Energy 92 (2015) 260–269

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Achieving 33% renewable electricity generation by 2020 in California

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ARTICLE INFO

Article history:
Received 8 December 2014
Received in revised form
6 May 2015
Accepted 21 May 2015
Available online 23 June 2015

Keywords:
Energy planning
Carbon Emission Pinch Analysis
Energy Return on Energy Invested
Renewable energy

ABSTRACT

This paper investigates the impacts of California, USA reaching its renewable electricity target of 33%, excluding large hydro, by 2020, which is set out in the state's RPS (Renewable Portfolio Standard). The emerging renewable electricity mix in California and surrounding states which form the WECC (Western Electricity Coordination Council) is analysed using the CEPA (Carbon Emission Pinch Analysis) and EROI (Energy Return on Energy Invested) methodologies. The reduction in emissions with increased renewables is illustrated and the challenge of maintaining high EROI levels for renewable generation is examined for low and high electricity demand growth. Results demonstrate that wind and solar PV collectively form an integral part of California reaching the 33% renewables target by 2020. Government interventions of tax rebates and subsidies, net electricity metering and a four tiered electricity price have accelerated the uptake of electricity generation from wind and solar PV. Residential uptake of solar PV is also reducing overall California electricity grid demand. Emphasis on new renewable generation is stimulating development of affordable wind and solar technology in California which has the added benefit of enhancing social sustainability through improved employment opportunities at a variety of technical levels.

1. Introduction

Reducing GHG (greenhouse gas) emissions from electricity production in California is a significant challenge, especially with a growing population, which is expected to grow from 37 million in 2010, to 41 million by 2020, and 51 million by 2050. Electricity demand in California is even more sensitive to population growth due to the higher per capita electricity consumption relative to the rest of the world. Even with moderate economic growth and business as usual efficiency gains, California will need roughly twice as much electricity in 2050 as required in 2010.

In an effort to reduce GHG emissions, California Governor Arnold Schwarzenegger issued Executive Order S-3-05 in 2005, which set overall GHG emissions reductions targets such that 2010 emissions were at 2000 levels (466 Mt CO_2-e), 2020 emissions be at 1990 levels (425 Mt CO_2-e), and 2050 emissions be 80% below 1990 levels (85 Mt CO_2-e).

To target GHG emissions from electricity generation specifically a RPS (Renewable Portfolio Standard) was established in 2002 by the State Senate (Senate Bill 1078) and a 33% renewable electricity requirement (excluding large hydro) by 2020 was mandated in 2011 (Senate Bill 2) [1]. The requirement included all publically owned utilities, investor-owned utilities, electricity service providers, and community choice aggregators. All of these entities were required to adopt the new PRS goals of 20% renewables by 2010, 25% by the end of 2016, and the 33% mandate by 2020 [2]. The California Energy Commission and California Public Utilities Commission are working collaboratively with generators to implement RPS.

Numerous reports have been commissioned to provide insights into how California can reduce GHG emissions to meet the 2020 requirement and also the long range target in 2050. The energy sector including electricity and transport are the major contributors of emissions in California and four key actions are proposed for reducing emissions [3]. These include:

1. more energy efficient buildings, industry and transport;
2. more electrification in place of fossil fuel where technically feasible;
3. decarbonizing electricity supply and developing zero-emission load balancing approaches to manage load variability and to minimise the impact of variable supply renewables like wind and solar;

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http://dx.doi.org/10.1016/j.energy.2015.05.087
0360-5442/

4. decarbonizing the remaining fuel supply where electrification is not feasible.

Scenarios for achieving the 2050 target have been extensively modelled, accounting for demand growth trends, technology feasibility, behaviour models, energy resource availability and technology cost projections [4].

Meeting the interim 2020 emissions target involves many government measures, policies and initiatives. In 2007, reporting of GHG emissions from the largest industrial sources became mandatory and a "cap and trade" emissions trading system. In 2008 the state released a 2020 scoping plan which provides an outline for action [5] and in 2009 new passenger vehicle efficiency standards were adopted through to 2016. There is growing confidence the 2020 emissions target for California can be met. The 2008–2009 recession has also helped to keep energy demand growth down, and along with the persistent sluggishness of the US economy and various energy efficiency measures, overall California emissions are trending down [6].

The aim of this paper is to investigate how California can raise its renewable electricity generation to 33% by 2020 using CEPA (Carbon Emission Pinch Analysis) and EROI (Energy Return on Energy Invested) methodologies. The goal of 33% renewable electricity generation by 2020 is a critical interim step to achieving sustained emissions reduction to 1990 levels and 80% reduction of this level by 2050. EROI values are correlated to levelized cost of power production to understand the cost implications of increasing California's renewable generation to 33%.

2. Methods

2.1. Carbon Emissions Pinch Analysis

CEPA is a macro-scale technique for studying emissions constraint planning of sectorial and regional systems [7], including CCS [8], multi-period scenarios [9] and variable CO_2 sources and sinks [10]. It was first developed by Tan, Foo, and co-workers [11] for planning carbon constrained large energy sectors. CEPA has also been applied to national electricity sectors [12] and to electricity generation mix optimised for minimised energy cost [13]. Recently the method has been applied to national transport sector planning [14].

A major aspect of CEPA applied to multi-state electricity network generation involves the construction of multiple supply and demand composite curves that plot cumulatively the quantity of electricity generated in each state by generation type (supply) and electricity consumed in each state including imports and exports (demand), against total equivalent carbon emissions (CO_2-e) for all states or all generation types. The state and generation type with the lowest EF (Emissions Factor), which is the amount of emissions produced per unit of useful electricity output (i.e. kt CO_2-e/GWh), is plotted first, and followed by the next highest and so on. The slope of the supply profile is equal to the EF. The overall GEF (Grid Emissions Factor) is simply the weighted average of the individual EFs for the entire system.

To illustrate the method, an example using hypothetical data is presented in Table 1 and Fig. 1 for a three-state electricity network system. Fig. 1A presents the overall supply and demand for all three states in terms of generation mode or fuel type with the associated overall emissions of 1000 kt CO_2-e. Fig. 1B gives a breakdown of the supply profile and demand profile for each state. The supply GEF for States A, B and C is 0.45, 1.00 and 1.83 kt CO_2-e/GWh respectively. However for State A that imports 100 GWh electricity, the GEF for in-state generation is only 0.45 kt CO_2-e/GWh, with the remaining imports coming from States B and C. The GEF for imports can be treated a number of ways depending on the available information. In this case the EF for the import is split between States B and C so the average GEF for these states is used (i.e. 1.24 kt CO_2-e/GWh). Other approaches such as using the average GEF of the exporting states only could also be used.

If the new emissions target is 600 kt CO_2-e, emissions can be reduced through replacing 160 GWh of Fuel B generation with new Renewables (Fig. 1C). Similarly one may decide the contribution each of the three states to increase renewable energy; for example, replacing fuel B with 30 GWh of renewable generation in State A, 80 GWh of renewable in State B, and 50 GWh of renewable in State C (Fig. 1D).

There are many combinations that can achieve a 40% emissions reduction target, but options illustrated in Fig. 1C and D identify important limits bounding the various combinations. Fig. 1C shifts generation from Fuel B to renewable and thereby takes advantage of the near zero emissions of renewables relative to Fuel B. Fig. 1D illustrates how each state profile is lowered with more renewable generation to achieve the overall 40% reduction of emissions.

2.2. Energy returned on energy invested analysis

Switching to renewable electricity generation to reduce emissions makes sense provided the renewable energy is in good supply and the technology is available at an economic price; however CEPA analysis alone cannot predict the economics of generation. Therefore EROI principles and generation cost analysis are also needed to ensure conclusions from CEPA are economically relevant.

EROI is essentially the ratio of the amount of useful energy produced for society to the amount of energy that has to be expended to get the useful energy in the first place. The concept was first proposed by American systems ecologist Charles Hall [15]. EROI involving electricity generation is defined by Eq. (1) where $\dot{E}_{gen}$ is the amount of useful or gross energy per year, t_{life} is the expected lifetime of the plant and $\dot{E}_{exp}$ is the energy expended for extracting ($\dot{E}_{ex}$) and processing ($\dot{E}_{pro}$) the natural resource including construction (E_{con}) and decommissioning (E_{dec}) of the power plant [13]. Processing conversion loses are not included in useful energy produced. All energy units should either be in work equivalent or heat equivalent units, where 3 units thermal may be assumed to equal 1 unit of work.

$$EROI = \frac{\dot{E}_{use}}{\sum \dot{E}_{exp}} = \frac{\dot{E}_{use}}{\sum(E_{con} + E_{dec})\Big/t_{life} + \dot{E}_{ex} + \dot{E}_{pro}} \tag{1}$$

EROI for electricity generation can vary greatly depending on the type and quality of the natural resource being exploited and the technology used for extraction and conversion [16]. Hall et al. [17] discuss these issues and reviews EROI values from literature.

EROI values also vary over the life cycle of a technology or over the lifetime of a generation plant or device. In the early stages of development a technology's EROI may be low (e.g. solar PV); but as a new technology matures through development of the technology itself, the production process, and the installation process, the EROI of the technology vastly improves [18].

Where fossil fuel resources like oil or coal feed a plant, the fuel can become harder to find and extract over time and this causes fuel EROI to fall and generation EROI to also fall over the lifetime of the plant. Renewable energy sources are strongly dependent on climate and geography in and around the area where the generation device is located. Climatic conditions can vary dramatically in both the short term (minutes and days) and the long term (months and years) and this can have a significant effect on EROI and hence the levelized cost of renewable electricity generation.