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ANALYSIS

# Deep greenhouse gas reduction scenarios for California – Strategic implications from the CA-TIMES energy-economic systems model

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ABSTRACT

**California has taken a leading role in regulating greenhouse gas (GHG) emissions, requiring that its economy-wide emissions be brought back down to the 1990 level by 2020. The state also has a long-term, aspirational goal of an 80 percent reduction below the 1990 level by 2050. While the steps needed to achieve the near-term target have already been clearly defined by California policy makers, the suite of transformational technologies and policies required to decarbonize the energy system over the long term have not yet been explored. This paper describes an effort to fill this important gap, introducing CA-TIMES, a bottom-up, technologically-rich, integrated energy–engineering–environmental–economic systems model that has been developed to guide the long-term policy planning process. CA-TIMES is useful for exploring low-carbon scenarios, and the analyses described here focus on the potential evolution of the transportation, fuel supply, and electric generation sectors over the next several decades in response to various energy and climate policies. We find that meeting California's 80% emission reduction goal can be achieved through a combination of mitigation strategies, including managing the growth in energy service demand, increasing investments in efficiency and low-carbon energy supply technologies, and promoting demand technologies that facilitate end-use device electrification and a decrease in the direct use of hydrocarbon fuels through efficiency improvement and fuel switching. In such deep emission reduction scenarios, we estimate that energy system costs (accounting for investments on the energy supply side and in transportation demand technologies, as well as fuel and O&M costs) could be around 8–17% higher than in a reference case. Meanwhile, average abatement costs could range from \$107 to \$225/t$CO_2$. These estimates are very much dependent on a range of socio-political and technological uncertainties, for instance, the availability and cost of biomass, nuclear power, carbon capture and storage, and electric and hydrogen vehicles.**



## 1. Introduction

In 2005 and 2006, California took several initial steps to address the threat posed by climate change. First, Governor Schwarzenegger issued Executive Order S-3-05, which declared an aspirational goal for California to reduce its greenhouse gas (GHG) emissions to 80% below the 1990 level. Then, in 2006 Assembly Bill 32 (AB32), the "Global Warming Solutions Act" became law, setting a binding target that GHG emissions be brought back down to the 1990 level by 2020. AB32 included a requirement that specific plans were to be developed as to how the state might achieve the 2020 goal. The AB32 scoping plan [1] provides a number of recommended actions to reduce emissions from a wide variety of sources and sectors and provides an important roadmap for achieving the near-term target. These policy measures include market-based mechanisms including cap-and-trade and a low-carbon fuel standard, and technology-specific standards and regulations including vehicle efficiency standards (commonly known as the Pavley standards), energy efficiency measures, a renewable portfolio standard (33% renewable electricity by 2020), truck and tire standards, etc. In contrast, the long-term 80% goal was set based on the anthropogenic

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emission rates needed in all industrialized countries to help stabilize atmospheric GHG concentrations at levels that would avoid dangerous climate change [2]. There exists significant uncertainty as to how these deep emission cuts would be achieved, what they would cost, and what policy measures would be needed.

This paper explores the potential of various technology and policy options for reducing emissions across a number of different sectors, specifically the electricity generation, fuel supply and transportation sectors. It describes the development of an energy-economic optimization model of the California energy system (CA-TIMES) and presents scenarios for technology adoption and cost to 2050.

## 2. Background and motivation

### 2.1. Literature review

Over the past several years, a variety of scenario analyses and energy modeling tools have been used to envision how deep cuts in GHG emissions can be made in the long-term, using commercial or near-commercial low-carbon and advanced technologies and fuels [3–7]. These studies have shown protecting the global climate will necessitate dramatic changes in the way societies produce and consume energy. A robust finding of these studies is that the transport and electric sectors must be significantly decarbonized if deep economy-wide emissions reduction targets are to be achieved.

Until somewhat recently, however, there were relatively few analyses focusing specifically on making deep emissions cuts in California, and in particular California's transport sector, which comprises the largest GHG-emitting sector in the state. One example is the 80 in 50 study, which looked at snapshots of 2050 to see what combination of travel demand reduction, efficient vehicle technologies and low-carbon alternative fuels could be used to meet an 80% reduction within the transportation sector [8,9]. Similarly, the California Air Resources Board (CARB) examined how an 80% reduction could be achieved exclusively in the light-duty vehicle sector, primarily using zero-emission vehicles (ZEVs) to achieve the target [10]. The California Energy Futures (CEF) project made an important step forward when it broadened the scope of the analysis to cover all energy sectors in California, including transportation, and how California might achieve an 80% reduction from a pure technology perspective [11]. However, all the above mentioned scenario studies have an important omission: they do not utilize a systems modeling approach, meaning that they fail to explicitly assess costs or adequately address critical questions related to the optimal allocation of resources — both physical and financial. While macroeconomic models such as E-DRAM, a top-down model of the California economy, can partially fill this void by capturing important system dynamics in the larger economy, these models lack the rich technological detail of bottom-up engineering-economic approaches. Nevertheless, several macroeconomic models have been extensively used to assess the economic costs associated with meeting AB32 goals in 2020 as laid out by the Scoping Plan and to inform California's near-term climate policy discussions [12,13]. The Energy2020 model has subsequently been used to provide more detailed energy system representation; the model links to E-DRAM and attempts to understand the energy supply and demand technologies that could be utilized to meet the AB32 goal in 2020 [14].

For longer-term analyses, as California continues to move forward with a broad spectrum of carbon emissions reduction policies, there is a strong need for new tools that are able to provide strategic guidance to decision makers and to help them envision the multiple paths to a low-carbon society. The CA-TIMES model attempts to fill an important gap in the California energy policy space by offering a transparent and flexible analysis platform that can address the specific conditions that exist within the state.

### 2.2. Current snapshot of California GHG emissions

California is somewhat unique within the United States from an energy and emissions perspective. While the state ranks first in population (37 million) and second in total energy use [15], per capita energy use and emissions is among the lowest 10% among all US states. Its petroleum and electricity prices are well above the US average, and its electricity generation mix has a lower carbon intensity than the US average. Historically, California has had some of the most aggressive energy and environmental policies in the country, including policies addressing greenhouse gas and air quality emissions, and vehicle and building energy efficiency standards.

The single largest contributor to emissions in California is direct combustion of fuels (i.e., tank-to-wheels) in the transportation sector, accounting for almost 50% of total emissions (compared with the US average of 34% [15]). Fig. 1 shows the distribution of energy-related GHG emissions by the five main end-use sectors (agriculture, commercial, industrial, residential and transportation) and two energy supply sectors (fuel supply and electricity). For end-use sectors, only direct end-use emissions are counted (fuel combustion in that sector). Combustion emissions from the production of electricity that is used in these end-use sectors is included in the electricity category. Upstream emissions associated with extraction, transport and conversion of energy resources to produce fuels and electricity (including activities that occur both inside and outside the state) are accounted for in the supply category (i.e., well-to-tank emissions). Because there is relatively little coal power generation for the California market (including from imports), and a relatively high amount of natural gas and hydro power, electricity accounts for only about 19% of statewide emissions, while the production and direct combustion of fuels accounts for the remaining 81% of emissions (see Fig. 1). These shares are in sharp contrast to the rest of the US, where electricity generation accounts for 40% of total GHG emissions [15].

The relatively small contribution to emissions from California's electricity sector is important to recognize, as electric generation has been identified in a number of studies and contexts as one of the least costly sectors to decarbonize [7,16]. The large proportion of emissions from the production and use of fuels (e.g., natural gas and liquid

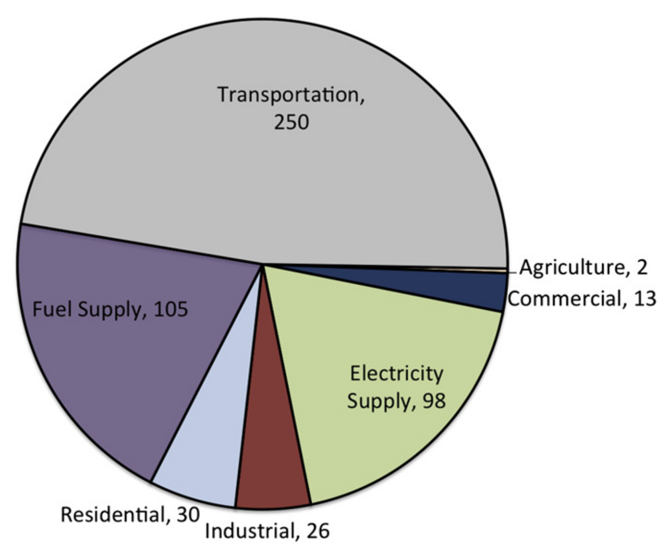


**Fig. 1.** Breakdown of California's energy-related GHG emissions ($MtCO_2e$) by sector for 2010. End-use sectors (agriculture, commercial, industrial, residential and transportation) and electric sector emissions capture direct combustion emissions. Upstream emissions associated with extraction, transport and conversion of energy resources to produce fuels and electricity (including activities that occur both inside and outside the state) are accounted for in the supply category.