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A comparative analysis of renewable energy simulation tools: Performance simulation model vs. system optimization

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ABSTRACT

Whether you are beginning to learn about renewable energy or are an expert, there are a number of software-tools that can be used to help simulate and optimize your system. Performance models simulate energy outputs with system configurations specified by the user, while optimization models can help plan appropriate system sizes to meet energy goals such as minimizing life-cycle system costs or maximizing carbon reduction.

The models reviewed in this paper have been categorized into different project level subgroups: 'Multi-scale Renewable Energy (RE) Tools', 'District Level Tools', and 'Regional Level Tools'. The tools in each category will be compared to one another to show similarities and differences. Concluding this research, a summary of which tools are more suitable for each scale will be suggested.

1. Introduction

1.1. Overview

With the growing demand for energy in the world today, expanding 2.4% annually, interest in renewables technologies are growing fast [1]. When installing renewables, there is great potential to have significant reductions in emissions, as well as cost savings [2].

Models and tools that are developed for renewable energy are used to assess, analyze, and optimize the potential energy and cost impact of renewable energy and energy efficiency technologies [3].

These tools can be applied on many different levels, such as local, district, and regional. These models differ in scale and complexity, as well as the inputs that the software requires to generate the intended outputs [4].

Models need to balance simplicity and ease of use; accuracy, precision, and representativeness; and data granularity [5]. Many models make performance estimates based on installation and operating costs and system design parameters that you specify as inputs into the model. General technical inputs include site location and resource data (weather information) [6], system components [7], electricity rates, and electric load (energy usage per month) [7]. Financial inputs can be, but are not limited to, system costs (i.e. cost of module and inverter, construction, land acquisition, tax) [8], system degradation rate [9], financial parameters (debt ratio, depreciation rate, inflation rate, energy escalation rate, analysis Period, and insurance Rates) [10], and incentives (tax credits, investment based incentives, production based incentives, capacity based incentives, and the Modified Accelerated Cost Recovery System (MACRS)) [11]. Incentives can lead to a great cost advantage when wanting to pursue a renewable energy system in your area. Some advanced modeling tools require more input data such as fuel types, investment options, operation costs, and precise site load data, such as fifteen-minute interval data for gas and electricity consumption [12,13].

The most appropriate model to assess a renewable energy opportunity will depend on the type of renewable technology being considered, complexity of the project, sophistication of the user, and data that you have available. This paper describes the different renewable energy tools available today, including technologies they evaluate, the scale and level of analysis, their modeling approach and limitations, data inputs required, and typical outputs. It also provides case studies of each tool.

The tools are divided into three sections: Multi-scale RE Tools (including basic renewable energy modeling tools that are easier to use), District Level Tools (including more detailed level result models taking more inputs into account), and Regional Level Tools (including higher scale project tools that can be applied at a national level).

1.2. Previous reviews

A number of previous modeling reviews have examined different aspects and approaches to RE modeling. The tools investigated are not all specifically ones reviewed in this paper, but similar in their focus on performance and financial modeling.

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Allegrini, Orehounig, Mavromatidis, Ruesch, Dorer, and Evins [14] published a review of models and tools for energy systems on the district-scale level. The research discussed modeling approaches that are relevant to urban and district-level energy systems. They discussed details about the tools and software packages available that implement these models. The discussion section of the review covered key topics emerging in urban energy systems modeling, particularly cross-disciplinary and integration issues.

Li and Wen [15] discussed renewable energy building modeling for control and operation. The research focused on building energy modeling and forecasting, with studies included focusing on building energy forecasting, modeling for major components such as power generation, energy storage, and short-term weather forecasting. The conclusion of the review suggested choosing the modeling tool depending on the system type.

Vreenegoor, Hensen, and de Vries [16] researched the advantages and disadvantages of eleven simulation tools (not all being renewable energy related), which are all different than the tools reviewed in this paper. The tools discussed in their research primarily relate to district-level modeling and how energy is calculated. The objective of this work was to develop a district evaluation model based on energy performance to support housing associations in choosing the optimal renovation solution.

Crawley, Hand, Kummert, and Griffith [17] summarized existing building-level energy simulation tools. They surveyed more than 230 tools and listed the best ones, in their opinion. The main tools in the building energy field are the whole-building energy simulation programs, which provide users with building performance indicators such as energy use and demand, temperature, humidity, and costs.

Kandt et al. [18] completed a comparative analysis of seven different solar mapping tools in 2010. This research showed how the modeling tools have changed over time, and described new commercially available tools. They felt it was important to assess each individual modeling tool based on its accuracy and portrayal of PV potential.

Although previous reviews have assessed different modeling tools and their advantages and disadvantages, none of these reviews have specifically targeted renewable energy modeling tools. This review will focus on renewable energy modeling tools, and the unique characteristics that distinguish them.

2. Review of renewable energy tools

In this section, we will discuss the different modeling tools that can be used for renewable energy assessment and what each one entails. This review paper classifies each tool by project scale. Multi-scale RE tools have the capability of modeling residential, commercial, and utility-scale projects. District level tools can model residential and commercial buildings, as well as higher scale projects like microgrids. Regional scale tools are mainly focused on large scale projects, such as regional and national.

Table 1 provides a detailed matrix in which the twelve tools evaluated in this paper are shown, along with thirteen attributes that classify and make each tool unique. Two classifications are indicated on the table: the model having the specific attribute (green box with an X), and the model not having the specific attribute (empty red box). This

Table 1
Synopsis of renewable energy modeling tools' complexity, capability, and general attributes.

	Simulation	Optimization	Photovoltaics	Wind Energy	Biomass Energy	Battery Storage	Residential Modeling	District Modeling	Regional Modeling	Consecutive Technology Modeling	Finance	Performance	Free?	Capability of modeling large plant	Beginner Tool	Advanced Tool
SAM	x		x	x	x	x	x	x			x	x	x	x	x	x
CREST	x		x	x	x		x	x			x		x		x	
PVWatts	x		x				x				x		x		x	
Pvsyst	x		x				x	x			x	x			x	x
Windographer	x			x			x					x			x	x
windPro	x			x				x				x		x		x
RETScreen	x		x	x	x		x				x	x	x		x	x
Helioscope	x		x			x	x	x			x	x			x	x
REopt	x	x	x	x	x	x		x		x	x	x		x		x
HOMER	x	x	x	x	x	x		x		x	x	x		x		x
Gatecycle	x				x			x				x		x		x
ReEDS	x		x	x	x				x	x	x	x	x	x		x
EnergyPLAN	x		x	x	x	x			x	x	x	x	x	x		x
KomMod	x		x	x	x	x			x	x	x	x	x	x		x