that the share of renewable energy resources in global electricity generation is expected to increase from 19% in 2008 to almost a third in 2035 [1].

Often it is of paramount importance to model the energy system before implementing the project for decision making and pre-feasibility analysis. Several software tools, both commercial and free, are available for assessing the energy systems. Connoolly et al. [2] has reviewed 37 computer tools for analyzing the renewable energy systems in collaboration with the tool developers. In this paper, necessary information was provided for identification of appropriate energy tool for various energy systems under different study objective. The authors concluded that there is no such tool that may be considered as 'ideal' energy tool rather the tool selection is highly dependent on specific objectives for individual scenario.

Among the software tools used by researchers, RETScreen and HOMER have the highest number of users having downloads more than 200,000 and 28,000 times [2]. Some other popular software tools used for modeling energy systems are EnergyPlan, energyPro and LEAP. EnergyPlan software tool [3], programmed in Delphi Pascal, was developed in Aalborg University, Denmark in 1999. The purpose of this software tool is to aid the design and modeling of national and regional energy systems through simulating the entire energy system [2]. It has been used for analyzing integration of

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large scale wind power in Danish [4] and Chinese electricity system [5], for analyzing 100% renewable energy system for Denmark [6], Ireland [7] and Macedonia [8], for analyzing large-scale integration of wind power, photovoltaic and wave power into Danish energy system [9].

energyPRO has been developed and maintained by EMD International A/S in Denmark [10]. It can be used for combined techno-economic design of both fossil and bio-fuel powered cogeneration and trigeneration projects along with wind power and other types of complex energy projects [2]. It has been used for comparing impact of electricity, heat and biogas storage on renewable energy integration in Aalborg, Denmark [11], for modeling boiler, solar thermal and decentralized CHP for net zero energy building [12], and for modeling scenario consisting CHP and wood boiler for district heating in Lithuania [13]. LEAP (Long-range Energy Alternatives Planning) [14] is an integrated modeling tool developed in the USA in 1980 and currently maintained by the Stockholm Environment Institute. It is employed for analyzing national energy systems for tracking energy consumption, production, and resource extraction [2]. It has been used for forecasting future energy demand and supply patterns, greenhouse gas emissions for several alternative scenarios of energy policy and energy sector evolution for Taiwan [15], for assessing landfill gas electricity generation in Korea [16] and for identifying the feasible penetration of sustainable energy in Crete island, Greece [17].

The two most popular software tools, RETScreen and HOMER, have their unique features for energy system modeling. HOMER is an optimization tool for renewable energy systems developed by National Renewable Energy Laboratory (NREL) in USA and can be used for both standalone systems and power grid-connected systems [18]. This tool optimizes the system architecture of the energy system and provides cost of electricity based on the cost parameter of the system components being fed by the user and does not consider the civil engineering cost, installation cost and other costs associated with system installation and operation. RETScreen is a project analysis and decision support tool developed by Natural Resource Canada. RETScreen does not provide renewable energy system optimization rather it analyses the energy scenario provided that the energy mix input is provided by the user and provides detailed cost analysis, financial analysis and emission analysis [19].

HOMER has been used to evaluate and simulate many systems in the past years, some of the examples being evaluation of economic effects of distributed generation in Greece [20], feasibility study of small hydro/PV/Wind hybrid system in Ethiopia [21], analyzing energy systems comprising solar PV, wind turbines, fuel cells and battery for island resorts in Malaysia [22], feasibility analysis of wind energy system integration and hydropower generation in Ireland [23], optimization of solar PV power system for a health clinic in Iraq [24], techno-economic optimization of solar PV-biogas-diesel hybrid energy system for an island in Bangladesh [25], modeling hybrid renewable energy system for north American off-grid community [26], and techno-economic feasibility study of solar PV-diesel system for northern parts of Bangladesh [27].

RETScreen have been used to analyze the energy scenario of different energy systems and provide detailed financial analysis and emission analysis. It has been used for assessment of feasibility of developing wind farms in Algeria [28], for feasibility analysis of solar water heating system in Lebanon [29], for analyzing potential of 10 MW PV power plant in Abu Dhabi [30], for studying feasible sites to build power-grid connected PV power plant in Egypt [31], for feasibility study of building a Solar PV power plant in Australia by replacing gen-sets with solar PV [32], for assessing techno-economic feasibility of power-grid connected Solar PV systems in Bangladesh [33] and for performance analysis of integrated wind, PV and biomass energy systems in India [34].

Although utilizing just one software tool for modeling energy systems is the most common approach, modeling frameworks combining the competences of two or more software tools have been developed in different projects with the aim of capturing different dimensions of energy systems in recent years. The combination of two or more models facilitates aggregating the strengths of the models combined without developing single large modeling tool having large computational requirements [35]. Laurent et al. have presented the conjoint work carried out by REME (ASSESSECO and EPFL) and KANLO team for building a master program which manages the coupling of the top-down model GEMINI-E3 and the bottom-up model ETSAP-TIMES [36]. Lund et al. have compared between the methodologies and results of EnergyPlan and H_2RES for the island of Mljet, Croatia [37]. Pina et al. have presented a high resolution modeling framework by combining EnergyPLAN and TIMES for analyzing electricity systems with high penetration of renewables in continental Portugal. The aim of the modeling framework is to achieve significant reduction of CO_2 emission by increasing renewable penetration [35]. Rosen et al. have presented a framework that combines the long-term and short-term modeling approaches for analyzing the effects of large scale wind power production in a system. Alongside PERSEUS-CERT model, a multi-periodic cost-optimizing long-term energy system model, MATLAB/Simulink® package based model AEOLIUS was used for the simulation of interdependencies between increasing amounts of fluctuating electricity production [38]. Østergaard has used EnergyPlan model for identifying aggregate consumption for the production technologies and demand in the specific hours. Subsequent grid analysis was carried out using EnergyPro Grid model. EnergyPlan is not directly linked with EnergyPro model and hence sequential analysis was carried out [39].

This paper presents a modeling framework that combines two energy software tools having very high number of users [2], HOMER and RETScreen, and its application to the case study in an island in Bangladesh. This modeling framework is used to obtain techno-economic optimization of renewable energy systems along with detailed energy scenario analysis. As a case study, two hybrid renewable energy systems (Solar PV-Diesel and Wind-Diesel) have been modeled for a small locality in Kutubdia island, Bangladesh combining HOMER and RETScreen, both having a bottom-up approach [2], sequentially utilizing unique features of each software tool. HOMER has been used to obtain the optimized system architecture; cost associated with the components and the energy mix of the electricity generation components. The optimized energy systems are further analyzed with the help of RETScreen where the energy mix and cost parameters obtained from HOMER were used. Detailed cost analysis, financial analysis and sensitivity analysis were obtained using RETScreen. Although this paper focuses on renewable energy systems generating electricity, this modeling framework may also be considered for energy systems having other forms of energy e.g. thermal energy as output. This framework combines the capabilities of HOMER and RETScreen and take advantages of the strengths of these two software tools by analyzing the tools subsequently for assessing the renewable energy systems.

2. Methodology approach in modeling renewable energy systems

The objective of the study is to present a modeling framework for assessing the renewable energy systems from techno-economic and energy scenario perspectives. In order to analyze the energy systems, two different software tools, namely HOMER and RETScreen having unique characteristics have been sequentially