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INCREASED RENEWABLES IN CALIFORNIA: IMPACT ON FOSSIL FUEL GENERATION, LEVELIZED COSTS, AND GRID CO_2 EMISSIONS

Lori Smith Schell, Empowered Energy, Phone: +1 970 247 8181, E-mail: LSchell@EmpoweredEnergy.com
Joshua D. Eichman, University of California-Irvine, Phone: +1 949 824 5326, E-mail: jde@apep.uci.edu
G. Scott Samuelsen, University of California-Irvine, Phone: +1 949 824 7302, E-mail: GSS@apep.uci.edu

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Overview

California is a leader in both environmental and energy policy. California's environmental and energy policies intersect to a large measure, given the significant level of carbon dioxide ("CO_2") emissions associated with electricity generation. California is the first state in the United States to mandate a cap-and-trade program for reducing CO_2 emissions, with program implementation starting in 2012 to be ready for mandated compliance by major sectors (including electricity generation) in 2013. California also has a legislative mandate to obtain 20% of all electricity sales from renewable energy sources by 2013 and 33% by 2020. The anticipated penetration of carbon-free renewable generation is assumed to make a significant contribution toward achieving California's goal from Asembly Bill 32 of reducing CO_2 emissions to 1990 levels by 2020.

The three-year Renewable Energy-based Secure Communities ("RESCO") project is designed to examine the technical and economic impacts of integrating increasing levels of renewables into community-scale grid systems. These systems can range from as small as a university campus, to a city, or to an entire state. The goal of the RESCO project is to provide a roadmap for enhancing the energy security of communities and regions while simultaneously increasing levels of renewable generation. The heart of the RESCO project is a MATLAB-based computer program that integrates different modules to simulate the interaction of each generator type. This in turn enables the calculation of the levelized cost of electricity ("LCOE") for varying levels of renewable penetration onto an electric grid. The purpose of this paper is to examine the impacts of increased renewable penetration on grid system operation, CO_2 emissions and levelized cost of electricity.

Methods

The integrated MATLAB-based computer model is structured as indicated in Figure 1. The integrated computer model contains four major modules: (1) Renewable generation; (2) dispatchable load; (3) balance generation; and, (4) cost of generation. The electricity demand to be satisfied is based on historical California load. The model is calibrated based on historical electricity generation data released by the Federal Energy Regulatory Commission and existing legacy generating capacity from the California Independent System Operator and the California Energy Commission.

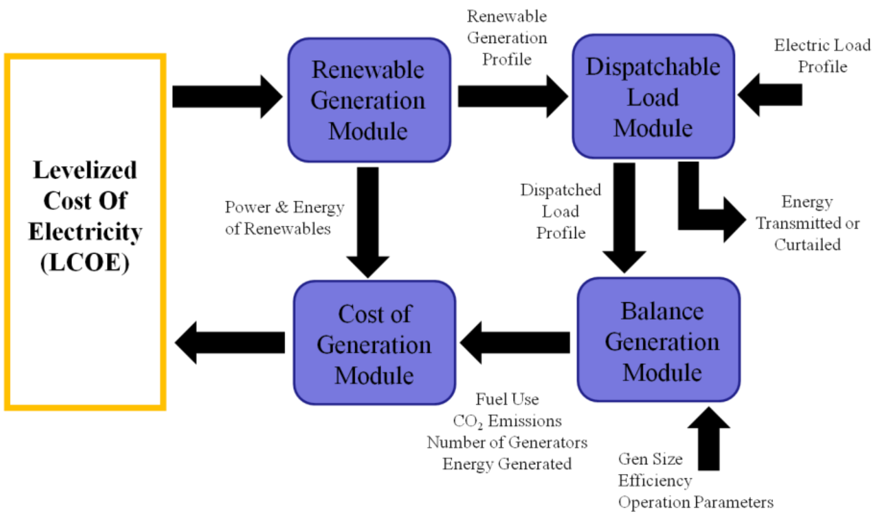

Figure 1: Generator and Renewable Integrated Dispatch Model Flowchart

The renewable generation module calculates the spatial and temporal renewable generation profile for different renewable resources, including solar photovoltaics, wind, and geothermal. Effects on the load profile from hydroelectric generation, energy storage, and demand response are included in the dispatchable load module. The net amount of energy that must be generated or curtailed is calculated, where the curtailment is defined as energy that cannot be used or stored by the grid system at the time it is generated. Using generator size and operation characteristics, the balance generation module balances the system, ensuring that demand is met and sufficient reserve capacity is provided to meet reliability criteria. The cost of generation module draws the operational information from each module that is required to calculate the LCOE not only for each generator type included in the portfolio, but also for the portfolio as a whole. Using the model in an iterative manner, system operation can be optimized for different criteria (*e.g.*, minimum LCOE, maximum system efficiency, minimum CO_2 emissions).

A comparison between the weighted average LCOE for different portfolios, each representing a different level of renewable penetration, is used to calculate what level of CO_2 tax on fossil fuel generation would be required to balance the increased costs of renewable energy. In addition, the trade-off in CO_2 emissions between increased renewable penetration (reducing CO_2 emissions) and the consequent increases in dispatchable fossil fuel generation required for balancing the grid system (increasing CO_2 emissions) will be examined. This examination will include an assessment of the impact of renewable curtailment on both CO_2 emissions and required dispatchable generation, with the goal of determining what level of renewable generation would be required to actually achieve California's goals of reducing CO_2 emissions to 1990 levels by the year 2020.

Results

Both economic and technical results will be presented for different scenarios, with 2005 serving as the baseline model year. Results will be presented largely as graphs showing which type of generators are required to satisfy load as progressively more renewables generation is brought online. The types of generators required and their mode of operation have a significant impact on CO_2 emissions, sometimes in unexpected ways. As an example, the CO_2 emissions and LCOE of load-following and (particularly) peaking dispatchable generation are highly impacted by changes in capacity factors that result from changes in the fleet of generators required to balance intermittent renewable generation. Thus, increased renewables penetration does not affect CO_2 emissions and LCOE in a linear manner; rather, diminishing reductions in CO_2 emissions and exponential growth in LCOE result as the renewable energy penetration level increases.

The results will be presented as follows: The introduction will: (i) lay out the legislative requirements for renewable generation and CO_2 emissions that must be met in California, and (ii) provide a high level summary of the various modules that make up the integrated computer model. The second section will provide a brief overview of the various renewable energy penetration scenarios that were examined. The third section will address near-final results of the various renewable energy penetration scenarios in terms of technical, cost, and CO_2 emissions impacts and the interaction between the three.

Conclusions

Increased levels of renewable generation makes grid management and balancing of the electric grid more challenging. Understanding the effects of integrating renewables requires a detailed knowledge of the behavior of the generating resources that comprise the electric grid and their ability to mitigate intermittencies. The model presented has the ability to explore system-wide interactions between conventional generation and additional renewable generation. This information is pivotal to developing a "complete picture" for how California can achieve low CO_2 emissions, high renewable penetration, and reliable electricty provision at the lowest LCOE.

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