California's Renewables Portfolio Standard (RPS) requires 33% renewable electricity generation by 2020 - Dream or Reality?

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ABSTRACT

Progress on California's Renewable Portfolio Standard (RPS), which requires 33% of all retail electricity sales to be served by renewable energy sources by 2020, excluding large hydro, is reported in this paper. The emerging renewable electricity mix in California (CA) and surrounding states which form the Western Electricity Coordination Council (WECC) is analysed using the Carbon Emission Pinch Analysis (CEPA) and Energy Return on Energy Invested (EROI) 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. The role of the California government in facilitating progress towards a more sustainable renewable electricity future is also highlighted.

The investigation shows that wind and solar PV collectively form an integral part of California reaching the 33% renewables target (excluding large hydro) by 2020. Government intervention of tax rebates and subsidies, net electricity metering and a four tiered electricity price has accelerated the uptake of renewable 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

The challenge of reducing greenhouse gas (GHG) emissions from electricity production in California is significant especially with a growing population. In 2020 and 2050 California's population is expected to grow from the 2010 level of 37 million to 41 million in 2020 and 51 million in 2050. 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. California already has a relatively high per capita electricity consumption, and so many questions confront the political leaders of the state. Where will the future low emissions electricity of the state come from? How reliable will the energy supply be? Will there be enough into the future? How much state-wide investment will be needed over the next 30 years? Will the voting public continue to support low emission electricity initiatives?

To their credit the California State Government is taking seriously the challenge of reducing greenhouse gas (GHG) emissions. In 2005, California Governor Arnold Schwarzenegger issued Executive Order S-3-05 which requires California to reduce overall GHG emissions across all sectors (i.e. transportation, electricity, heating, agriculture etc.) from 470 Mt CO_2-e in 2005 to 85 Mt CO_2-e (20% of 1990 levels) by 2050. As a first step in 2006, the California government signed into law, the Global Warming Solutions Act, which requires state wide GHG emission to be lowered to 1990 levels by 2020 (i.e. 425 Mt CO_2-e). Again in 2009, led by Governor Arnold Schwarzenegger, California's Renewable Portfolio Standard (RPS) was signed into law as Executive Order S-21-09. The RPS requires 33% of all retail electricity sales to be served by renewable energy sources by 2020.

The 33% Renewable Electricity Standard applies to all electricity retailers including publically owned utilities, investor-owned utilities, electricity service providers, and community choice aggregators. All of these entities must adopted the new RPS goals of 20% of retails sales from renewables by the end of 2013, 25% by the end of 2016, and the 33% requirement by the end of 2020. 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 interim target in 2020 and 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 [1]. 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. (4) Decarbonizing the remaining fuel supply where electrification is not feasible. Scenarios for achieving the 2050 target have also been extensively modelled, accounting for demand growth trends, technology feasibility, behaviour models, energy resource availability and technology cost projections [2].

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 system was proposed, but not yet implemented. In 2008 the state released a 2020 scoping plan which provides an outline for action [3] 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 [4].

The goal of 33% renewable electricity generation by 2020 is a critical interim step to achieving sustained emissions reduction to the 1990 level and 80% reduction of this level by 2050. Progress towards this important environmental goal is examined and evaluated in this paper using Carbon Emissions Pinch Analysis (CEPA) and Energy Return on Energy Invested (EROI) methodologies to determine the impact on the amount of total energy expended for electricity generation and possible effect on the average price of electricity.

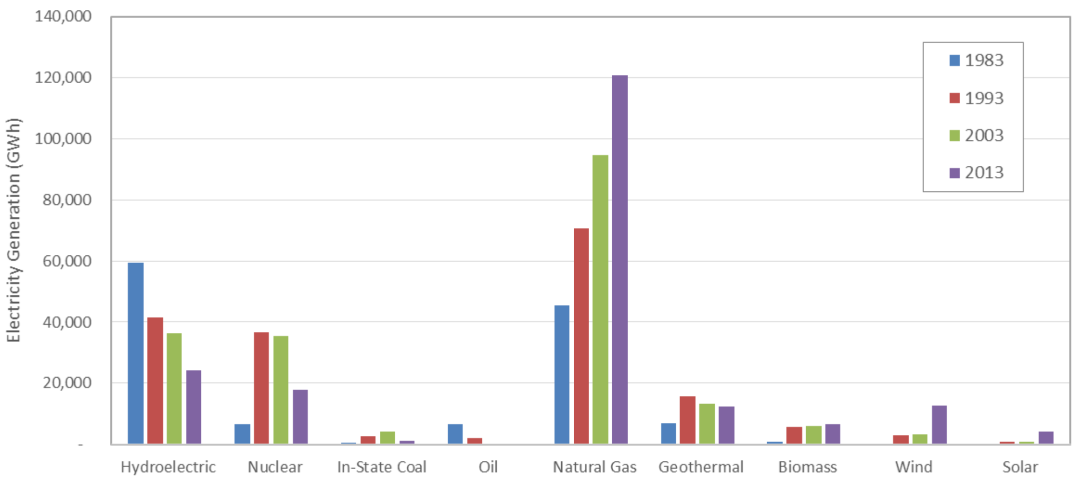

Figure 1. Comparison of California in-state electricity generation over the last 30 years [5].

1.1. Background information on the California Electricity Generation Sector

California has abundant natural resources to support a high renewables electricity target. Hydro, geothermal, biomass and onshore wind have all played a significant role in electricity generation in California over the last 30 years (Figure 1). Natural gas is still the dominant energy resource with combined cycle natural gas plants growing as oil, nuclear and coal plants decline. Hydroelectric generation has also trended down possibly due to climate change and competition for water resources from irrigation. No significant new large hydro has been installed since 1979. Wind and solar are the two renewable resources that have experienced significant growth since 2003. Generation from these two sources has grown to 8.5% in 2013, from 2.1% in 2003 and 1.8% in 1990 [6].

In terms of average levelized cost (2009$/MWh) including taxes and subsidies, renewable electricity generation from geothermal, hydro and wind, are competitive in California with traditional carbon based methods, such as combined cycle natural gas and integrated gasification combined cycle (IGCC) for coal (Figure 2) [7]. Hydro capacity upgrades of existing sites and onshore wind at the right sites are also competitive and in some cases cheaper on average. Solar PV and solar parabolic trough methods, however, are still more than double other generation methods, even with significant tax rebate benefits, and simple cycle plants used for electricity peaking have the highest MWh costs.

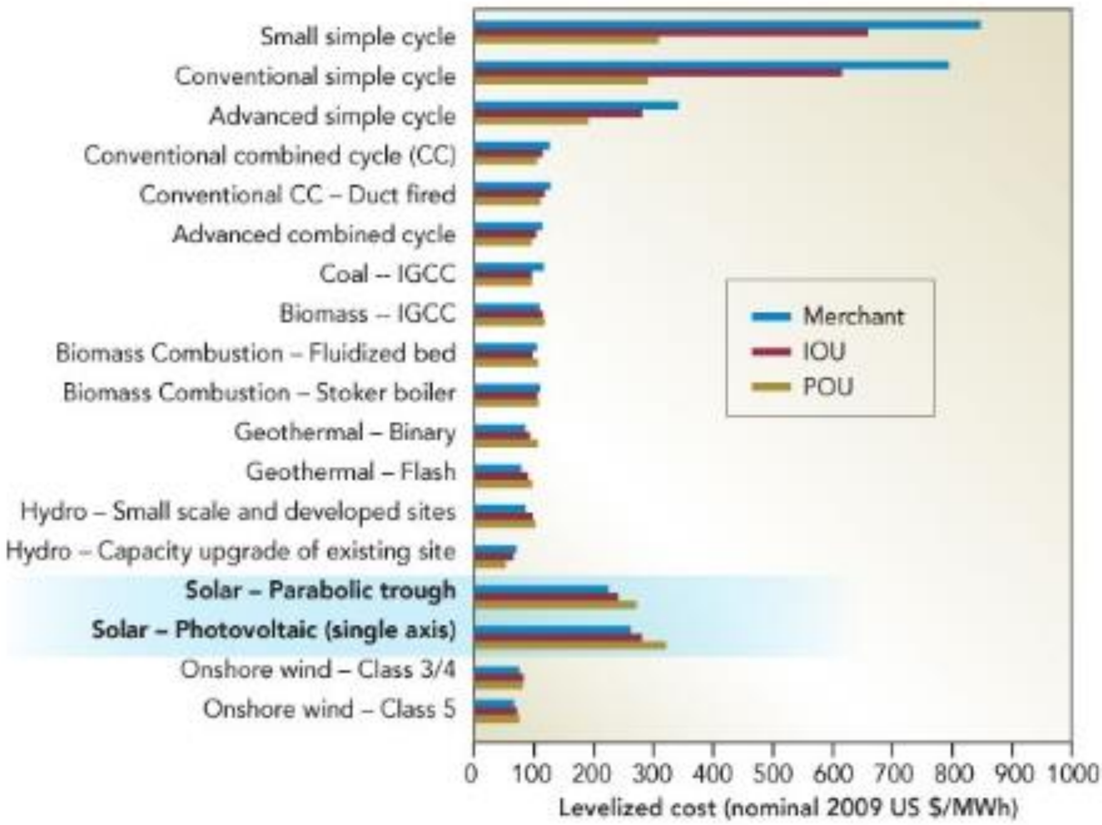

Figure 2. Average levelized costs-in-service for California electricity generation in 2009 for private merchants, investor-owned utilities (IOUs), and publicly owned utilities (POUs) [7].

On an initial capital expenditure basis, called instant costs (2009$/kW), solar PV and solar parabolic trough costs are predicted to keep falling along with onshore wind (Figure 3). Solar PV is predicted to inevitably become cheaper than solar parabolic trough and may even surpass onshore wind and be within range of the gas-fired combined cycle plants by the end of the study period in 2028. Subsidies on solar will reduce as the technology matures becomes competitive. Reduction in solar cost per MWh generation is attributed to on-going learnings from large scale manufacturing and installation [8]. Cost reduction will be caused by lower PV module costs (<20% costs), reduction in non-module "hard" costs for inverter, racking, electrical equipment etc. (<30% costs), and reduction in "Soft costs" from labour, permitting fees, etc. (50-60% costs). Most other well established technologies, like hydro (small and large), geothermal (flash and binary), combined cycle gas (conventional and advanced), biomass combustion and coal or biomass (IGCC) have little or no expected improvement in terms of real cost over the 20-year period of the study.

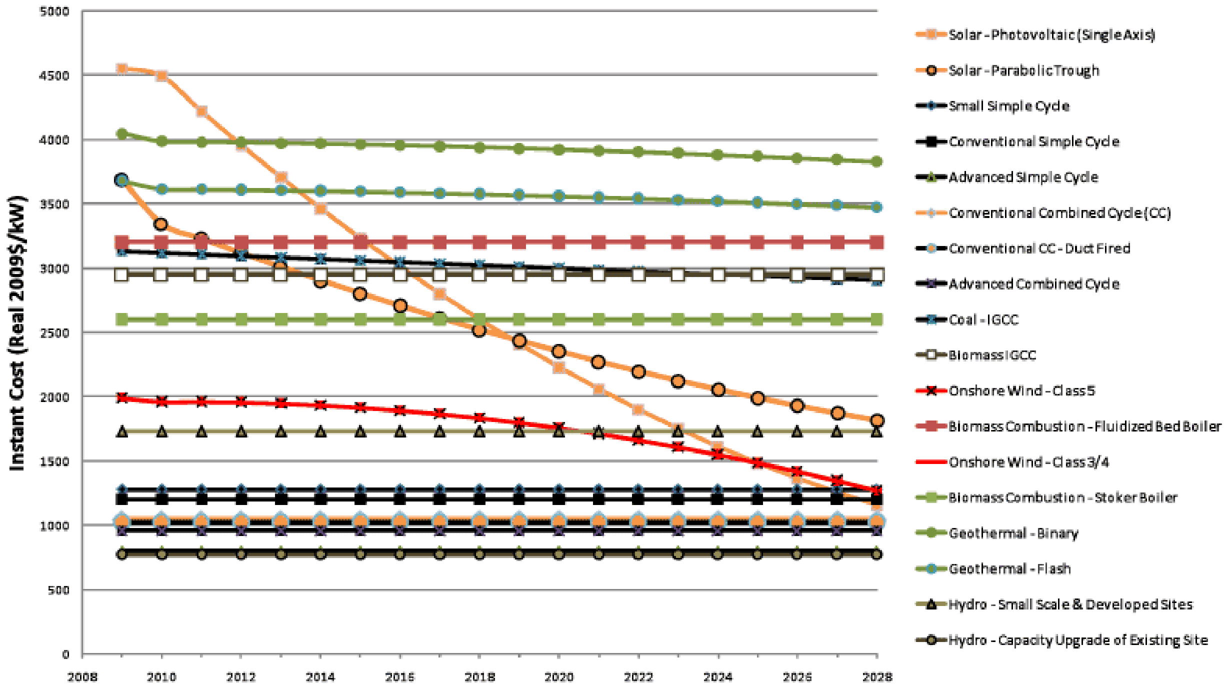

Figure 3. California electricity production average instant cost trend from 2008 to 2028 (Real 2009 $/kW) [7].

California produces about two thirds of its electricity needs. The other one third is imported from the Western Electricity Coordinating Council (WECC). Large quantities of residential solar PV have also been installed over the last 10 years and this new generation is officially counted as demand reduction rather than new network generation [9], however in this study all solar generation is counted as generation.

1.2. Background information on the Western Electricity Coordinating Council

North America is divided up into four independent electric power interconnects (Figure 4). California is part of the Western North American electric power interconnect, coordinated by the WECC. Thirteen North American states or provinces, including two from Canada, plus small portion of North West Mexico, North West Texas and North West Nebraska make up the WECC. These include British Columbia, Alberta, Washington, Oregon, Idaho, Montana, Wyoming, California, Nevada, Utah, Colorado, Arizona and New Mexico. States export and import electricity to the combined network and depending on minute-by-minute supply and demand requirements many states are interdependent for reliable electricity supply. California imports electricity from the Pacific Northwest, most likely from hydroelectric power sources, and from the Desert Southwest, most likely from coal and nuclear power sources. Other states with low populations and proportionately more natural energy resources like Arizona, Wyoming, Washington, and New Mexico are significant net exporters.

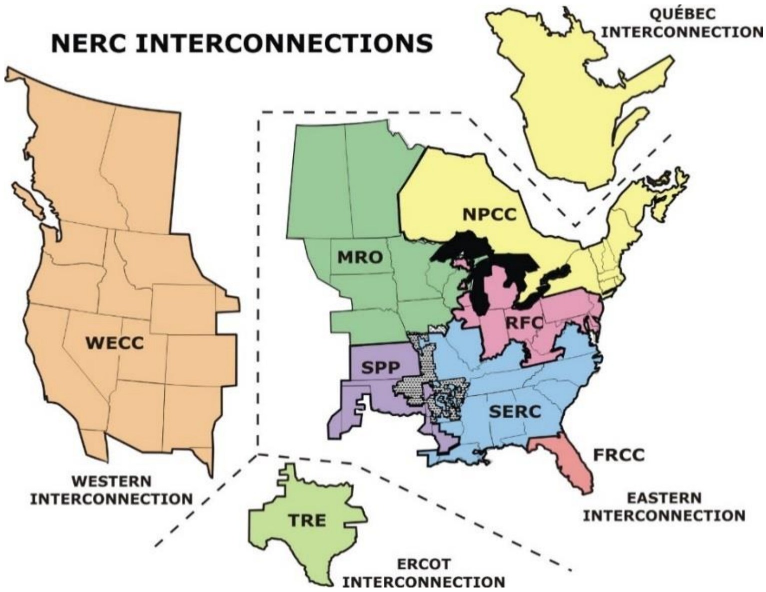

Figure 4. North American Electricity Reliability Corporation (NERC) [2].

For this study the WECC have been modelled as an integrated generation and supply network. Electricity generated in-state has been assumed to be first consumed within that state and electricity imported has been assumed to come from the remaining WECC network. Similarly states that are net exporters are assume to export electricity to the remaining WECC states, after consuming what they need.

2. THEORY AND METHODS

2.1. Carbon Emissions Pinch Analysis

Carbon Emissions Pinch Analysis (CEPA) is a macro-scale technique for studying emissions constraint planning of sectorial and regional systems [10], including CCS [11], multi-period scenarios [12] and variable CO_2 sources and sinks [13]. It was first developed by Tan, Foo, and co-workers [14] for planning carbon constrained large energy sectors. CEPA has also been applied to national electricity sectors [15] and to electricity generation mix optimised for minimised energy cost [16]. Recently the method has been applied to national transport sector planning [17].

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 Emissions Factor (EF) (the amount of emissions produced per unit of useful electricity output, i.e. kt CO_2-e/GWh) is plotted first, followed by the next highest and so on. The slope of the supply profile is equal to the emissions factor. The overall Gross Emissions Factor (GEF) is simply the average total emissions factor or specific emissions for the entire system.

An example of the method is presented in Table 1 and Figure 5 for a three-state electricity network system. Figure 5a 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. Figure 5b gives a breakdown of the supply profile and demand profile for each state. The supply GEF for States A, B and C is 0.3, 1.0 and 2.0 kt CO_2-e/GWh respectively. However, for State A that

imports electricity, State A electricity consumption is responsible for GEF of 0.55 kt CO_2-e/GWh, made up of in-state generation plus the average GEF of the remaining States B and C network. 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 (Figure 5c). One scenario is 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 (Figure 5d).
There are many combinations that can achieve a 40% emissions reduction target, but options illustrated in Figures 5c and 5d identify important limits bounding the various combinations. Option 6c shifts generation from Fuel B to renewable and thereby takes advantage of the near zero emissions of renewables relative to fuel B. Option 5d illustrates how each state profile is lowered with more renewable generation to achieve the overall 40% reduction of emissions.

Table 1. Example of three-state electricity network and emissions scenario.

	Quantity [GWh]	**Inter-State [GWh]**	**Emissions [kt CO_2-e]**	**Emissions Factor [kt CO_2-e/GWh]**
Demand				
State A	400		90	0.3
State B	400		510	1.0
State C	200		400	2.0
Total Demand	**1000**		**1000**	1.0
Supply to State A				
Renewable	150		0	0
Fuel A	120		60	0.5
Fuel B	30		75	2.5
Total Supply to A	**300**	**100 (imports)**	**135**	0.45
Supply to State B				
Renewable	100		0	0
Fuel A	250		125	0.5
Fuel B	150		375	2.5
Total Supply to B	**500**	**-100 (exports)**	**500**	1
Supply to C				
Renewable	30		0	0
Fuel A	30		15	0.5
Fuel B	140		350	2.5
Total Supply to C	**200**		**365**	1.825
Total Supply	**1000**		**1000**	1.0

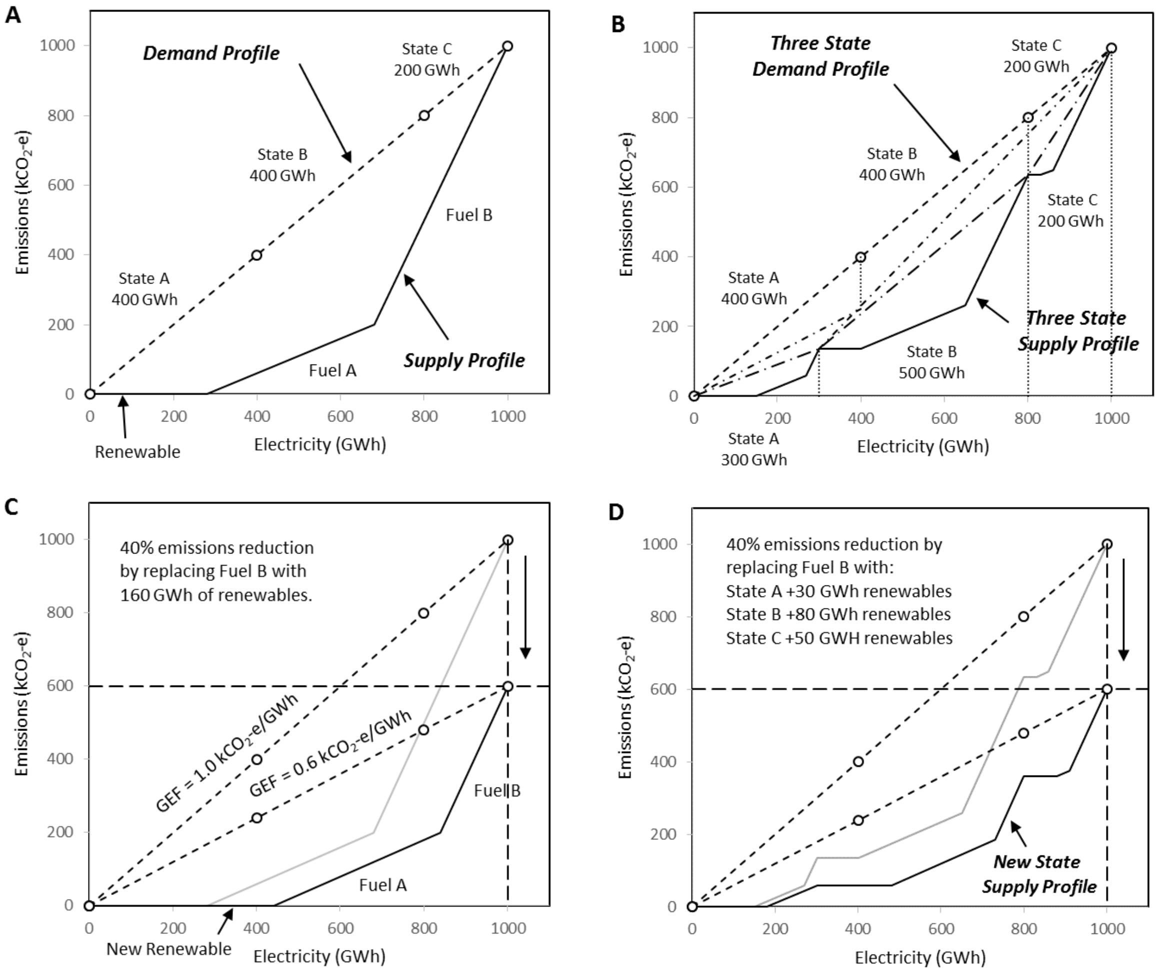

Figure 5. Example of multi-state demand and supply composite curves (a) overall profiles, (b) individual State profiles, (c) 40% emissions reduction by switching to more renewables and (d) State profiles for 40% emission reduction.

2.2. Energy Returned on Energy Invested Analysis and Electricity Generation Costs

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. CEPA analysis alone cannot predict the economics of generation. Therefore Energy Return on Energy Invested (EROI) principles and generation cost analysis are also needed to ensure conclusions from CEPA are also 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 by society to get the useful energy in the first place. The concept was first proposed by American systems ecologist Charles Hall [18]. The useful energy produced may be in the form of a *primary energy source* such as natural gas (NG), crude oil, coal, wind or hydraulic head or in the form of a refined *energy carrier* such as electricity, gasoline or briquettes [19].

EROI for an energy project 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 [16]. 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 equals one unit of work.

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

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 [20]. Hall et al. [21] discuss these issues and the EROI ranges presented in their review paper have been combined with high, low and average California levelized cost data for electricity generation (minus taxes and subsidies) in 2009 and 2018 [7] to create Figure 6. The cost of electricity generation in both 2009 and 2018 were found to be closely related to EROI through Eq. 2, for all generation methods except coal. The high levelized cost reported for coal generation in California is for IGCC coal only and not for conventional coal power generation. For the study EROI values for conventional coal are used.

$$EROI = \frac{1850(\$/\text{MWh}_{\text{exp}})}{C_{levelized}(\$/\text{MWh}_{\text{gen}})} \tag{2}$$

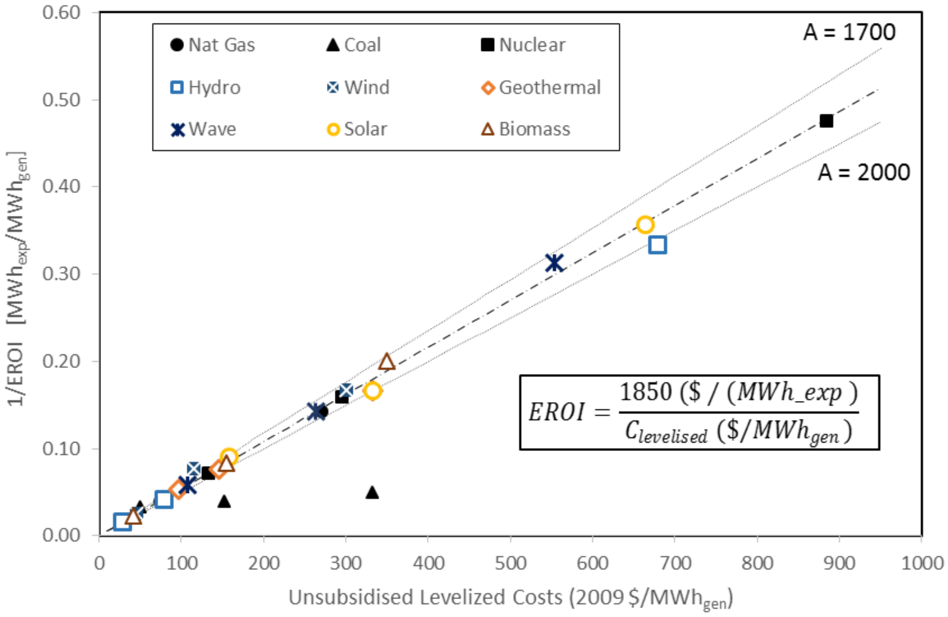

Figure 6. Relationship between EROI values and levelized costs for different electricity generation options in California [7,21].

Energy resources with traditionally high EROI, like large hydro, natural gas, and coal, have low levelized cost and are economically desirable and first to be exploited. Where EROI is much lower e.g. solar, wave/tidal and small hydro, levelized costs are higher and the economics for widespread adoption are less favourable without significant government intervention.

EROI values can 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). However, as innovative practice improves manufacturing and installation methods, conversion efficiencies, and as the new technology gains commercial acceptance and starts to be mass produced, EROI of the technology can vastly improve [22].

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.

While renewable energy resources like solar, wind and hydro are ‘free’ from nature, they often require access to large amounts of land to harvest the resource, and considerable energy and costs has to be expended to build infrastructure, storage facilities and equipment to harness the dispersed and low intensity renewable energy resources. The economics of renewable resources are therefore technology and site dependent and quite variable region to region, state to state and country to country.

The EROI values used in this study are presented in Figure 7 and Table 2. Values are based on 2018 levelized cost data for California excluding taxes and subsidies, except for coal which is based on Hall et al. [21].

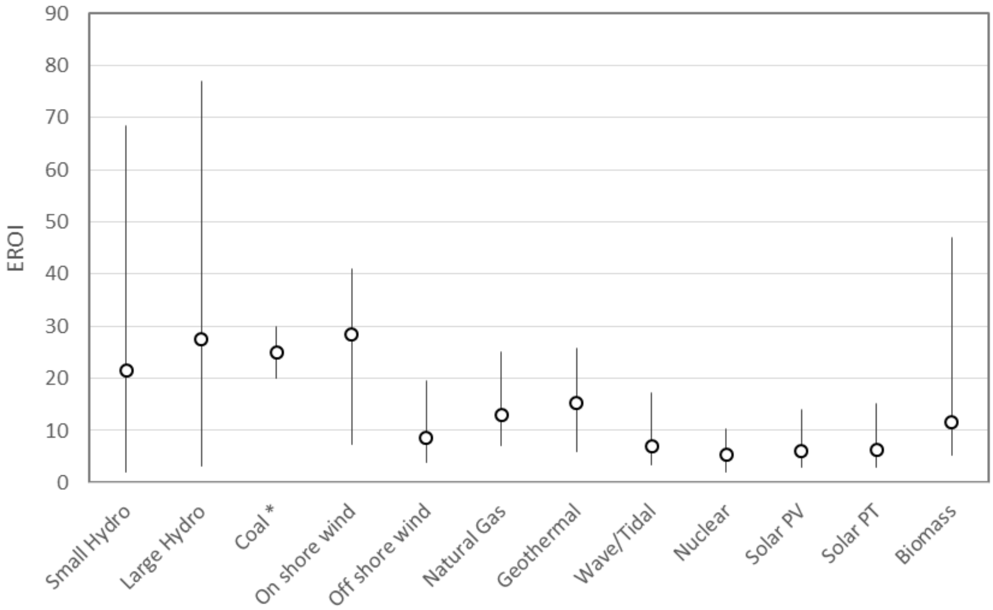

Figure 7. EROI levels for California based on Equation 2 and 2018 levelized cost [7,21].

Table 2. Emissions factor and EROI values used in this study.

Generation Type	Emissions Factor [kt CO_2-e/GWh]	Levelized Cost (Ave) [2018$/MWh]	EROI [GWh/GWh-e] Low	Average	High
Large Hydro	0	66	3	28	77
On shore wind	0	69	7	28	41
Coal (*conventional)	0.733	74	20	25	30
Small Hydro	0	84	2	22	69
Geothermal	0.128	123	6	15	26
Natural Gas	0.422	142	7	13	25
Biomass	0	154	5	12	47
Off shore wind	0	206	4	9	19
Wave/Tidal	0	264	3	7	17
Nuclear	0	370	2	5	10
Solar PV	0	308	3	6	14
Solar PT	0	308	3	6	15

3. RESULTS AND DISCUSSION

3.1. California electricity sector and population growth analysis

Increases in population in California and slight increases in electricity per capita are expected to result in electricity demand of about 320 TWh (9.6% increase) in 2020 and 449 TWh (54% increase) in 2050 for medium growth models compared to 292 TWh in 2010. Figure 8 shows high, medium and low growth projections for electricity demand. Population is also anticipated to increase. In 2020, California population will reach about 40.6 million people (8.8% increase) and, in 2050, grow to about 51.5 million people (38.1% increase) from 37.3 million people in 2010. In 2020 8.8% of the demand growth can be attributed to increased demand per capita whereas, in 2050, 29.4% of the demand growth relates to increased demand per capita. Electricity demand per capita is anticipated to rise due to electrification of the transport fleet, e.g. plug-in hybrids for personal use vehicles, and higher standards of living.

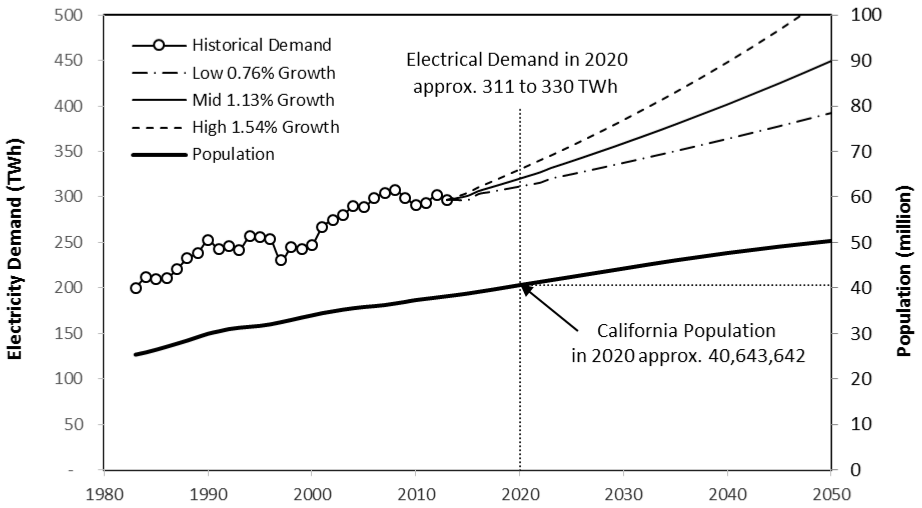

Figure 8. Projected population and electricity demand growth in California to 2050 for low, mid and high growth scenarios [4,6].

3.2. Carbon emissions pinch analysis

3.2.1 WECC and California emissions in 2010

The total electricity generation and its associated emissions in WECC is presented in Figure 9 using CEPA. Figure 9a shows the contribution of individual states to the supply of the total electricity demand and the emissions arising from this supply. Figure 9b shows the amount of electricity delivered and carbon emitted by the various resources. Electricity derived from coal has the highest emissions factor as indicated by the relatively steep slope, followed by oil and natural gas.

Figure 10 highlights the contribution of California to WECC. California generates 23.7% of the electricity on WECC, but uses 34.5% of the electricity. The difference between supply and demand is the electricity imports to California from other states in the WECC. As a result, Figure 10 shows California importing electricity from the remainder of WECC, which imports carries with them responsibility for proportion of emissions from the remainder of WECC. These imported related emissions are calculated using the average grid emissions factor of the remainder of WECC.

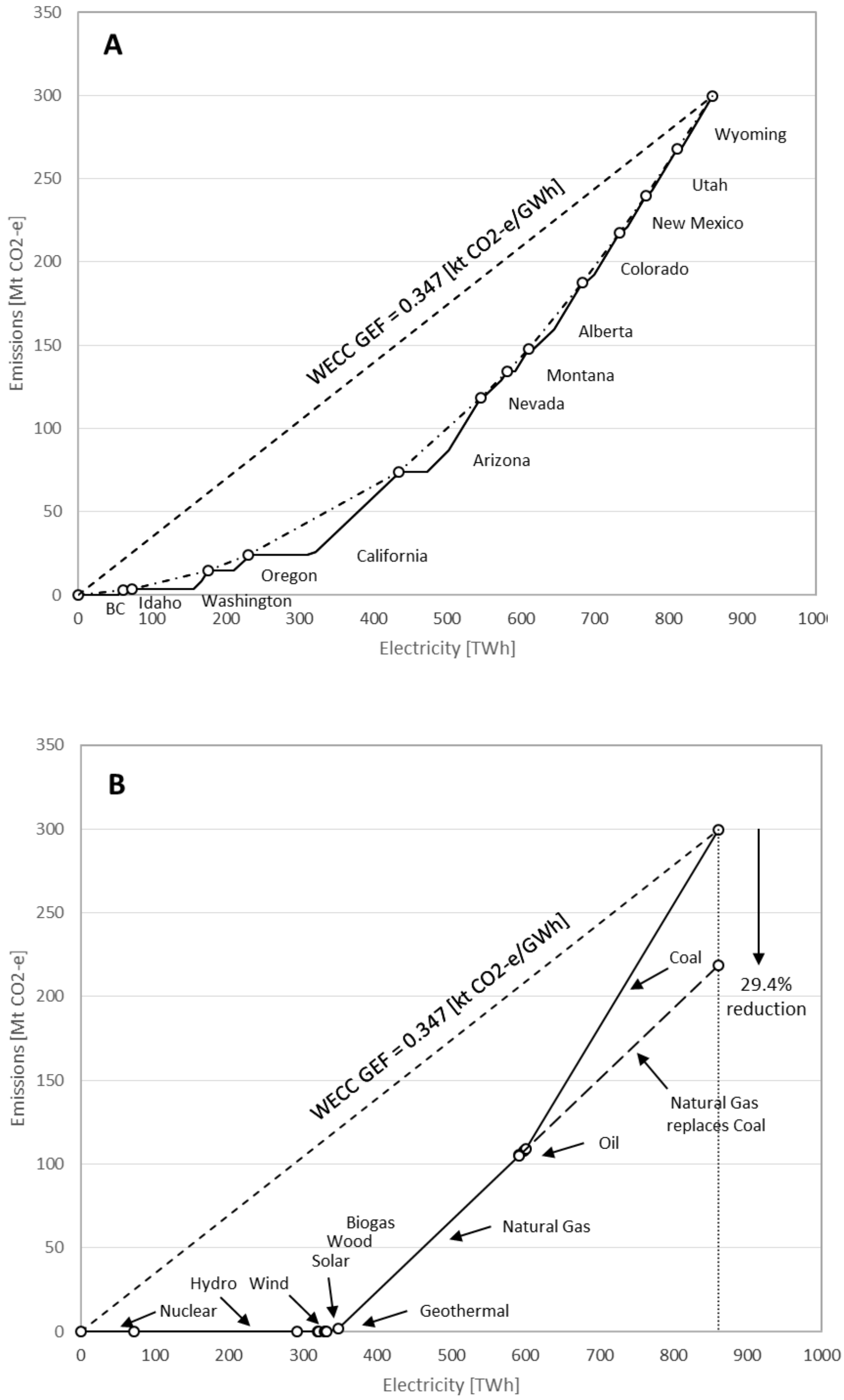

Figure 9. WECC emissions for electricity generation in 2010 by state (A) and by resource (B) [4].

Two methods to reduce emissions in the electricity sector are: (1) decrease demand for the same generation mix through improved energy efficiency, i.e. do more with less, and (2) switch supply to a resource with a lower emissions factor, i.e. natural gas for coal. Meaningful reductions in emissions from electricity in WECC of 80 Mt CO_2-e (29.4% decrease) is achievable by switching coal power plants for natural gas power plants as illustrated in Figure 9b. Energy efficiency initiatives targeted at both residential and industrial customers also reduce the need for new generation and grid network upgrades and expansions.

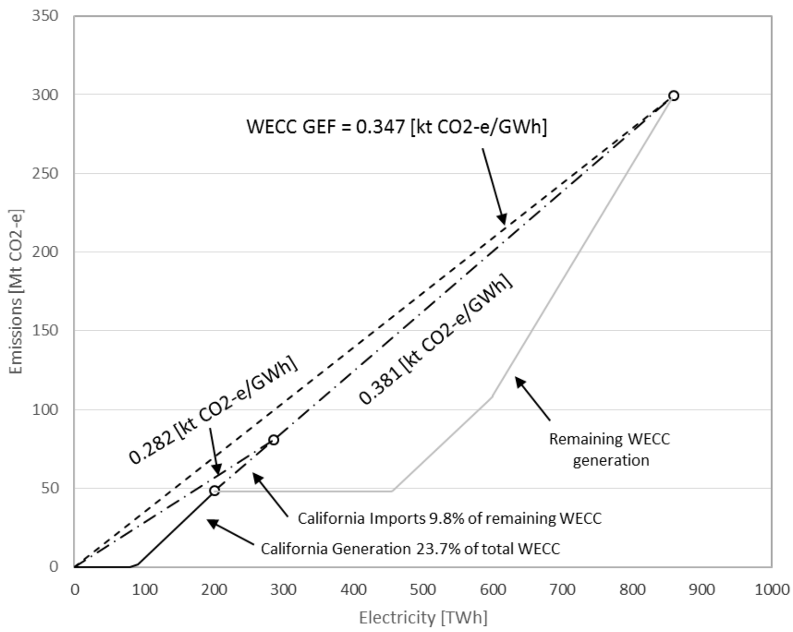

Figure 10. WECC and California electricity emissions 2010.

Natural gas has been rightly identified as a transition fuel that enables maintaining a high standard of living while also reducing emissions [23], while electricity generation from very low emission renewable energy resources becomes sufficiently economic in a great enough quantity to be competitive to replace fossil fuel power stations. With the recent glut in recovery of shale gas in North America, which has caused a considerable reduction in the price of natural gas, the economics for installing new combined cycle and combined heat and power plants powered by natural gas have significantly improved. However the supply of natural gas will be limited in years ahead and may be less accessible to some states within WECC, which means a continued focused on improving renewable energy technologies is still required.

In the case of California, there is minimal electricity generation from coal and so the opportunity for reducing in-state emissions generation via fossil fuel switching is not an option. The average emissions factor of imported electricity to California, other the other hand, can decrease from 0.379 kt CO_2-e/GWh to a minimum of 0.290 kt CO_2-e/GWh through replacing natural gas for coal in the other WECC states.

3.2.2 Annual electricity emissions for California in 1990 and 2010

Since 1990, California has generated slightly more than two thirds of its electricity demand and imported the remainder. Figure 11 shows the breakdown of electricity generation within California in 1990 (Fig 11a) and 2010 (Fig 11b), together with its associated emissions.

Imported electricity is shown in Figure 11 with an emissions factor equivalent to the average emissions factor for the remainder of the WECC grid system. Between 1990 and 2010 electricity from renewable resources increased from 26 TWh to 31 TWh, and as a percentage of California's electricity the share of renewable generation (excluding large hydro) remained similar at 14.9% in 1990 and 15.1% in 2010. Low emitting technologies like nuclear have remained nearly unchanged over the past three decades, and large hydro has fluctuated between 20 and 60 TWh per year due to variable snow and rainfall in hydro catchment area of California year to year.

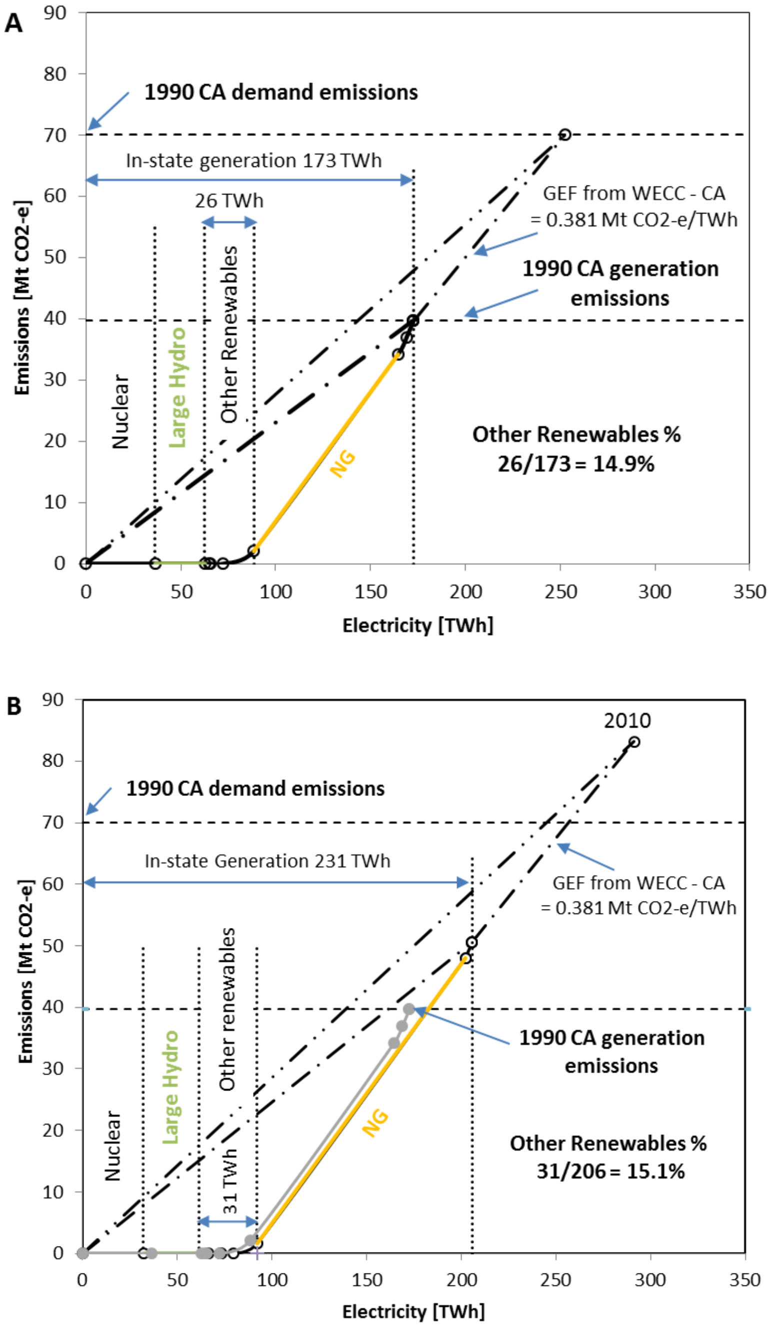

Figure 11. California electricity demand and emissions for 1990 and 2010.

3.3. Energy return on energy invested analysis

The energy expended to generate electricity for WECC is estimated using low, average, and high EROI values for the various resources and technologies as plotted in Figure 12. Based on the low EROI values, fossil fuels offer the best energy return for energy invested. However, based on high EROI values, hydro gives a better return on investment than coal and natural gas. Furthermore geothermal and wind generation are apparently a better energy investment than coal power plants when projected to 2018. This result is surprising as coal power plants have traditionally offered inexpensive energy. The positive EROI outlook for geothermal and wind generation may be the product of optimism for still to be determined energy costs such as maintenance for wind and/or the high EROI values may apply to a very limited number of sites and limited potential quantity of generation.

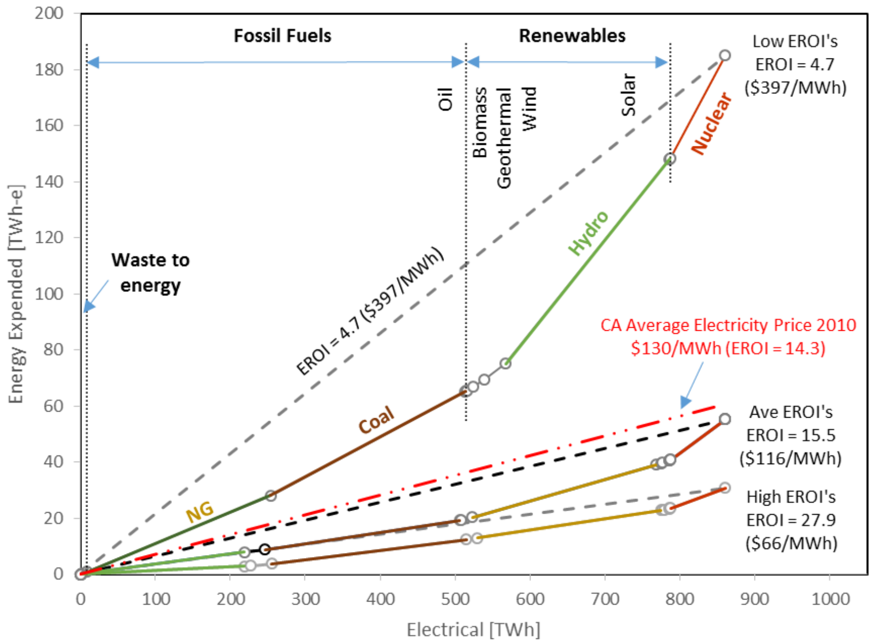

Figure 12. WECC energy expended for low, average and high EROI levels in 2010.

Using the average EROI values, the electricity generation in CA is split out from the remaining states in the WECC as shown in Figure 13. The average EROI for CA generation is 14.1, which is less than the average EROI for the remainder of the WECC at 18.7. The difference between the EROI values is chiefly due to the proportion of nuclear electricity generation in CA (15.8%) compared to the rest of WECC (6.2%), and natural gas electricity generation, which is 53% in CA and 21% in the rest of the WECC. Interestingly the CA gross EROI level of 14.1 corresponds to a levelized cost of $131/MWh (based on Eq. 2), and this value is very similar to the actual average price of electricity that existed in CA in 2010.

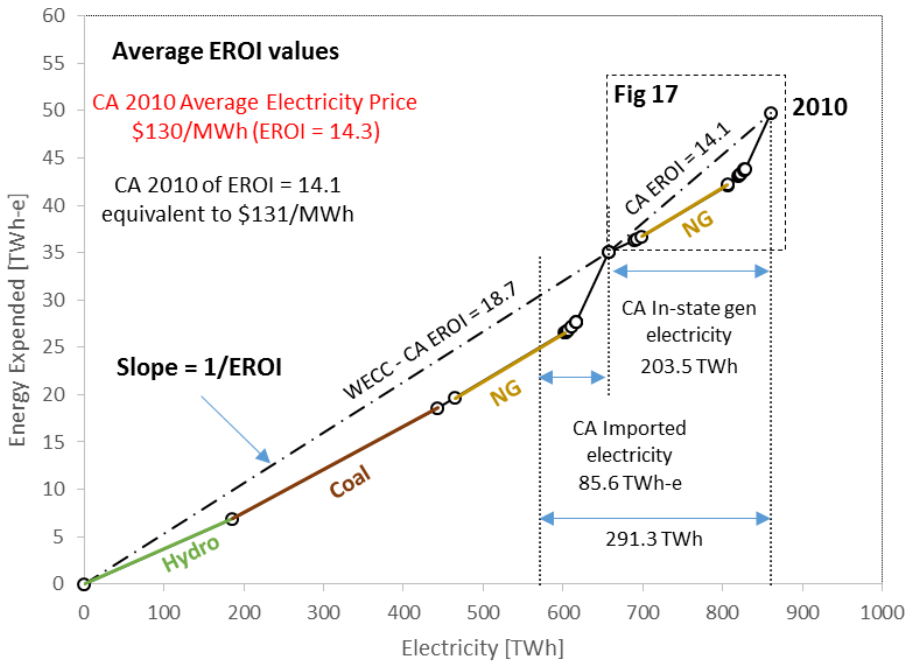

Figure 13. WECC and California energy expended for average EROI levels in 2010.

3.4. Electricity planning for California through to 2020

3.4.1 Meeting 1990 emissions levels and RPS 33% target

California's RPS (Renewable Portfolio Standard) requires 33% of all retail electricity sales to be served by renewable energy sources by 2020. To achieve this goal, most of the growth in renewable electricity generation will need to come from solar and on-shore wind. Figure 14 shows one possible projection from this study for solar of 640% (or 7.4 times) and on-shore wind of 100% (or 2 times) that meets the RPS target. Recent extra capacity for solar and on-shore wind in CA have followed an exponential growth curve since RPS was signed to law in 2008 as partly evidenced in Figure 14.

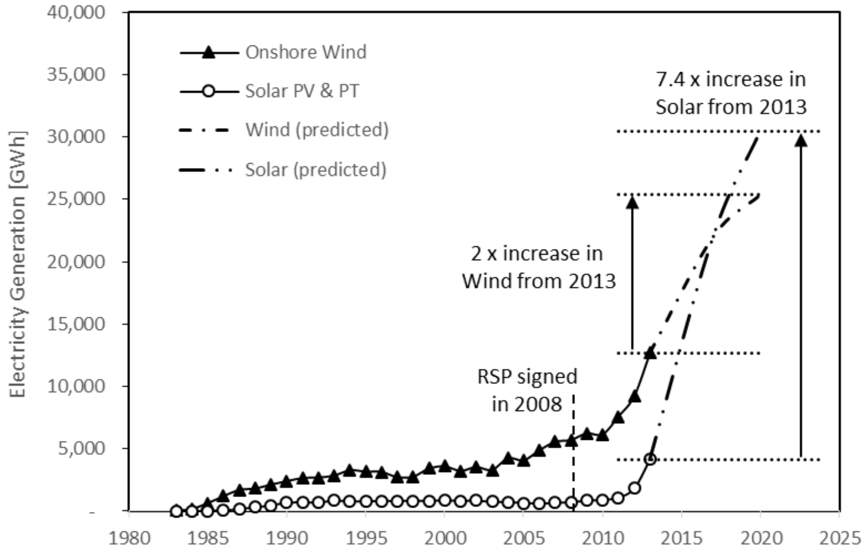

Figure 14. Projected electricity supply growth in California for on-shore wind and solar PV and PT required to meet 33% renewable target by 2020 for low electricity growth scenario.

The effect of increasing solar and on-shore wind to the levels indicated in Figure 14 on generation and emissions is graphically shown in Figure 15. Two cases of renewable electricity generation increases for high and low cases is also plotted in Figure 15. In both cases, the proportion of renewable electricity generation will exceed the RPS's minimum of 33% in 2020. Projections to 2020 assume electricity imports to CA are at 1990 levels of 79 TWh. If higher levels of electricity imports arise (e.g. 2010 levels of 85.6 TWh) proportionately less new renewables will be required to meet the RPS target.

CA Renewables (excluding large hydro) electricity generation and % renewables (excluding large hydro) levels, historically back to 1983 and projections to 2020 are presented in Figure 16. The low growth scenario has been modelled using the solar and wind generation projections of Figure 14, and assuming other generations stay constant. Natural gas has been the predominant generation method, followed historically by nuclear, large hydro, geothermal then wind and biomass. Solar has traditionally been a minor generation source, but with CA's RPS signed into law in 2008, and through a variety of government initiatives, solar PV has been made to be economically feasible for some segments of the market and the growth in those segments has been phenomenal. For example more solar PV was installed in CA 2013 than the proceeding 30 years combined. On-shore wind generation has also seen steady growth and generation is predicted to accelerate with favourable comparative economics and EROI levels. Overall new renewable growth reached 19.6% in 2013, which is very close to the interim target of 20% by 2013, and plans are in place to install more wind and continue promoting solar PV to residential and commercial customers to ensure 25% is reached by 2016, and 33% by 2020 [24]. With the CA state regulation manipulated to make on-shore wind and solar PV economically attractive there is no reason these targets won't be reached, other than a shift in political will to lower electricity prices by allowing cheaper forms of fossil fuel generation (e.g. conventional coal) once legislated taxes and subsidies are removed.

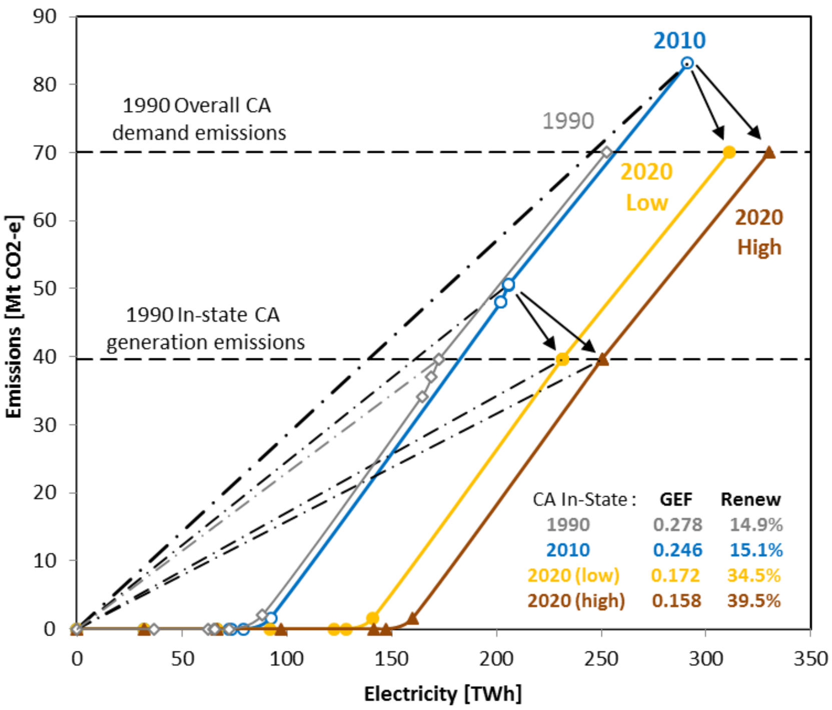

Figure 15. Projected CA electricity supply and demand in 2020 for high and low electricity growth scenarios.

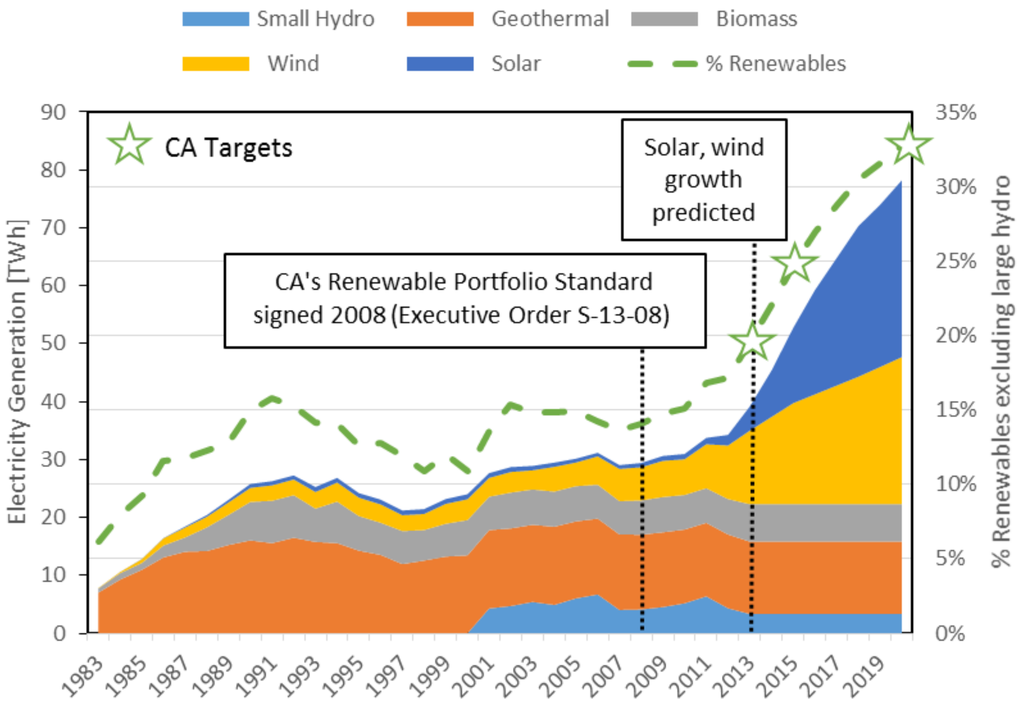

Figure 16. Historical and predicted Californian renewable electricity generation and % renewables (excluding large hydro) through to 2020.

To drive the electricity market towards solar renewable energy and especially residential and commercial solar PV, CA have implemented tax rebate subsidies on solar renewables, net energy metering (NEM) for solar PV owners and a four tiered pricing structure for residential and commercial electricity sales. NEM is a special billing arrangement that enables the customers with solar PV systems to pay only for the net amount of electricity they used, therefore receiving the full retail value for the electricity they generate. The four pricing tiers are set based on the amount of electricity demanded. For low users the price of electricity is relatively inexpensive and as consumption increases, so does the marginal price. The tiered structure means renewable electricity only needs to be competitive with the marginal price at the top end of the scale for the economics to favour renewable installation. The tiered pricing structure is one regulatory measure that has been implemented to encourage growth in the CA residential and commercial solar energy, and the measure is working.

The drive for more wind generation has been facilitated by an attractive federal tax credit and on-going wind R&D efforts that have lowered 2009 levelized cost for on-shore wind to a competitive $65/MWh [7]. Wind energy is also considered to create more jobs per MWh compared to convention generation technologies, especially when operations and maintenance, construction, manufacturing and many support sectors is contracted to local companies [25]. In addition, wind power projects produce lease payment for landowners and increase the tax base of communities. Wind generation is certainly not without environmental challenges, which include a large land footprint (7 hectares of land per MW), erosion in desert areas, changes in visual quality, disturbances to wildlife habitats include bird deaths and noise.

Current wind generation capacity in CA is 5830 MW, producing 12,694 GWh in 2013 at an overall capacity factor of 25% [5]. An additional 4,253 MW of generation is in the planning stage and according to data from the National Renewable Energy Laboratory, California's onshore wind potential at 80 meters hub height is 34,110 MW, enabling Wind power to potentially meet more than 40 percent of the state's current electricity needs [25].

3.4.2 Energy expended and electricity prices

The extent of the electricity cost penalty for promoting and subsidising solar PV when cheaper generation options are available can be determined through EROI analysis. Using Equation 2, gross EROI values for state wide generation options can be converted into levelized electricity generation costs and compared. Composite curves for energy expended versus electrical generation in 2010 and three 2020 generation mixes are presented in Figure 17. For 12.4% electricity growth from 2010 to 2020, energy expended increases by 21.5%. Similarly for the high growth scenario, 21.7% increase in generation requires 35.3% increase in energy expended. On a 2018 $/MWh basis, in real terms electricity will be 8 and 11% more expensive than if the same mix of generation was maintained as in 2010. If the RPS renewable target was abandoned and natural gas was expanded to meet the extra demand in place of new solar, then EROI would equal 11.9 and levelised cost would be approximately $155/MWh. This corresponds to a reduction in levelised cost of 4.9% relative to the 2010 base case, and an overall difference in costs compared to the 2020 low NG case of 12.9% for low and 15.9% for high as a result of implementation of a solar and wind renewable option.

The results of four scenarios investigated are summarised in Table 3, with emissions, GEF and RPS target values also listed. Inclusion of large scale solar, (shaded region) clearly affects average generation costs, and an electricity cost penalty is paid by California for meeting reduced carbon emissions targets and the Renewable Portfolio Standard. The cost penalty of up to 8% appears to be politically acceptable, with sustainability benefits of capacity building in terms of technology leadership, new manufacturing, skills, jobs and long term secure supply being perceived as more valuable than reduced average electricity prices. Certainly California is leading the way in the United States with emission reductions and solar installations, and the political foresight of Governor Arnold Schwarzenegger within the American context is to be praised.

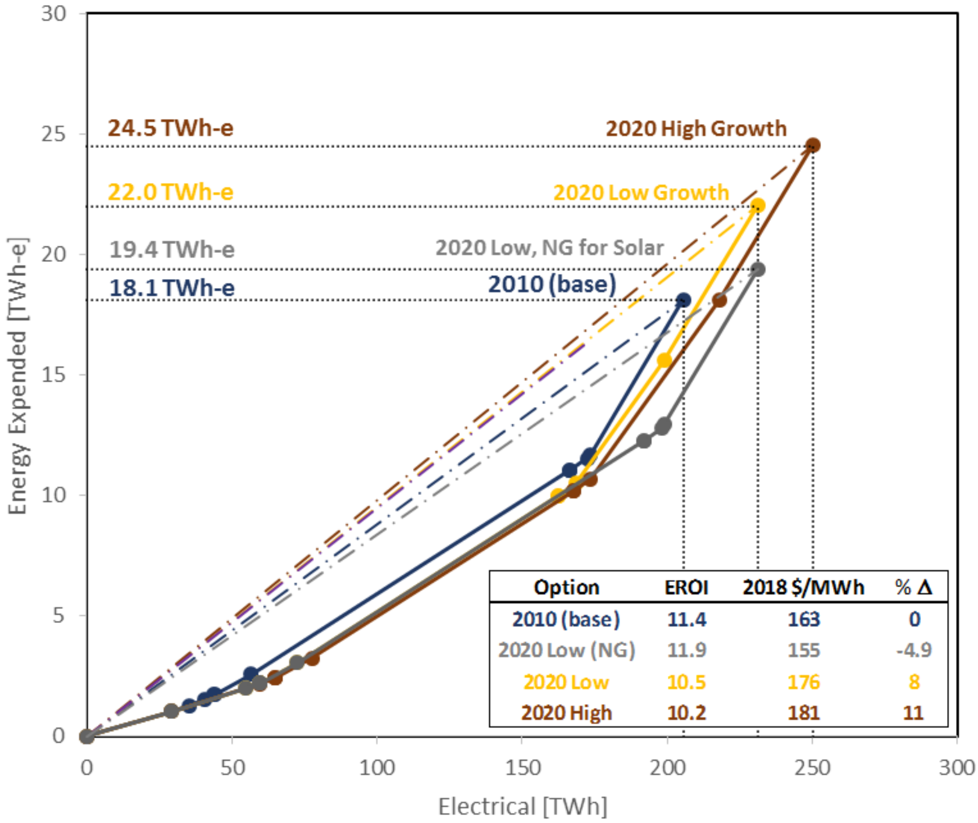

Figure 17. Projected CA expended energy for new generation to meet low and high electricity demand growth in 2020 and 2020 low growth with natural gas (NG) in place of new solar.

Table 3. Summary of CEPA and EROI findings for four California scenarios.

Scenario	**In-State** [TWh]	**Emissions** [Mt CO_2-e]	**%Δ** Emiss.	**GEF**	**RPS** [%]	**EROI**	**2018 Cost** [$/MWh]	**%Δ** Cost
1990	173	39.7	0	0.230	-	-	-	-
2010 (base)	205.7	50.6	27	0.246	15.1	11.4	163	0
2020 $_{Low\ (NG)}$	231.3	52.2	31	0.226	20.9	11.94	155	-4.9
2020 $_{Low\ (Coal)}$	231.3	61.4	55	0.265	21.1	12.6	146	-10.4
2020 $_{Low\ (Solar)}$	231.3	39.7	0	0.172	34.0	10.5	176	8
2020 $_{High\ (Solar)}$	250.3	39.7	0	0.158	39.0	10.2	181	11

4. CONCLUSION

California is well on the way to achieving the ambitious goal of 33% renewable generation, excluding large hydro, by 2020 with the focus clearly on a seven fold expansion of solar from 2013 levels and a doubling of onshore wind capacity over the same period. The 33% renewable target coincidently will bring California back to 1990 emissions level for the electricity sector. The expansion of solar is being led mainly by expansion of residential and commercial solar PV, rather than Solar PT. A four tier electricity pricing structure plus state legislated net metering and tax rebate subsidies enables solar to compete favourably with the top tier marginal price of residential and commercial electricity of US$33/MWh. The cost of solar PV, is rapidly falling due to ongoing innovation and improved know-how around product manufacture, sales and installation, plus soft costs reduction associated with selling, permitting, insurance, financing and installation as the market becomes more confident about a maturing technology. The high levels of tax rebate subsidies on solar are also anticipated to reduce over time as the price of solar generation becomes competitive with other generation technologies. The foresight shown by California political leaders within the American context is to be commended.

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