LONG-RUN SOCIOECONOMIC AND DEMOGRAPHIC SCENARIOS FOR CALIFORNIA

A Paper From:
California Climate Change Center

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DRAFT PAPER

DISCLAIMER

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts focus on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

In 2003, the California Energy Commission's PIER Program established the **California Climate Change Center** to document climate change research relevant to the states. This center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

The California Climate Change Center Report Series details ongoing center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the center seeks to inform the public and expand dissemination of climate change information, thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

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Abstract

The State of California is developing and implementing a new generation of environmental policies to transition to a low-carbon economy and energy system in order to reduce the risks of future damages from global climate change. At the same time, it is increasingly clear that climate change impacts are already occurring and that further effects cannot be completely avoided. Thus, anticipating and planning for emerging and potential future climate change impacts in California must complement the state's greenhouse gas mitigation efforts. These impacts will depend substantially on the future evolution of the state's social structure and economy. To support impact studies, this report describes socioeconomic storylines and key scenario elements for California that are broadly consistent with the global "A2" and "B1" storylines in the 2000 *Special Report on Emissions Scenarios* of the Intergovernmental Panel of Climate Change, including qualitative socioeconomic context as well as quantitative projections of key variables such as population, urbanization patterns, economic growth, and electricity prices.

Keywords: SRES emissions scenarios, climate change impacts, long-run California socioeconomic and demographic trends, economic growth, scenarios

1.0 Introduction

With AB 32,[1] Executive Order S-3-05, and a range of other policy initiatives, the State of California is leading the development and implementation of a new generation of environmental policies to transition the economy and energy system to a low-carbon future. In part due to California's example, other U. S. states as well as the federal government have in the past several years accelerated their efforts to achieve significant, large-scale reductions of greenhouse gas (GHG) emissions. These efforts and concurrent initiatives around the world are aimed at the United Nations Framework Convention goal of preventing "dangerous anthropogenic interference" with the global climate system.

It is, however, increasingly clear that climate change impacts are already occurring and that further effects in the near term cannot be avoided. Moreover, human society's increasing but still-limited understanding of the immensely complex climate system implies that even the establishment of an internationally coordinated, worldwide GHG abatement regime can be expected to reduce but not eliminate the risks of future impacts of climate change on the global environment and human society. Accordingly, anticipating and planning for emerging and potential future climate change impacts in California must complement the state's GHG mitigation efforts.

The impacts of climate change on California's natural and human environment will depend substantially on the future evolution of the state's social structure and economy. Climate change, particularly as manifest in localized changes in weather and precipitation, will have complex, differentiated effects across sectors of the economy, income groups, and geographical regions. For example, climate change-driven increases in summer temperatures may weigh most heavily on low-income households in the inland region, while precipitation changes will affect agriculture far more than service industries. At the same time, expectations of California's future socioeconomic configuration will influence the manner in which adaptation to climate change is conceived and implemented. This socioeconomically mediated nature of potential climate change impacts, and the interactions among vulnerabilities and response strategies, are the motivations for this paper.

As noted by Meehl et al. (2007), variations in assumptions regarding future trends in social and economic variables, and the consequent range of potential paths of anthropogenic GHG emissions, are by far the biggest source of uncertainty in numerical projections of future climate change. The quantitative projections of global climate change conducted under the auspices of the Intergovernmental Panel of Climate Change (IPCC) and applied in this study are driven by modeled simulations of two sets of projections of twenty-first century social and economic development around the world, the so-called "A2" and "B1" storylines in the 2000 *Special Report on Emissions Scenarios* (SRES) (IPCC 2000). The SRES study was conducted as part of the IPCC's Third Assessment Round, released in 2001. The A2 and B1 storylines and their quantitative representations represent two quite different possible trajectories for the world

[1] California Global Warming Solutions Act of 2006 [Assembly Bill 32 (Nuñez), Chapter 488, Statutes of 2006]

economy, society, and energy system, and imply divergent future anthropogenic emissions, with projected emissions in the A2 being substantially higher.[2]

This paper describes socioeconomic storylines and key scenario elements for California that are broadly consistent with the global SRES A2 and B1. In contrast to the A2 and B1-driven regional climate projections, we do not formally "downscale" the scenarios or conduct economic simulation modeling of twenty-first century California. Instead, to support the impact analyses in this study, we provide a general, qualitative socioeconomic context as well as quantitative projections of key variables, including population, urbanization patterns, and economic growth, that reflect the main elements of the global scenarios.

The paper is organized as follows. Section 2 summarizes the SRES framework and results, emphasizing the A2 and B1 storylines and quantitative scenarios. Scenarios of economic growth, population, urban growth and land use patterns, and other key drivers are presented in Section 3. Concluding remarks are given in Section 4.

2.0 SRES: Overview and Selected Results

Understanding the factors that determine anthropogenic GHG emissions is both critical for climate science and policy making, and extremely challenging. Both the importance and the difficulty increase when attempting to project possible paths of these emissions a century into the future. It is universally understood that emissions on this time scale cannot be predicted with any plausibility or reliability. Basic data requirements for applying conventional forecasting methods can probably not be met in the case of global GHG emissions; if they could, the statistical errors associated with such methods would substantially dominate their predictions. The need for some means of quantitatively and defensibly projecting long-run GHG emissions in the face of such hurdles has led over the last several decades to the use of various "scenario" techniques for this purpose.

There is no single or standard definition of "scenario" in energy and environmental analysis and modeling, but the term is generally used to convey the idea of a "plausible projection," whether qualitative or quantitative, of future events, variables, or system behaviors. As summarized in the SRES,

> "Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold. A set of scenarios assists in the understanding of possible future developments of complex systems...many physical and social systems are poorly understood, and information on the relevant variables is so incomplete that they can be appreciated only through intuition and are best communicated by images and stories...Scenarios can be viewed as a linking tool that integrates qualitative narratives or stories about the future and quantitative formulations based on formal modeling."[3]

[2] In SRES terminology, "storyline" refers to a qualitative description of a pattern of global and regional socioeconomic development, including the characteristics of energy systems and implications for greenhouse gas emissions. A "scenario" is a simulation of a storyline by a specific numerical model.

[3] IPCC 2000, Chapter 1, p. 62.

The work that culminated in SRES was undertaken by the IPCC in 1996, following a review of its 1990 and 1992 emissions scenarios and an assessment of advancements in understanding the drivers of anthropogenic GHG emissions and the increasing importance of the scenarios in climate modeling and policy analysis. The IPCC Working Group III convened the initial team in 1997, and the SRES project evolved into an international, multi-group and multi-model effort. The analytical process was developed, the emissions scenarios created, and the SRES written, over the following three years; the scenarios were used in the IPCC Third Assessment Round, released in 2001.

The foundation of both the qualitative storylines and the quantitative scenarios in SRES is the recognition of economic development, demographics, and technological change as primary drivers of GHG emissions. Four primary storylines summarize the SRES view of how these drivers might evolve:

> A1: Rapid economic growth and technological change, low population growth, and international socioeconomic convergence;
>
> A2: Slower economic growth and technological change, higher population growth, and less socioeconomic convergence;
>
> B1: Intermediate economic growth and low population growth, global convergence emphasizing environmental priorities and sustainability;
>
> B2: Moderate economic and population growth, and an emphasis on environmental priorities, but with continued heterogeneity among regions.

In addition, the A1 storyline encompassed three different elaborations with respect to the main sources of primary energy as well as energy-saving technological change: (a) Fossil-fuel intensive, A1FI; (b) Accelerated energy-efficiency and renewable energy, A1T; and (c) A "balanced" combination of different energy sources, A1B.

It is important to emphasize that no likelihoods were assigned to any of the storylines or their quantified associated scenarios. Each is regarded as a plausible future that might unfold under certain conditions; none is a "base case" or "business as usual" case. Equally important, the storylines and scenarios are all "no GHG policy" cases, meaning specifically that it is assumed that no coordinated global emissions mitigation such as the Kyoto Protocol is enacted. As noted in the report, however, this assumption does not preclude in principle either other environmental policy actions or underlying economic or technological developments, that would result in lower GHG emissions than might otherwise occur.

This framework is schematically represented in Figure 1, in which two primary "axes" are conceived as indices of potential future large-scale trends in these drivers, one relating to social choices regarding economic growth and environmental protection, the other relating to degrees of future international and interregional convergence or divergence in primary economic and demographic trends.

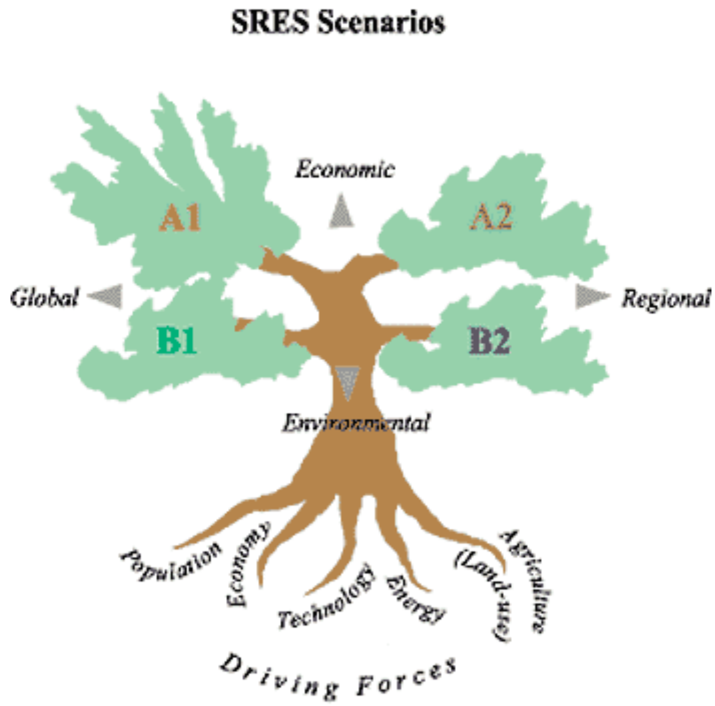

Figure 1. The "SRES Tree"

The quantification of these storylines was conducted using six different numerical models, representing a range of approaches to energy and emissions modeling.[4] This multi-model approach was used among other reasons to capture the uncertainties associated with the representation of economic dynamics, technological change, demographic effects, and other key factors. Multiple models were used to simulate each storyline, with the aforementioned uncertainties resulting in varying emissions projections even for a given storyline. However, for each of A1, A2, B1, and B2 storylines, a single model was selected to provide the "marker" scenario for the given storyline; these markers were selected by the SRES team to illustrate the complete set of storylines in a more manageable form (than the forty scenarios comprising the complete set). The markers are not in any sense "most likely," but these scenarios did receive a higher degree of technical review and scrutiny, in accord with their intended purpose.

Figure 2 illustrates the range of emissions projections across the storylines; the solid line in each graph represents the marker scenario projection. (In the A1 group, only A1B had a marker assigned.)

[4] The quantification of the storylines is described in detail in SRES (IPCC 2000) Chapter 4.

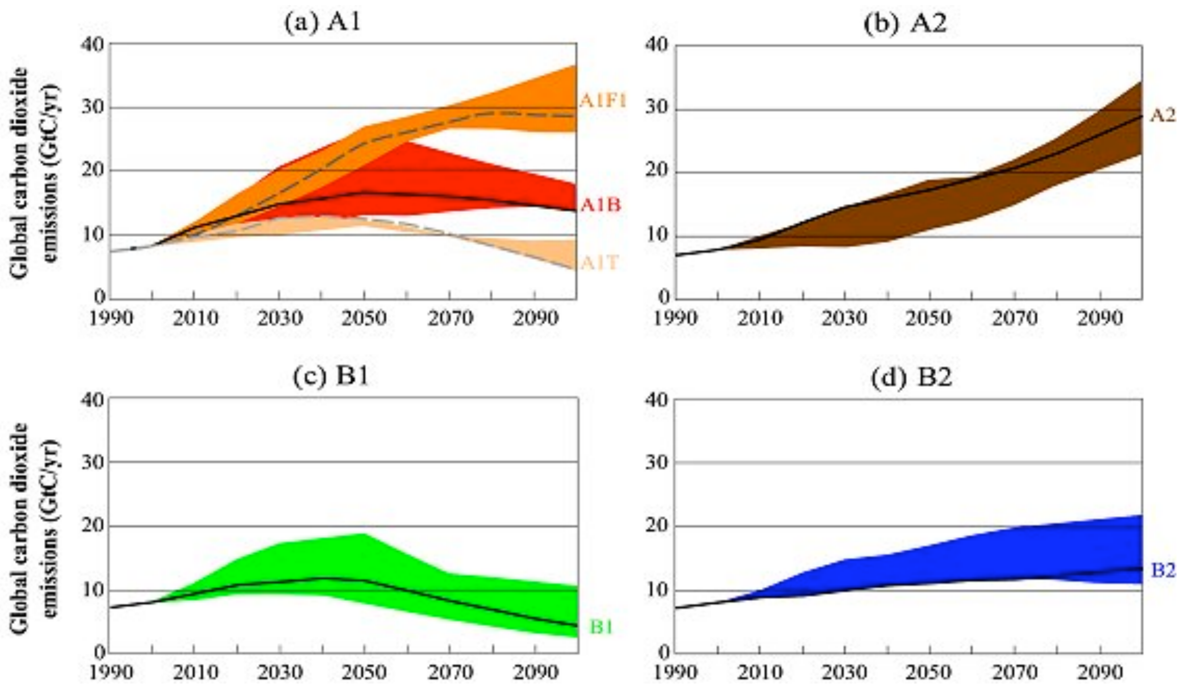

Figure 2. SRES emissions projections, by storyline

As can be seen in the figure, the A2 and B1 families constitute a “high” and “low” set of projections, respectively. (By contrast with the A1FI scenarios, however, the A2 does not reflect a continued or increased reliance on fossil fuels across regions.) This motivated their selection for the current study.

2.1. Storyline Summaries for A2 and B1

As described in the SRES, A2 represents a “differentiated world,” with respect to demographics, economic growth, resource use and energy systems, and cultural factors (although the latter are not represented, per se, in the quantitative scenarios). There is what in current terminology what could be called a de-emphasis on globalization, reflected in heterogeneity of economic growth rates and rates and directions of technological change. Globally, slow decline of fertility rates results in very high population, 15 billion by 2100. Lack of convergence of economic growth rates, among other factors, results in substantial differences in per capita income across regions. As noted above these assumptions, when quantified, result in continued growth in global CO_2 emissions, which reach nearly 30 gigatons of carbon (GtC) annually in the marker scenario by 2100.

The B1 storyline is in essence the reflection of the A2 across the key dimensions (as is literally true in the schematic diagram in Figure 1). It can be characterized as a “global sustainability” scenario. Worldwide, environmental protection and quality and human development emerge as key priorities, and there is an increase in international cooperation to address them as well as convergence in other dimensions. A demographic transition results in global population peaking around mid-century and declining thereafter, reaching roughly 7 billion by 2100. Economic growth rates are higher than in A2, so that global economic output in 2100 is approximately one-third greater. The combination of these economic and demographic trends results in a much richer world, in terms of per capita income, in B1 than A2.

Although not driven by global GHG emissions policies, a worldwide transition to efficient and renewable energy technologies results in a peaking and subsequent decline in global emissions comparable to what might be achieved with such policies: In the B1 marker scenario, annual emissions reach about 12 GtC in 2040 and decline to about 4 GtC in 2100.

2.2. United States Projections in the A2 and B1 Marker Scenarios

The SRES reported numerical scenario results on a global basis as well as for four large regions.[5] In most cases, however, a finer degree of geographical or geopolitical disaggregation was incorporated in individual models and scenario results, including the models that generated the A2 and B1 markers: The Atmospheric Stabilization Framework (ASF) for the A2, and the Integrated Model to Assess the Greenhouse Effect (IMAGE) for the B1. For this study, we obtained the main U.S.-specific results from these two models/scenarios.

Table 1 contains key results on U. S. economic and population growth from A2–ASF and B1–IMAGE, as well as U. S. historical figures for comparison. The latter are for the second half of the twentieth century (1950–2000 and 1975–2000), as well as the decade ending in 2005. For the SRES scenarios, results are presented for 2000–2020, 2000–2050, and 2050–2100. As the numbers indicate, both scenarios anticipate declines in growth rates from historic levels in all three of the drivers: Real Gross Domestic Product (GDP), national population, and GDP per capita. These can be interpreted as continuations of trends already observed at the time (1990s) that the SRES was written—that is, long-run slowing of both economic and population growth. It is important to emphasize, however, that even these lower-than-previous rates of economic growth imply that the United States economy will continue to expand and that in dollar terms the United States will be substantially wealthier in the future than it is today, in both absolute and per capita terms.

[5] The four regions are: (1) “OECD90,” all member countries of the Organization for Economic Cooperation and Development as of 1990; (2) “REF,” reforming or in-transition economies, including Eastern European nations and former states of the Soviet Union; (3) “ASIA,” all developing economies in Asia, and (4) “ALM,” other developing countries including those in Africa, Latin America, and the Middle East.

Table 1. United States economic and population growth: Historical and SRES projections*

Average annual growth rates in percent

		Period	Real GDP	Population	Real GDP per capita
Historical		1950–2000	3.48	1.25	2.20
		1975–2000	3.35	1.07	2.25
		1985–2005	3.03	1.11	1.90
Projected	A2–ASF	2000–2020	1.91	0.90	1.0
		2000–2050	1.80	0.79	1.0
		2050–2100	1.83	0.82	1.0
	B1–IMAGE	2000–2020	2.63	0.78	1.84
		2000–2050	1.96	0.64	1.31
		2050–2100	1.23	0.36	0.86

* Real GDP in chained 2000 dollars. Sources for historical data: U. S. Bureau of Economic Analysis 2008 (GDP); U. S. Energy Information Administration (2007) (population).

3.0 Scenarios for California

Quantitative scenario analysis in energy and climate policy applications has generally been organized around "baseline" or "business as usual" cases with "policy" cases represented as fundamentally incremental departures there from. This reflects, among other influences, the static cost-benefit origins of the economic models that are typically the basis of such analysis. The SRES departure from this convention reflects in part the essential impossibility of defending any particular projection of the society and economy as a base or business as usual case a century into the future.[6]

This logic applies *a fortiori* to climate change-related scenarios during the present era of rapid developments in state, national, and international efforts to significantly reduce GHG emissions. While we regard as increasingly likely the implementation of a coordinated global emissions reduction policy in the coming decades, we cannot foretell its timing, magnitude, costs, or other aspects of the ultimate portfolio of abatement strategies that national governments will implement individually and collectively. Even the final architecture of AB 32 in California remains to be determined, and at this stage the path that the state will pursue to reach the 2050 goal is in the earliest stages of determination.

Addressing these issues in California scenarios of key socioeconomic and demographic trends that are broadly consistent with the global SRES A2 and B1 presents a particular challenge in the A2 case. The SRES emphasizes that its blanket assumption of no global GHG abatement regime does not exclude mitigation actions at sub-global levels that may be consistent with individual storylines and scenarios. In the A2 case, however, global, regional, and national

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[6] As noted in the SRES report, the choice of an even number of broad storylines was deliberate, to prevent selecting a "middle" case as an implicit baseline.

emissions continue to rise. Thus, a narrow interpretation requires a scenario in which California achieves a transition to a low-carbon economy and energy system by mid-century while the United States as a whole, as well as the rest of the world, continues to increase GHG output. We regard this outcome as implausible at best. On the one hand, as noted at the outset, efforts to design and implement policies to achieve significant GHG reductions are well underway around the world; successful implementation and execution of AB 32 by California will stimulate these efforts. In the longer term, a demonstration by California of progress toward the mid-century emissions reduction called for in Executive Order S-3-05 would similarly provide support for comparable progress elsewhere. On the other hand, by the same token, any problems California might encounter reaching either its near-term or long-term GHG targets could reasonably be expected to impede the abatement efforts of other governments. We would here draw an analogy with electricity restructuring, a case in which the California experience affected other states' regulatory strategies and decisions.[7]

Thus, with the present "state-of-play" of GHG reduction policy around the world, the A2 must be interpreted somewhat differently than was appropriate at the time of the *SRES* report. It now can be viewed as describing a future in which current efforts to reduce GHG emissions within OECD countries as well as sub-national entities (notably U. S. states and Canadian provinces) fail to reach fruition, and the developing world does not itself undertake or achieve significant reductions.

By contrast, despite the assumption of "no global policy," the B1 case is consistent both in general and in key specifics with a storyline in which aggressive worldwide emissions mitigation policy is undertaken and results in a peaking and then decline in emissions globally and regionally in this century. As illustrated in Figure 2 above, B1 is not a "stabilization" scenario of the type that is increasingly the focus of policy, for example, in the mid-century goal established in EO S-3-05 and contemplated in proposed U. S. Congressional legislation. Figure 2 depicts worldwide emissions; in the IMAGE B1 marker scenario, OECD and U. S. emissions peak and begin to decline by mid-century, but are not on the order of eighty percent below 1990 or 2000 levels by 2050. Nevertheless, with reasonable flexibility of interpretation regarding exact levels and timing, B1 can be seen as describing a future in which California's and the United States' long-term efforts to radically reduce emissions succeed, including the maintenance of robust economic growth and improving living standards while transitioning to a low-carbon energy system. As in the *SRES* interpretation of B1, a variety of social and market drivers would contribute to this future, but in contrast to that interpretation, in this alternative view of B1 policy plays a fundamental role.

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[7] It is certainly possible to imagine a scenario in which problems with policy implementation in California yield lessons that other governments apply to improve their own processes. But in this case, one would in turn expect a "feedback" to California, so that the overall process becomes in a sense self-correcting. The point is that, in this case also, California's and the rest of the world's GHG emissions trajectories would in the long term be convergent.

3.1. U. S. and California Economic Growth

Since the early 1960s, growth in California's gross state product has on average exceeded that of the U. S. GDP, although not in every year or succession of years. This is summarized in Table 2, which presents various measures of state and national economic growth in this period.

Table 2. Comparison of historical economic growth rates, U. S. and California*

Average annual growth rates, in percent

Period	Units	U. S. Gross National Product	California Gross State Product
1963–1997	SIC-based, current dollars	7.94	8.37
1997–2007	NAICS-based, current dollars	5.34	6.07
1990–1997	SIC-based, chained 2000 dollars	2.98	1.6
1997–2007	NAICS-based, chained 2000 dollars	2.89	4.06

* Source: U. S. Bureau of Economic Analysis (2008). Series are separated at 1997 due to inconsistencies in state-level data between the SIC (Standard Industrial Classification) and NAICS (North American Industrial Classification System).

3.2. Scenarios of California Economic Growth

The A2 and B1 storylines and U. S. economic growth projections shown in Table 1 suggest corresponding "lower" and "higher" growth scenarios for California, as well as their respective relationships to the U. S. scenarios. In its most recent forecast, the California Energy Commission projected annual state economic growth to average 3.1% from 2006 to 2011, declining to 2.5% from 2011–2018. We use these figures for transition between recent historical and long-run future trends; both lower and higher growth scenarios match these growth rates to 2020. In the lower growth scenario, this rate then declines to 2% until 2050, and then to 1.8% to 2100. In the higher growth scenario, economic growth remains at 2.5% annually to 2050, and is then 2% until 2100. These scenarios and their implications for the size of California's economy over the coming century are summarized in Tables 3a and 3b.[8]

[8] These scenarios were developed prior to the disruptions in the second half of 2008 in the financial system and the macroeconomy. As a consequence, our near-term growth estimates may be unrealistically high unless there is a fairly rapid (i.e., within several years) global economic recovery. Assuming that such a recovery occurs over the coming decade, however, we do not view current events as materially affecting the plausibility of the longer-term estimates.

Table 3a. Two scenarios of California economic growth: Growth rates

	Average annual growth rates in Gross State Product, in percent	
Period	Lower growth	Higher growth
2008–2020	2.5	2.5
2020–2050	2.0	2.5
2050–2100	1.8	2.0

Table 3b. Two scenarios of California economic growth. Gross state product in trillions of chained 2000 dollars.

	2007	2020	2030	2040	2050	2060	2070	2080	2090	2100
Lower growth	\$1.55T	\$2.14T	\$2.60T	\$3.17T	\$3.87T	\$4.62T	\$5.53T	\$6.61T	\$7.9T	\$9.44T
Higher growth	\$1.55T	\$2.14T	\$2.73T	\$3.5T	\$4.48T	\$5.46T	\$6.66T	\$8.11T	\$9.89T	\$12.01T

Source for 2007 estimate: U. S. Bureau of Economic Analysis (2008).

These two scenarios are broadly consistent with the SRES A2 and B1 storylines, respectively, in envisioning slower-than-historical rates of economic growth. They also assume a continuation of the observed historical pattern of California's growth being somewhat higher than the national rate, with respect to the SRES United States projections. The end consequence of growth differential in the two scenarios is an approximately 30% difference in the size of the state economy in 2100. Note, however, that in both cases this size is immensely increased from its present-day magnitude. To understand the implications of these two scenarios for per capita state income, we first discuss scenarios of future state population growth.

3.3. California Population Projections

The manifold uncertainties associated with long-run social and economic scenarios are exemplified by population forecasting. Population projections are inherently uncertain. The underlying processes which govern population growth are difficult to forecast and include economic, political, environmental, technological, social, and behavioral elements. Social scientists do not fully understand how these elements have shaped fertility, mortality, and migration in the past, let alone how each of these forces might change in the future. Moreover, long-term projections and projections for small areas, including states and particularly counties, are even less certain than projections for large areas. Climate change could affect demographic forces directly, for example by increased mortality associated with high temperatures (or decreased mortality associated with a reduction in cold weather), or indirectly, for example through climate-induced changes in local economies.

For this study, three sets of population projections for California and its counties to 2100 were developed: A low series, a middle series, and a high series. The projections include breakdowns by age, gender, ethnicity, and nativity (U.S. born and foreign born). A cohort component model was used in which the population was aged over time by applying mortality and migration rates. New cohorts were created by applying fertility rates to women of childbearing ages. Projections were developed for every five years from 2005 to 2100. Existing national population projections were used to estimate the size of populations providing the sources of migrants to California. Past trends in migration, fertility, and mortality rates in California were used to develop future rates.

The three sets of projections developed for California and its counties were designed to provide a subjective assessment of the uncertainty of the state's future population. The projections present three very different demographic futures. In the low series, population growth slows as birth rates decline, migration out of the state accelerates, and mortality rates show little improvement. In the high series, population growth accelerates as birth rates increase, migration increases, and mortality declines. The middle series, consistent with (but not identical to) California Department of Finance projections which extend to 2050, assumes future growth in California will be similar to patterns observed over the state's recent history, patterns that include a moderation of previous growth rates but still large absolute changes in the state's population. In the middle series, international migration flows to California remain strong to mid-century and then subside, net domestic migration remains negative but of small magnitude, fertility levels (as measured by total fertility rates) decline slightly, and age-specific mortality rates continue to improve. Specific assumptions for each of the series are shown in Table 4. A number of storylines could be developed that are consistent with each of these projections series. These storylines do not necessarily involve climate change, but could be consistent with different climate change scenarios.

The low series projections for California envision a future for the state in which fertility rates decline to levels similar to those experienced in California during the nadir of the baby bust. Even lower total fertility rates are observed today in many high-income countries, including Germany, Italy, and Japan (but also in some eastern European countries with troubled economies). International migration slows quickly and considerably in this scenario, consistent with the A1 and B1 SRES storyline themes of relatively high economic growth rates and international socioeconomic convergence.

In contrast, the high series projections envision a future in California of increasing migration, both international and interstate, and an increase in total fertility rates to 2.6 children per woman, still well below the baby boom peak of 3.6 reached in 1961 in California, but much higher than the replacement level of 2.1. This scenario is consistent with strong economic growth in California (recall that the baby boom occurred during a period of rapid economic growth) and continued global disparities in income, as observed in the A2 storyline, that lead to large and sustained flows of international migrants to the state.

Finally, the middle series projections could be thought of as consistent with the B1 storyline. Growth rates in California slow, but absolute increases remain large as the state's economy continues to attract international migrants from developing countries that continue to experience strong population growth.

Table 4. Components of change assumptions for statewide population projections

		Net international migration (thousands per year)	Net interstate migration (thousands per year)	Total fertility rate /1	Mortality rate /2
Low series	2005–2010	161	-113	2.15	1.00
	2020–2025	26	-63	2.06	0.98
	2045–2050	1	-71	1.93	0.96
	2095–2100	0	-1	1.64	0.94
Middle series	2005–2010	190	-90	2.15	0.98
	2020–2025	225	-30	2.09	0.95
	2045–2050	225	-30	2.09	0.90
	2095–2100	50	-25	2.09	0.85
High series	2005–2010	220	7	2.23	0.98
	2020–2025	240	45	2.30	0.92
	2045–2050	250	50	2.46	0.80
	2095–2100	360	100	2.64	0.67

Source: Public Policy Institute of California (PPIC) climate change population projections
Notes:
/1 The total fertility rate is the average number of children a woman will have over her reproductive years.
/2 Age-specific mortality rates relative to 2005

The key drivers of uncertainty are first migration, and second fertility. For many decades, changes in age-specific mortality rates been relatively stable, and the projections assume that no long-lasting catastrophic events will occur. Migration, in contrast, has been quite volatile, with the state experiencing both large net flows into and out of the state at different times within the past 25 years. Fertility changes have also been notable, with total fertility rates in California reaching 3.6 children per woman during the height of the baby boom and subsequently falling by about half to 1.7 children during the nadir of the baby bust.

The level of uncertainty reflected in these projections is striking. National population projections developed by the U.S. Census Bureau reflect even greater relative uncertainty for the nation, with the high series four times as great as the low series. To the extent that the U.S. population determines one of the most important pools for potential migrants to California, the widely divergent national projections are necessarily incorporated into the California projections. Table 5 provides comparisons of the new California projections created for this project, with national projections developed by the Census Bureau and state projections developed by the California Department of Finance (DOF).

Table 5. Population projections for California and the United States

	U.S. Projections			PPIC California Projections			DOF
	Low	Middle/1	High	Low	Middle	High	California
2005	284,000	295,896	292,339	36,982	36,982	36,982	36,982
2010	291,413	308,936	310,910	38,862	39,170	39,896	39,136
2020	303,664	335,805	354,642	41,978	44,184	46,863	44,136
2030	311,656	363,584	409,604	43,653	49,321	54,054	49,241
2040	314,673	391,946	475,949	44,103	54,214	61,237	54,226
2050	313,546	419,854	552,757	44,204	59,283	69,376	59,508
2060	310,533	449,312	642,752	44,554	63,968	79,677	
2070	306,589	482,207	749,257	44,683	68,818	91,466	
2080	300,747	517,767	873,794	44,377	74,018	106,192	
2090	292,584	554,975	1,017,344	43,924	79,476	124,982	
2100	282,706	593,820	1,182,390	43,835	85,264	147,698	

Notes:
/1 The middle series to 2050 is based on the Census Bureau's 2004 interim projection series;
From 2050 to 2100, the Census Bureau's 2000 series was used but modified in light of the 2004 series.
Contact authors for details.

Divergence in the PPIC projection series increases with the time horizon; the range in the projections is not large in 2020, but accelerates thereafter. This reflects the compounding effects of the demographic components that drive population change. For perspective, realize that in 1900 California's population was 1.49 million and by 2000 the state's population had grown 23 times larger to 34 million. For one comparison, we might turn to Japan, a country of similar geographic size to California. In 1900, Japan was home to 43 million people, somewhat more than California's current population of about 38 million. By 2000, Japan's population had reached 127 million (similar to the high series projection for California for 2100). In contrast to the explosive growth of the twentieth century, projections for Japan to 2050 suggest the country will lose about 20 percent of its residents, declining to a population of 103 million by 2050.

Global population projections also exhibit considerable uncertainty. Even without the volatile and most difficult to project component of migration, United Nations projections to 2050 place the world's population at 7.8 billion in the low variant to 10.8 billion in the high variant, an increase of 20 percent over the 2005 global population in the low variant and 65 percent in the high variant (United Nations 2006, 2007).

Finally, it should be noted that there is substantial disagreement about the state's current (c. 2008) population, with the California Department of Finance estimating that the state's population is about one million higher than Census Bureau estimates for the state (Figure 3). It is not surprising, then, that population projections to 2100 exhibit such great uncertainty.

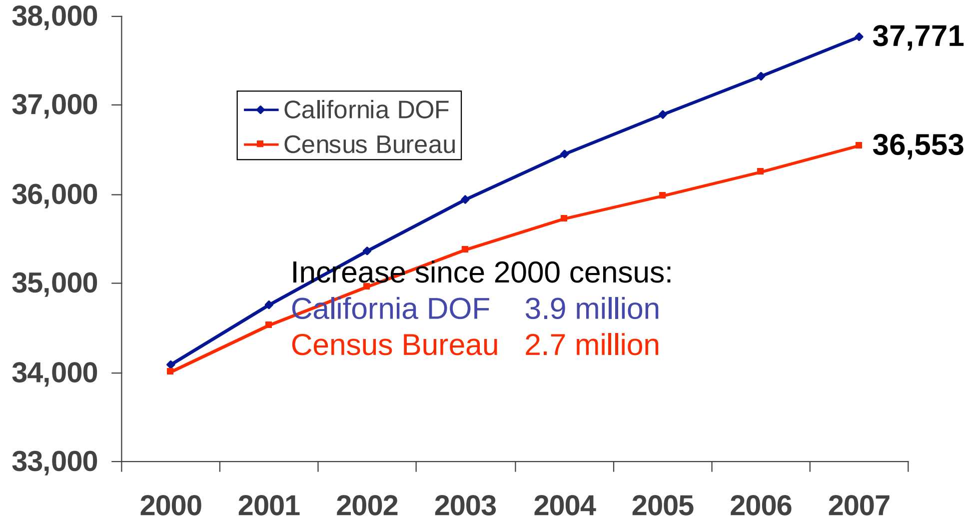

Figure 3. Population estimates for California (in thousands)

3.4. California Economic Growth in Per Capita Terms

The economic wealth of a state or nation is a function not just of absolute output but also of per capita output. A given sized economy (in dollar or other currency terms) can reflect vastly different standards of living and social conditions depending on the population size as well as the distribution of income. Thus, in the long run economic and population growth are closely related in determining the wealth of a society. Recall (cf. Table 2) that California's growth rate of overall economic output had generally exceeded that of the U. S. in recent decades. Table 6 shows that, in per capita terms, population trends resulted in California's per capita income growth being somewhat lower than the nation as a whole from 1959 through 2006, despite a higher absolute growth rate.

Table 6. Growth of real personal income, U. S. and California, 1959–2006

	Average annual growth rates in percent	
	U. S.	California
Personal income	3.05	3.9
Per capita personal income	2.40	2.1

Source: California Dept. of Finance

Table 7 presents two scenarios of long-run per capita income growth in California implied by our lower and higher economic growth scenarios jointly with our middle population scenario.

Table 7. Per capita income in California under lower and higher economic growth scenarios

	Average annual growth rate in percent		End-of-decade per capita personal income in thousands of chained 2000 dollars	
Decade	Lower	Higher	Lower	Higher
2010–2020	1.10	1.10	40.3	40.3
2020–2030	0.88	1.38	44.1	46.3
2030–2040	1.04	1.54	48.9	53.9
2040–2050	1.09	1.59	54.5	63.1
2050–2060	1.03	1.23	60.3	71.2
2060–2070	1.06	1.26	67.0	80.7
2070–2080	1.06	1.26	74.5	91.5
2080–2090	1.08	1.28	82.9	103.9
2090–2100	1.09	1.29	92.4	118.0

Note that the growth rate of per capita income in the lower growth case approximately matches that of the SRES A2 U. S. projection, while the higher growth case is substantially higher starting in 2020, reaching the recent historic trend in mid-century. As in the case of absolute economic growth, the lower-than-historical future rates still imply a substantial increase in the income of individual Californians over the coming century.

The population and economic growth projections for this report were developed separately. It is, however, relevant to consider their joint implications for future labor productivity growth rates in California.[9] This topic is addressed in Appendix B.

3.5. California Urbanization Projections

During the next century, California will expand its urban extent in multiple dimensions. Urban areas will expand to nearby vacant brownfields. Infill will provide more acreage for new residential, commercial, and industrial regions. Agricultural lands will be converted and the wildland-urban interface will grow. Using the methodology described in Appendix A, the rate of increase in urbanization was projected to follow a fairly constant rate of growth from the current 20,000 square kilometers (km^2) of urban extent to more than three times that amount: 65, 334 km^2 of urban land (Figure 4).

[9] We are indebted to Steven Smith for highlighting the importance of this issue.

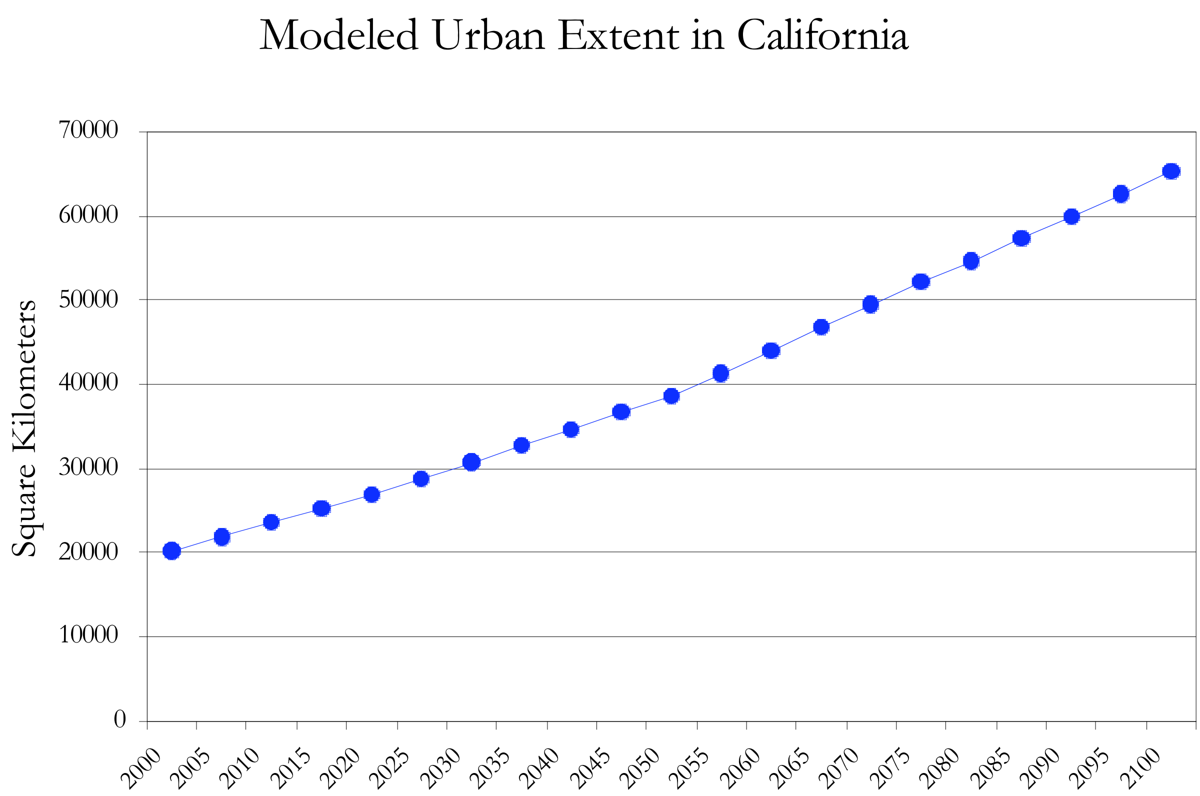

Figure 4. California's future urban extent

The pattern of the urban expansion can be seen in the maps of Figure 5.

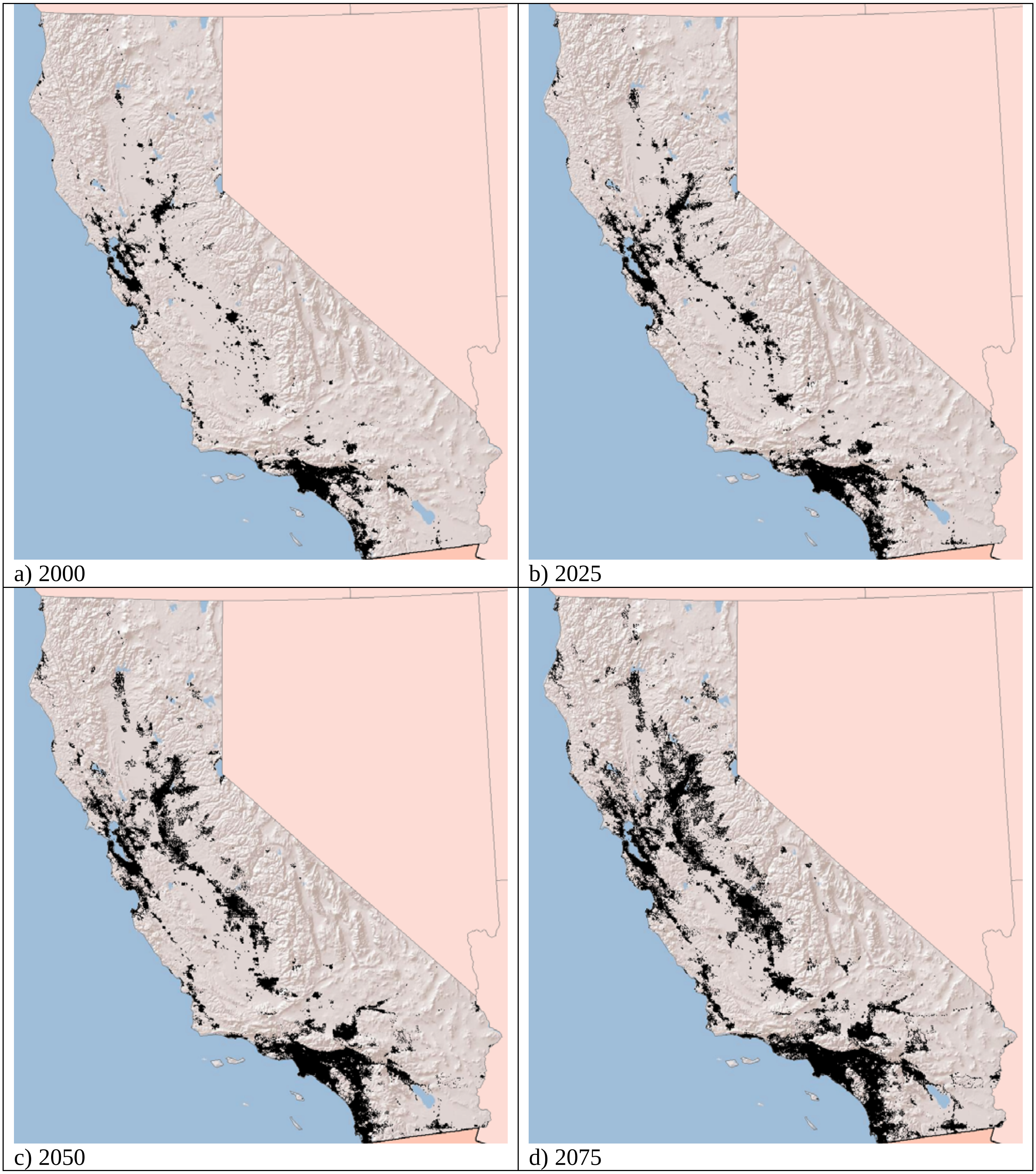

Figure 5. Forecasted urban footprint for California for sample years a) 2000, b) 2025, c) 2050, d) 2075, and e) 2100

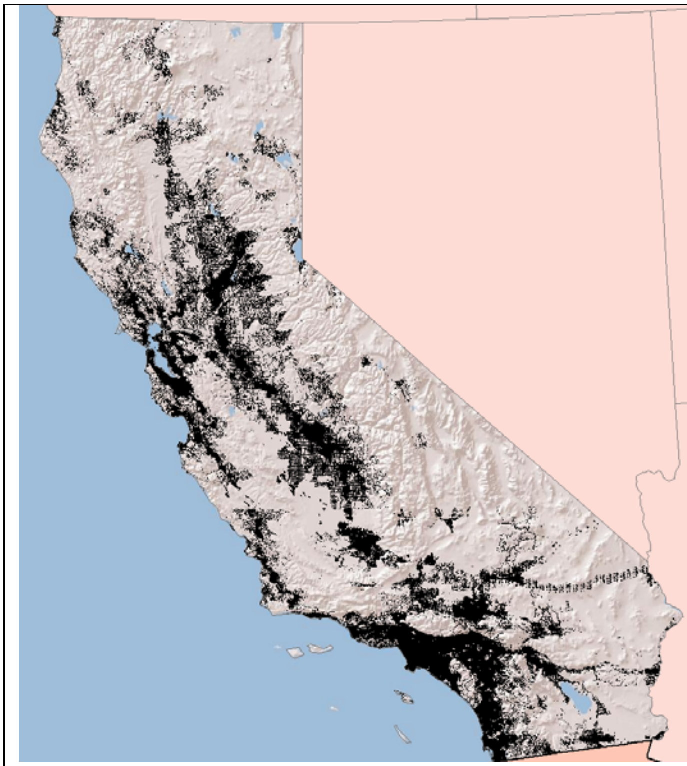
e) 2100

Figure 5. (continued).

In general, two major trends can be seen. The first is the “creeping” growth pattern expanding current urban regions along major highways and into nearby rural regions. The second is the massive conversion of the Central Valley from agricultural land to urban. This will have significant impact on regional and statewide social fabric, the environment, and the economy, as the new (or expanded) urban lands will shift population away from the coast, where it currently lies. The expanded urban region will need more services and a new infrastructure, as well as materials to build the new housing and commercial and industrial structures.

3.5.1. Allocating Future Population

The comparison and analysis of population trends of the three population series (low, middle, and high) was summarized in Section 3.3. In examining how the population is spatially distributed, it is clear that there are significant differences between the series, reflecting the differences in the aspatial estimates as well. Overall, the low series indicates that there will be large regions of sparse population in the state over the upcoming century. In addition, the extant urban regions will shrink in population, while not in extent. The high series estimates indicate that there will be denser cities and larger populations in rural regions. The Central Valley will balloon in population as well. The middle series indicate overall population growth, not as extreme as the high series, yet still shocking when compared to today’s urban landscape.

To examine the general trends of changing urban density, four regions were selected for illustrative purposes. These metropolitan regions are formal described by the U.S. Census Bureau as “Urbanized Areas” that “meet minimum population density requirements, along with adjacent densely settled census blocks that together encompass a population of at least 50,000 people." (ESRI 2007, U.S. Census Urbanized Areas Metadata) The four cities are:

1. the City and County of San Francisco,
2. the City of Fresno,
3. the Greater Los Angeles region (Los Angeles—Long Beach—Santa Ana),
4. the City of San Diego.

The outlines of these regions, according to the Census Bureau, were used as "bounding boxes" for population tallies. This methodology does not account for the changing (namely expanding) nature of city boundaries, due to functional or political means. Surely the political boundaries of these and other California cities will be changing over the next century; this methodology was used to compare and validate the relative and absolute densities of the cities as the model progresses through time.

Figure 6 and Table 8 (low series) show that the urban densities of the region converge on low regional densities like that of San Diego. San Diego's density remains constant due to a relatively level population growth and a small expansion of urban extent. The de-population of San Francisco is startling in this projection, while it falls to a level on par with other urban regions. Fresno's doubling of population is matched with its urban expansion at a fairly even rate.

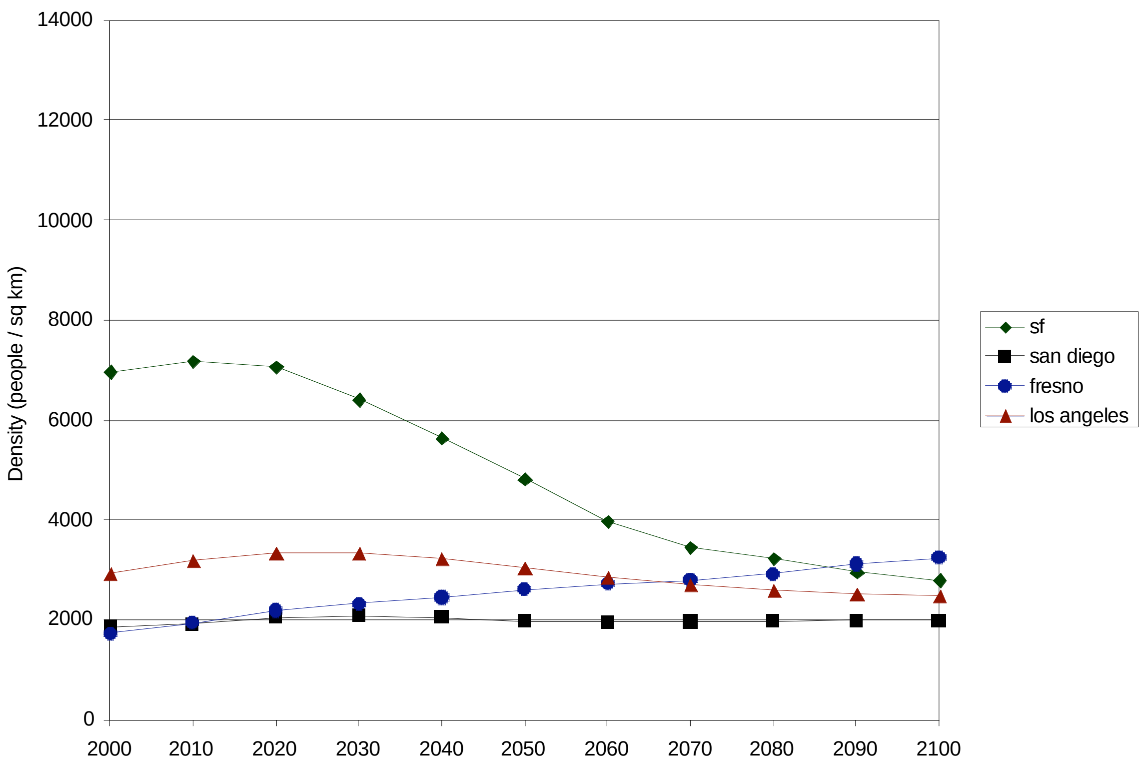

Figure 6. Low series urban projections for selected California regions

Table 8. Low series population densities (people/square mile [sq km]) for selected cities over time

Year	San Francisco	San Diego	Fresno	Los Angeles
2000	6966	1843	1725	2913
2010	7172	1909	1931	3174
2020	7062	2039	2179	3339
2030	6412	2081	2317	3345
2040	5639	2040	2439	3212
2050	4824	1975	2604	3025
2060	3978	1948	2716	2850
2070	3449	1952	2791	2697
2080	3226	1967	2915	2583
2090	2960	1985	3109	2507
2100	2790	1986	3229	2466

Figure 7 and Table 9 (middle series) show a likely realization of the future of California: growth in the large cities (Los Angeles and San Diego) and rapid exponential expansion in the Central Valley (Fresno).

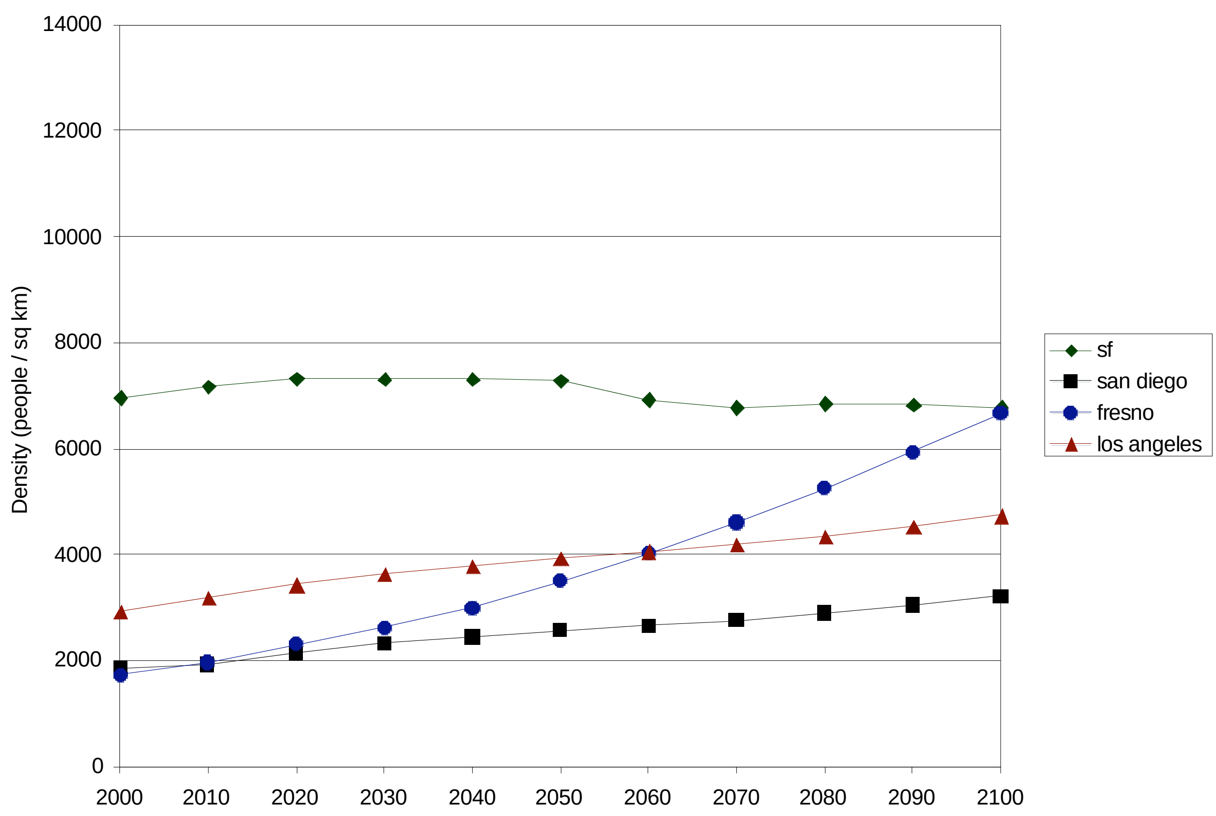

Figure 7. Middle series urban projections for selected California regions

Table 9. Middle series population densities (people/sq km) for selected cities over time

Year	San Francisco	San Diego	Fresno	Los Angeles
2000	6966	1843	1725	2913
2010	7178	1919	1960	3176
2020	7327	2126	2296	3431
2030	7317	2312	2611	3633
2040	7310	2438	2993	3774
2050	7285	2568	3494	3941
2060	6926	2651	4017	4058
2070	6777	2756	4599	4188
2080	6854	2890	5247	4340
2090	6832	3040	5933	4524
2100	6780	3212	6661	4735

Figure 8 and Table 10 (high series) illustrate statewide exponential growth. All current cities will increase in population density, San Francisco being the leader.

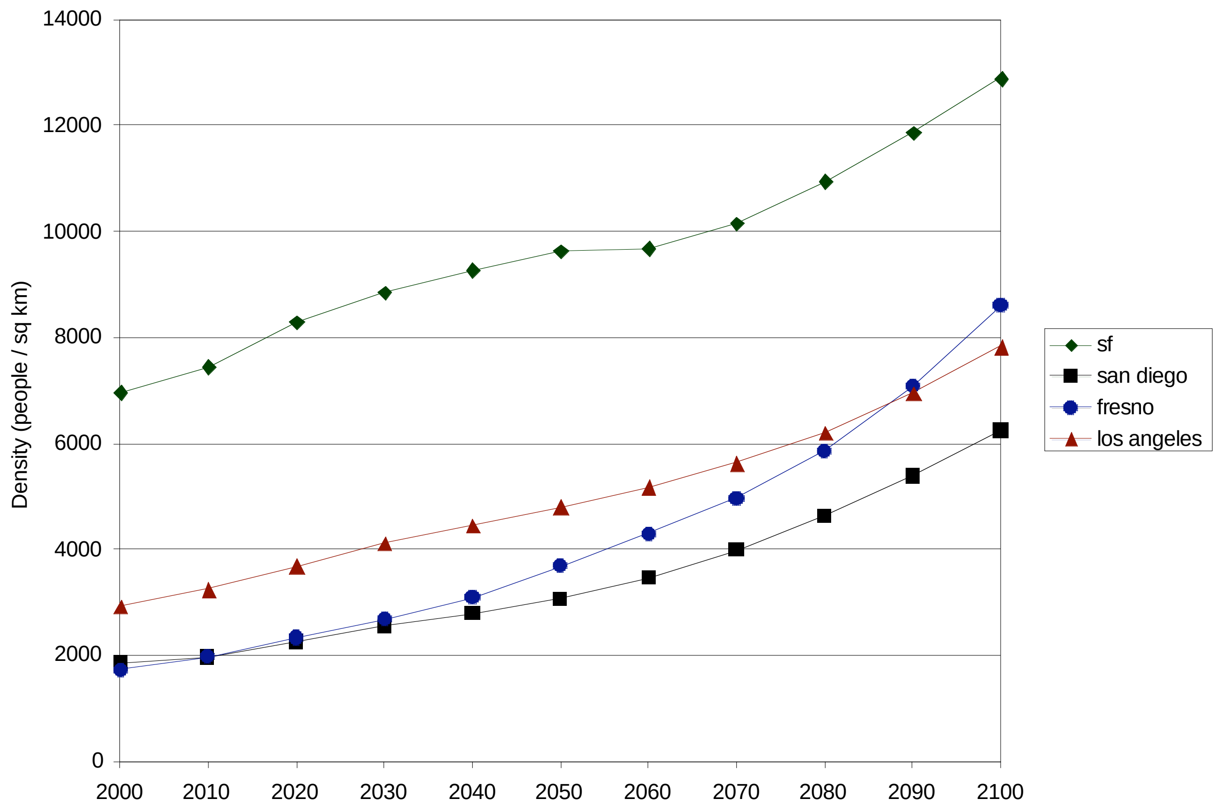

Figure 8. High series urban projections for selected California regions

Table 10. High series population densities (people/sq km) for selected cities over time

Year	San Francisco	San Diego	Fresno	Los Angeles
2000	6966	1843	1725	2913
2010	7445	1958	1972	3245
2020	8294	2254	2330	3688
2030	8849	2539	2675	4105
2040	9277	2787	3091	4450
2050	9636	3069	3677	4804
2060	9686	3462	4289	5180
2070	10158	3985	4958	5631
2080	10951	4622	5861	6207
2090	11866	5381	7069	6956
2100	12895	6243	8593	7829

Some of the forecasted urban densities in the high series (San Francisco in particular) appear extreme, but are comparable to current urban densities elsewhere in the world (Cox 2008). As illustrated by the data in Table 11, the population densities forecasted in the high series are plausible in a global context. For example, San Francisco in 2100 could resemble Casablanca in terms of density. Such expansive growth and increased population densities would arguably transform the look and structure of these cities, yet more densely populated cities like Hong Kong and New York have complete infrastructure and function as modern cities. The potential for California to practically accommodate such drastic increases or decreases in population and density is unknown and is worthy of future investigation.

Table 11. Population densities of world cities (from Cox 2008, except Manhattan, derived from the U.S. Census Bureau)

City	Country	Density (people / sq km)	Year
Hong Kong	China	29,400	2000
Manhattan	United States	27,000	2007
Mumbai	India	21,900	2001
Hanoi	Vietnam	15,450	2003
Casablanca	Morocco	12,700	2004
Istanbul	Turkey	8,850	2007
Mexico City	Mexico	8,450	2005
Rio de Janeiro	Brazil	6,900	2005
New York City (including all boroughs)	United States	1,750	2000

3.6. Future Costs of Driving in Southern California

In this section we apply our scenario results to project key inputs—household income and costs-of-driving—for use in the companion study on valuing economic impacts of climate change on Southern California beaches.

3.6.1. Household Income

Section 3.4 presented two statewide per capita income growth scenarios based on the middle series population projection presented in Section 3.3. Passing from statewide per capita to regional household income in principle requires additional information and assumptions regarding trends in California household composition that in turn are related to the evolution of other demographic factors. Full accounting for these details is beyond the scope of this study, and we apply the statewide aggregates directly with the following simplifying assumption. According to the California Energy Commission (Energy Commission), California's mean household size has increased in recent decades, and the Energy Commission's most recent energy demand forecast projects that it will reach 3 persons per household in the next decade (Marshall and Gorin 2007). Yi et al. (2006), in their "medium" projection, posit that average household size nationally will decline from 2.6 in 2000 to 2.4 in 2020 and remain stable thereafter. Table 12 presents growth rates in household income to 2100 under the assumption that the Energy Commission's estimate persists indefinitely (using estimates in Table 7).

Table 12. Real household income growth in California under lower and higher economic growth scenarios

	Average annual growth rate in percent	
Decade	*Lower*	*Higher*
2000–2010	1.10	1.10
2010–2020	1.10	1.10
2020–2030	0.88	1.38
2030–2040	1.04	1.54
2040–2050	1.09	1.59
2050–2060	1.03	1.23
2060–2070	1.06	1.26
2070–2080	1.06	1.26
2080–2090	1.08	1.28
2090–2100	1.09	1.29

3.6.2. Cost of Driving

The future cost of driving in Los Angeles and Orange counties will of course be determined by a range of local, regional, national, and international factors, both policy and market driven. Evolving cultural priorities and consumer preferences, fundamental shifts or stability in the structure of the global energy system, technological advances in vehicles, and local land-use planning and patterns, will be among the driving forces (pardon the pun). A comprehensive scenario analysis of these influences and their implications for travel costs is again beyond the scope of this study; we consider two plausible scenarios that relate future possibilities to historical and current trends.

The recent, rapid increase in the world price of petroleum and U. S. gasoline prices both serve as a reminder of the unpredictability of fundamental determinants of transportation costs and highlight the importance of historical perspective. Despite the oil shocks of the 1970s and early 1980s, transportation expenditures as a percentage of personal consumption expenditures among U. S. consumers were on average flat in real terms from 1970 through 2005, and they never exceeded 14% during this period (compared to 12.6% in 1970 and 12% in 2005).[10] The real cost of driving (nationwide) grew at an average of 0.7% annually from 1985 through 2005, but the share of gas and oil costs fell, and these latter costs on average were also essentially flat.[11]

Oil prices follow quite different trajectories under the SRES A2 and B1 scenarios, as shown in Table 13.

Table 13. Oil prices in SRES A2 and B1 scenarios

	Percentage increase (in real dollars) over year 2000 price	
Year	A2 – ASF model	B1 – IMAGE model
2020	7%	32%
2050	41%	92%
2100	70%	170%

In interpreting the implications of these projections for California scenarios, however, it is important to bear in mind that the relationship between oil prices and driving costs is likely to become more complicated. Comparable future driving costs could be achieved under quite different socioeconomic scenarios and oil price levels. For example, a continued dependence on petroleum and the internal combustion engine could lead to development of new, non-traditional fuel supplies and therefore gasoline prices that are relatively moderate in the long-run, although higher than historical levels.[12] This indeed might be one interpretation of the A2 projection. However, a similar outcome could occur under a radical shift in the transportation system toward alternative technologies and fuels, as might be envisioned under the B1 scenario. The reason is that such a shift could result in lower vehicle life-cycle operating costs for consumers, as has been projected in California (Arthur D. Little, Inc. 2002). Moreover, it is easy to imagine a scenario that began along one path but engendered a shift to another: Just as the increase in driving costs in the United States during the 1970s stimulated the introduction and penetration of fuel efficient vehicles, so might the persistence of current, extremely high gasoline prices lead to a similar shift in the vehicle fleet.

These complications notwithstanding, two cost scenarios are presented in Table 14. The first is a slight permanent increase in the growth in the cost of driving from recent trends; the second, a permanent approximate doubling of this growth. We assume, naturally, that the evolution of the regional transportation infrastructure is such that, while alternative modes may become more available, personal transport in essentially its current form remains readily accessible— that is, people driving vehicles on freeways and surface roads. The estimate of a $0.145 per mile cost in the year 2000 is taken from Pendleton et al. (2008).

Table 14. Projections of the cost of driving, 2020–2100

[10] See Table 10.13 in Davis and Diegel (2007).
[11] Table 10.11, Davis and Diegel, *op cit.*
[12] A supply curve for global petroleum resources including unconventional sources is presented in Farrell and Brandt (2006).

	Cost per mile in 2000 dollars	
Year	Lower growth ($)	Higher growth ($)
2020	0.18	0.22
2030	0.20	0.26
2040	0.22	0.32
2050	0.24	0.39
2060	0.26	0.48
2070	0.29	0.58
2080	0.32	0.71
2090	0.36	0.86
2100	0.39	1.05

3.7. Electricity Prices

This section develops several scenarios of future California residential statewide electricity prices for use in the companion study of potential climate change impacts on state residential electricity demand.

The *SRES* provides only limited information on possible future electricity prices, and none for the A2 or B1 scenarios. This reflects in part both methodological differences among the models used in the study and limitations of specific models. For this reason, we draw upon alternative sources.

Attempting to project California electricity prices, even in a scenario context, raises a host of issues that are more complex than those involved in long-term aggregates such as population and economic growth. Projecting these prices amounts to positing, at a minimum, how the state, Western United States, and national electricity systems will evolve under GHG regulation, a situation that remains profoundly uncertain. This is illustrated in a recent assessment by the Congressional Research Service of model-based projected economic impacts, including price impacts, of Senate Bill S. 2191, the Lieberman-Warner Climate Security Act of 2007 (Parker and Yacobucci 2008). Among six models, estimated increases in national average electricity prices under S. 2191 range from under 15% to nearly 130% by 2030. An even wider range of uncertainty was revealed in a recent model analysis of global atmospheric GHG concentration stabilization scenarios conducted by the U. S. Department of Energy. Among three economic models, carbon prices needed to achieve several stabilization targets varied by an order of magnitude (Clarke et al. 2007). It is important to emphasize that such uncertainty in outputs persists after several decades of model development and analysis, and shows no signs of narrowing.[13]

[13] The significance and potential sources of the large uncertainty in model-based estimates of the costs to the United States of large-scale GHG abatement policies are discussed by Fischer and Morgenstern (2006).

Figure 9 depicts real statewide average residential electricity prices in California from 1970 to 2005.[14] Following an increase over the decade of the 1970s, these prices have been on average flat for most of the past thirty years, regular fluctuations notwithstanding; 1980 and 2005 prices were approximately equal.

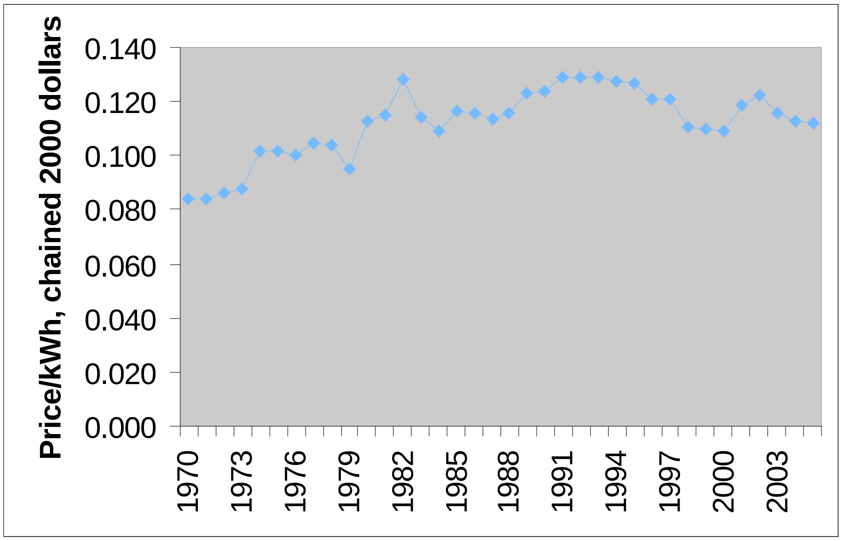

Figure 9. California real statewide average residential electricity prices, 1970–2005

A recent analysis on AB 32 compliance within the electric power sector conducted for the California Public Utilities Commission projected an average statewide rate increase of 30% over 2008 levels in 2020 in a scenario of accelerated energy efficiency and renewable energy deployment (Price 2008). This projected increase is comparable to that in the 1970s shown in Figure 9. It is also interesting to compare this finding with one of the above-mentioned recent national studies of S. 2191, the Lieberman-Warner Climate Security Act of 2007, by the U. S. Environmental Protection Agency (2008). S. 2191 aimed to achieve national GHG annual emissions reductions of approximately 11% below 1990 levels by 2030. A computable general equilibrium model simulation estimated that this would entail national average electricity price increases of 44% over 2010 levels by 2030.[15]

Work to-date on AB 32 and other California GHG policies has not encompassed potential price trajectories in the long term, and it can be expected that as this kind of analysis emerges the uncertainties will be comparable to those from national-level studies. To construct plausible scenarios, it is first useful to recall the magnitude of California's 2050 target. The California Air Resources Board has estimated California's 1990 GHG emissions as 427 million metric tonnes of carbon dioxide equivalent (MMTCO2e), and projected baseline 2020 emissions as 596

[14] Nominal prices were obtained from the U. S. Energy Information Administration (2008). Real prices were calculated using the implicit price deflator for personal consumption expenditures (U. S. Bureau of Economic Analysis 2008).

[15] Results from the Applied Dynamic Analysis of the Global Economy (ADAGE) model (M. Ros, pers. comm. 2008).

MMTCO2e (California Air Resources Board 2007, 2008). Thus, reductions of 169 MMTCO2e from baseline levels are required by AB 32. The 2050 goal of 80% below 1990 requires an additional 342 MMTCO2e of reduction, that is, twice again as much. It is not currently known how this target will be met, whether in terms of the mix of sectoral reductions, the specific technologies, or the portfolio of policies and measures.

Additional model results on S. 2191 from the U. S. Environmental Protection Agency are relevant. Beyond the previously noted 2030 target of 11% below 1990 levels, this legislation aimed for national GHG reductions to approximately 25% below 1990 levels by 2050. For this emissions trajectory, electricity prices in the Western U.S. region were projected to increase by 46% over 2010 levels by 2030 but recede to 34% over 2010 levels by 2050 (M. Ross, pers. comm. 2008).

Against this background, we posit the following two price scenarios: (A) A 30% increase as of the 2020–2040 time frame, followed by flat prices for the remainder of the century, and (B) The same 30% increase followed by another 60% increase by mid-century and flat prices thereafter. For the coming several decades, the first scenario is consistent with the recent California Public Utility Commission results. A flat trajectory thereafter can be interpreted in several ways. An "optimistic" interpretation is that it reflects technological breakthroughs that allow the widespread deployment of very-low carbon electric power generation technology, as well as demand-side energy efficiency, without further upward price pressures. This might be considered as naturally fitting with the *SRES* B1 storyline. A "pessimistic" interpretation is that, following initial GHG policy successes, further progress toward the more aggressive mid-century target is stalled, and the status quo as of the 2030 time frame prevails. This might be considered as consistent with the A2 storyline.

The second scenario is again consistent with the existing near-term estimate, and also admits several interpretations for the "out-decades." The assumption of a price increase that is linearly scaled with the percentage emissions reduction can be seen as either optimistic or pessimistic. A pessimistic view might be that technological progress is insufficient to forestall significant price increases, while the optimistic counterpart would be that the unprecedented GHG reduction is achievable at no more than a doubling of prices. Assuming no further change for the remainder of the century reflects both the lack of reasonable information upon which to base any alternative assumption, and our view that in any case only rough orders of magnitude are meaningful in this context.

4.0 Conclusion

Steadily improving scientific understanding of the evolution of the global climate system has sharpened our knowledge of the potential risks from climate change, both those that can be reduced by GHG mitigation and those that appear to be unavoidable. Consequently, projecting and planning for climate change impacts has emerged in recent years as a necessary complement to developing and implementing mitigation policies. Adaptation to climate change may be the most challenging environmental problem human society has yet faced, for it requires dealing successfully with unprecedented scientific complexity and fundamental uncertainty about the interactions of natural and social systems far into the future.

Scenario studies are a basic tool for approaching these issues. This report has suggested a context for California climate change impact assessment consistent with the *SRES* scenarios, and provided projections of specific key variables to support specific impact studies. Our hope is that this work and the companion studies in this overall second assessment will contribute to the knowledge base for California's successful response to the climate challenge.

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Appendix A

Overview of Methodology for Urban Projections

Appendix A: Overview of Methodology for Urban Projections

A.1. Methods

The purpose of the urban projections developed for this project was to provide urban extents and spatially distributed population output for use in sector-specific impact scenarios, applying the most readily available and appropriate methods. The outputs are twofold for each of the three demographic scenarios described in this report: (1) Future urban footprint for California, and (2) Scenario-derived population forecasts allocated to the urban footprint.

A.1.1. Creating the Urban Footprint Layers

We built on the methods and results of Landis (2001) and Landis and Reilly (2003). Their urban footprint forecasts were used, when and where available, as the "core" urban footprint. These forecasts were available at a one-hectare spatial resolution for 38 counties in California, excluding the northernmost and least populated counties for the years 2000, 2020, 2050, and 2100 (Landis and Reilly 2003).

The other source of geospatial data needed for the urban footprint was the Nighttime Residential Population dataset produced at Los Alamos National Laboratory (LANL) (McPherson and Brown 2003). This dataset modifies the vector-based U.S. Census dataset, which it itself a nighttime estimate of population, and attributes population using data products from GeoData Technologies, Inc. The LANL dataset attributes grid cells of 250 m with the population from the corresponding Census blockgroup.

The steps in generating future urban extents were as follows.

First, the complete urban "seed" layers were created. An urban "seed" layer is a complete, state-wide estimate of urban extent. As noted above, the Landis and Reilly estimates were incorporated as a starting point for the 2000, 2020, 2050, and 2100 estimates. Two aspects of these estimates necessitated the use of other forms of data. The first was their restriction to 38 of the states' most populous counties. The second was that the estimates were limited to the state's more dense regions, and not sparse and rural regions, where greater uncertainty lies in the location and scale of future population extent.

The completion of the "seed years" was done in two ways. First, urban extent from the LANL nighttime population set was added, given different thresholds for future years. This was done based on the hypothesis that new populations will live either in or nearby current urban extent, albeit at different densities than today. The thresholds for the additions of urban extent from the LANL data set are:

For year 2000 "seed" layer, densities > 40 people/km^2 are "urban"
For year 2020 "seed" layer, densities > 20 people/km^2 are "urban"
For year 2050 "seed" layer, densities > 8 people/km^2 are "urban"
For year 2100 "seed" layer, any gridcell with any nighttime population is "urban"

This is admittedly a very low population density. However, this was chosen to account for the highly dispersed nature of California population. In rural regions, this low density has an "urban influence" on the natural environment. This methodology of using thresholds is that for regions not modeled by Landis, the extremely sparsely populated regions will be under estimated. For example, in Humboldt County, the 2010 urban layer may not include urban extent of densities lower than five people/km^2. This implies that the use of these data for rural regions may require other forms of augmentation. Future work could examine more explicitly differential population densities for rural and urban regions in California.

The second way the Landis and Reilly data were augmented was by incorporating the spatial centroid of every U.S. Census as an urban cell to account for rural regions with very sparse population. In most regions in the 38 counties included in the Landis and Reilly study, the LANL urban extent was co-incident with the Landis and Reilly data. Less dense regions with the region did surface as urban extent. The effect of adding census centroids was largely coincident to the Landis and Reilly and LANL dataset, with the exception of rural census tracts, or census tracts that had most of the population located in a corner or along one side of the tract.

Second, once the seed layers were set up—for 2000, 2020, 2050, and 2100—the intervening quinquennial years were created by “growing” the seed layers in a crude manner. Under the assumption that all urban extents grow at a constant rate, and that urban regions grow from their edges outward (and not from “spotting,” as modeled in Clarke and Gaydos [1998]), the intervening years were created by adding urban pixels to a seed layer in five year increments. This was performed iteratively, until reaching the next seed layer.

A.1.2. Future Population Allocation

Once the quinquennial future urban footprint layers were created, future population was allocated to create a spatially distributed population map. This was done in two ways. The first was to allocate population evenly throughout each time step by county, which was the scale of the demographic forecasts. The second method allocated population according to relative Census tract population size in each county. The former method may be more useful for the sparsely populated counties, or those working at county-level scales. The latter method provides a finer-resolution of detail while containing potentially more spurious population estimates.

A.1.2.1. County-Scale Allocation

The county-level allocation method is fairly straightforward. This method assumes isotropy within the county, i.e., within the urban footprint or urban extent, all population is distributed evenly, at a uniform density. Given this assumption, the population for each county is divided evenly by the number of urban pixels for each county per time step. The pixel-based population value is then attributed to each pixel so that the sum of all pixels in each county provides the total county population for that time step.

A.1.2.2. Tract-Scale Allocation

Allocating the forecasted population to the tract scale uses a similar methodology to the county-scale allocation. First, using data from the 2000 U.S. Census, the relative population share of every tract in each county was calculated. This relative population share will most certainly change in the future; however, this level of forecasting was beyond the scope of this work. Next, the county population for each time step was divided by the geographical size of each tract, according to their relative share. Each pixel was then attributed with the appropriate number of people in each tract, reflecting the county-level population. Last, the number of households were calculated, using the proportion of number of households in each region, based on California Energy Commission earlier work (Abrishami et al. 2005). Household proportions were held constant for the study period; future investigations can incorporate explorations of dynamic household proportions in each region.

The allocation methodology for the three population scenarios differed slightly to account for prospective shifts in the density of urban core regions. In essence, the “Low Series” population forecast emphasizes a shift of population to the urban areas, while the “High Series” emphasizes a shift away from the urban core. The “Middle Series” forecast is unchanged.

The High and Low series augmentations were performed by adjusting the Census 2000 population up (in the Low series) or down (in the High series) if the tracts were in the "Census 2000 Urban Areas and Urban Clusters," as distributed by ESRI. The emphasis was a 1% cumulative change per time step. For example, the Low series the urban areas were over-emphasized 1% in 2005, 2% in 2010, and so on, maxing out at 10% in 2100. Conversely, the High series de-emphasized urban regions 1% in 2005, 2% in 2010, so that by 2100, the urban regions were de-emphasized by 10%. In future work the adjustments can be explored.

An additional adjustment was made for San Quentin State Prison in Marin County. Due to the way the prison is captured as a Census tract and represented in raster forms, it maintains the densest part of California, with over 6000 people in 432 acres, according to the U.S. Census Bureau. This high population skews the relative ranking for forecasted population growth. To mediate this affect, the population was fixed at its current state for the Middle Series, allowed to shrink to a population of 3800 for the Low series and constrained to "only" double in size for the High series. Specific anomalies for locations such as San Quentin are usually below the resolution of demographic analyses.

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Appendix B

Labor Productivity Implications of the California Scenarios

Appendix B: Labor Productivity Implications of the California Scenarios

B.1. Background

As noted in Section 3.4, the economic growth and population scenarios that we have reported were developed separately. By contrast, a procedure that is applied in "integrated assessment" models of the type used in the *Special Report on Emissions* Scenarios (SRES) is to project economic growth rates as a function of population growth, labor force participation, and labor productivity (Smith 2008). We here review the long-run California labor productivity rates that are jointly implied by our economic and population growth projections.

Because we have not projected future California labor force growth *per se*, we use population growth as a proxy. To compare with recent historical trends: According to data of the California Department of Finance and Employment Development Department, from 1981 to 2008 the annual average state population growth rate exceeded the labor force growth rate by 0.06%.[16] Thus, while labor force projections are beyond the scope of this study, assuming that the labor force grows at the rate of population increase in the long term may be considered a reasonable approximation for illustrative purposes.

B.2. Labor Productivity Estimates

Table B1 shows the labor productivity rates implied by the population and GSP growth rates for the 2020–2050 and 2050–2100 periods, by the low-, middle-, and high-growth projections, under the assumption that the labor force growth rate equals that of population.

Table B1. Average annual labor productivity growths (in %) implied by GSP and population scenarios, 2020–2050 and 2050–2100

	Population scenario		
GSP scenario	**Low series**	**Middle series**	**High series**
2020–2050 Low	1.8	1.0	0.7
2020–2050 High	2.5	1.5	1.2
2050–2100 Low	1.6	1.1	0.3
2050–2100 High	2.0	1.3	0.5

[16] Authors' calculations using State of California, Employment Development Department (2005, 2009) and State of California, Department of Finance (undated, 2007, 2008).

B.3. Discussion

Again by way of historical comparison, Bauer and Lee (2006) estimated California's labor productivity growth rate to have been approximately 1.7 annually from 1977 to 2004. Wilson (2002) noted that California's productivity exceeded that of the rest of the United States from 1986 through 2000. Given the derivation of our economic growth scenarios from the SRES, it is also worth comparing the estimates in the table with those reported there. The SRES noted the historical U. S. productivity growth rates (in annual average increase in GDP per hour worked) of 2.3% from 1870 to 1973, and 1.1% from 1973 to 1992.[17] According to the SRES, productivity assumptions were not directly comparable across the numerical models used to project the scenarios, but labor productivity projections ranged from 0.79% to 5.85% across the scenario families and world regions.[18] While no further detail is given, we assume that U. S. rates in the scenarios were on the lower end of that range.

More recent U. S. national data show a return to near the long-term historical level.[19] In addition, the U. S. Energy Information Administration recently projected national labor productivity improvement of 1.9% on average to the year 2030 (U. S. Energy Information Administration 2008).

We conclude that, while the implicit labor productivity projections shown in the Table are generally plausible, those below 1% implied by the High population growth scenario represent a very pessimistic view of future California productivity. By contrast, those implied by the Middle series and High series are consistent with the views that future productivity growth will tend toward the low end or the high end, respectively, of historical experience.

These results highlight the value of incorporating explicit assumptions regarding future productivity trends in any subsequent California climate change scenario studies of this type.

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