White Paper

State-level economic impacts of a **National Climate Change** policy

Prepared for the Pew Center on Global Climate Change

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Executive Summary

Ongoing climate-change research indicates that human activities are contributing to a warming of the earth through activities that result in emissions of large quantities of greenhouse gases (GHGs) that trap heat in the atmosphere. Among these activities are production and consumption of fossil fuels, changes in land-use patterns, production of agricultural goods, and various industrial processes. Climate models have projected temperature increases from these anthropogenic emissions at between 2.5˚F and 10.4˚F by 2100 (Houghton et al., 2001), potentially leading to significant environmental changes and climate variability across regions of the globe.

Numerous strategies to mitigate these impacts are being developed and implemented by governments around the world. Among these are the Kyoto Protocol, enacted by many Annex I countries; Canada's Climate Change Plan; and the ongoing European Union Emissions Trading System (EU-ETS), which represents the world's first multinational GHG trading system. Within the United States, a variety of national–, regional–, and state-level proposals for reducing GHG emissions are being developed. One example is the Regional Greenhouse Gas Initiative (RGGI), where a group of Northeastern and Mid-Atlantic states is cooperating to enact a cap-and-trade system for carbon-dioxide emissions from power plants another is in California, which has formally adopted a greenhouse gas reduction target of 1990 levels by the year 2020 and is debating the policy suite (including cap-and-traded) to implement. At the national level, a variety of bills have been proposed, with alternative elements including incentives for carbon capture and storage, renewable energy, automobile standards and even reengagement at the international level. A consistent element in most of these proposals however, is the inclusion of cap-and-trade system that allows the transfer of permits from firms with low cost of GHG controls to firms with higher costs. Accordingly, this report analyzes as a first step, the potential costs of a moderate national cap-and-trade policy that seeks to stabilize emissions at the level seen in the year 2000. The objective is to inform the debate about alternative policy options and how these might be expected to impact the types and relative impacts that could be experienced both at the national and regional level.

Policy simulations in this report indicate that the level of offsets allowed, the method of allocating permits, and the energy-intensity of states all have significant impact on the macroeconomic impacts. Results also indicate, however, that the impacts of a moderate GHG policy on the United States would be minimal and exhibit the following broad characteristics:

- ✓ Slight declines in the growth rates of national gross domestic product (GDP) and states' gross state products (GSP) over the next 15 years—generally on the order of one to two one-hundredths of a percent per year.

- ✓ Demands for electricity and oil fall modestly (natural-gas use rises), while energy prices increase slightly.
- ✓ While impacts on manufacturing and electricity generation vary moderately across individual states as a function of states' energy efficiency and carbon intensities, variation in the effects on states' household consumption (which have the same overall magnitude as the GSP impacts) depend fundamentally on how the policy is designed and implemented.

Table ES-1 summarizes these results using the metrics provided in other analyses of climate-change mitigation policies; these results are discussed in detail below. Allowance prices, which reflect costs associated with reducing emissions, range from $4 to $8 per metric ton of carbon dioxide equivalent, or $MTCO_2e$, when the policy scenario first takes effect in 2010. After another 10 years, these prices are between $7 to $14 per $MTCO_2e$. Adjustments in the economy associated with investing to improve energy efficiency, switching among fuels, and lowering energy consumption lead to minimal declines in GDP by 2020 and similarly slight declines in household consumption.

Table ES-1. Summary Results

	Free Offsets		Market Offsets	
Macroeconomic Variable	**2010**	**2020**	**2010**	**2020**
Allowance Price ($/MTCO2e)	$4.3	$7.0	$8.4	$13.6
GDP (%)	-0.01%	-0.12%	-0.04%	-0.24%
Household Consumption ($)	$20	-$49	$20	-$113

The analytic techniques used to estimate these policy effects are based on a long history of evaluating the impacts of climate-change mitigation policies using computable general equilibrium (CGE) models. By combining economic theory with empirical data, CGE models have the unique ability to estimate how the effects of policies with no historical precedents will ripple through an economy and influence all interactions among businesses and consumers. The Kyoto Protocol has been extensively analyzed through these methods—see, for example, Weyant and Hill (1999), which compares results for this policy from a group of models. Several CGE models have also been used to investigate the *Climate Stewardship Act* (see Paltsev et al. [2003] and Smith et al. [2003] and more recently the *Climate Security Act*, (see EPA [2008]).

This report follows methodologies similar to previous policy analyses and employs the RTI International *Applied Dynamic Analysis of the Global Economy* (ADAGE) model to examine the general insights that such economic models can provide and more specifically how a modest national climate-change mitigation policy such might affect the U.S. economy and the economies of individual states within the country. The model's structure, which is based on other CGE models designed to investigate such policies, allows it to estimate a price for emissions allowances that will

encourage the energy-efficiency improvements, shifts in fuel mix, and reductions in energy consumption needed to meet a particular emissions target. The resulting changes in energy markets can then be analyzed to see how they have influenced the behaviors of firms and households, affected energy prices and demands, and altered macroeconomic variables such as gross state product (GSP), gross domestic product (GDP), employment, and households' consumption spending.

Along with the capability to explore these economic effects at a state level, the ADAGE model has unique abilities to integrate and evaluate a mix of provisions included in several of the recent policy proposals that have not been considered in previous analyses. For example, along with carbon-dioxide emissions (CO_2), mainly from energy consumption, many of the proposed climate-change mitigation policies cover five additional types of non-CO_2 GHG emissions. Modeling research has shown that taking these gases into account can substantially lower estimated policy costs because they provide low-cost opportunities to reduce GHG emissions (see, for example, EPA, [2007] and [2008], *Energy Journal* [2006], Reilly et al. [2003], Babiker et al. [2002], Hyman et al. [2003], and Paltsev et al. [2003]). In addition to including these emissions reduction opportunities, the ADAGE model can handle policy exemptions like those proposed for small businesses, agriculture, and households.

Based on previous CGE investigations, various policy provisions suggested by bills proposed in the 110th Congress by Senator's Bingaman, Specter, Kerry, Snowe, Warner, Lieberman, McCain, Sanders, Boxer, Feinstein, Carper, Alexander and Congressmen Olver, Gilchrest, Waxman, and policy suggestions from the US Climate Action Partnership[1]- specific policy assumptions incorporated in this analysis include the following:

- A target for U.S. GHG emissions is established at year 2000 emissions levels, beginning in 2010.
- The emissions target covers CO_2 and the five most important types of non-CO_2 GHGs
- A nationwide cap-and-trade system (with some exemptions for households, agriculture and small businesses. This system gives affected entities the option to reduce their emissions, purchase allowances giving them the right to emit GHGs, or sell allowances if they have low-cost opportunities to reduce emissions below the number of allowances they receive under the policy scenario
- Several "flexibility mechanisms" are also incorporated, notably flexibility to overcomply and save (or "bank") allowances for use in the future and the ability to acquire allowance "offsets" equivalent to 15 percent of the target through emissions reductions made by sources outside the trading system.

[1] United States Climate Action Partnership (USCAP) is a group of businesses and leading environmental organizations (including the Pew Center on Global Climate Change) that have come together to call on the federal government to quickly enact strong national legislation to require significant reductions of greenhouse gas emissions.

Economic impacts associated with these policy assumptions will be influenced by the availability and cost of allowance offsets generated by emissions reductions outside the cap-and-trade system (such as those from noncovered entities, international GHG markets, and sequestration). This report follows previous analyses and addresses the issue by establishing lower and upper bounds on model results that depend on offset assumptions:

- **"Free Offsets"**—In this case, the full 15 percent of allowance offsets allowed by the policy are assumed to be available at no cost. This is a lower-bound approximation that represents what might occur if significant quantities of low-cost sequestration options are available or if purchases of allowances can be made from international GHG markets at very low prices (possibly from international avoided deforestation/sequestration opportunities).
- **"Market Offsets"**—In this restrictive case, offsets are assumed to only be available from emissions reductions made by noncovered entities within the United States at a market cost estimated within the model (and no offsets are generated from carbon sequestration).

Based on these policy assumptions, and its underlying data and theoretical structure, the ADAGE model estimates national allowance prices for each of these two cases (shown in Table ES-1 above). These prices reflect costs to the economy of abating emissions as necessary to meet a modest policy target[2], which in the case evaluated here requires emissions reductions on the order of 15 to 25 percent from baseline (or business as usual, or "BaU") levels by the year 2025. Specific allowance prices within these two cases will depend on the evolution of offsets' availability and cost. Inclusion in ADAGE of low-cost emissions reductions from non-CO_2 GHGs and noncovered entities keeps these allowance prices around 15 to 20 percent below where they would be if the model did not consider such options.

Establishing these allowance prices encourages businesses and households to consider the effects of their choices on GHG emissions, which leads to adjustments in the economy as people invest to improve energy efficiency, switch among fuels, lower energy consumption, and otherwise reduce GHGs. Accordingly, energy markets, which are an essential component of the economy but represent a small fraction of overall GDP, experience the largest adjustments under the climate-change mitigation policy. Coal, the most carbon-intensive fuel, experiences the largest consumption reduction, while natural gas consumption increases because people switch to this lower-carbon energy source.

Impacts on U.S. GDP associated with policy simulations analyzed in this report are minimal. In the absence of a climate-change mitigation policy, the average annualized GDP growth rate between 2005 and 2020 is expected to be 2.85 percent per year. In the "Free Offsets" policy case, this growth rate is 2.84 percent per year, and for the "Market Offsets"

[2] The reduction objective evaluated here is not intended to suggest a recommended level for policy but rather is used for illustrative purposes only.

case, it is 2.83 percent. On an annual basis, in 2010 (the first year of the moderate policy analyzed), there is essentially no change in GDP. By 2020, the improvements in energy efficiency, decreases in energy consumption, changes in fuel mix, and changes in energy prices associated with reducing emissions lead to a slight decline in the growth of GDP—on the order of 0.12 to 0.24 percent.

Similarly, distinguishing impacts of the policy on household consumption is difficult in terms of the average growth rate between 2005 and 2020; the effects are around one to two one-hundredths of 1 percent. Following a slight initial rise in 2010, aggregate household consumption declines by around a tenth of a percent in 2020 after the policy has been in effect for 10 years, which is equivalent to $50 to $110 per household. Across the U.S. economy, growth in employment under the two policy cases is around 1.22 percent a year on an annualized basis between 2005 and 2020, compared with 1.23 percent growth expected in the model baseline.

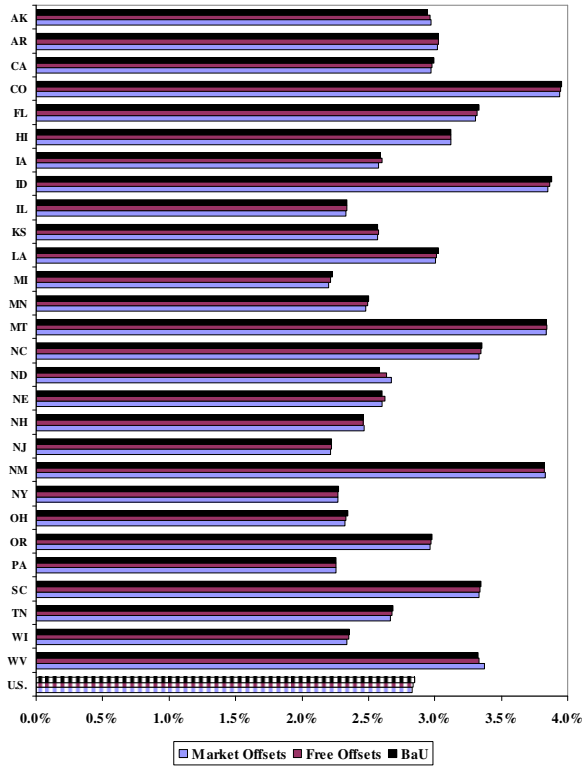
Impacts of the climate-change mitigation policy on individual states within the nation depend on a variety of factors considered by the model. Among the most important of these are each state's initial energy consumption, the mix of products it manufactures, how its electricity is generated, and the number (or endowment) of allowances it receives under the policy. States using relatively little energy in their manufacturing industries will need to make fewer economic adjustments to reduce emissions than more energy-intensive states. Also, because many of these adjustments are expected to occur in the electric-utility industry, the generation technology and fuel mix currently used will have an impact on how states adjust to the policy. Finally, the distribution of allowances across states, while not significantly affecting overall production, can have important implications for household income and consumption (this report assumes in the two main policy simulations that allowances are distributed across states according to historical emissions in the year 2000; findings are also presented for an alternative distribution scheme).

Figure ES.1 compares expected rates of growth in GSP for the 28 states listed down the side of the graph. Average annualized growth in the model's baseline between the years 2005 and 2020 are shown in black and compared to the two alternative offset cases shown in blue and red. As with the national-level results, relatively small macroeconomic effects are predicted. However, even with the most restrictive assumptions about the availability and cost of offsets, by 2020 after the policy has been in effect for 10 years, no states have declines in GSP of more than approximately 0.3 percent from their expected baseline levels.

States with high energy consumption per dollar of GSP, or those engaged in energy production, are more likely to experience adjustments in production activity that are larger than the U.S. average. This occurs because such states have both a greater capacity and a stronger incentive to modify their energy consumption in response to the climate-change mitigation policy. The trends in employment growth generally follow these changes in production, although they also depend on the mix of products made in a particular state. By 2020, in the "Free Offsets" policy case, employment impacts range from a decline of one-half of 1 percent in North Dakota to a slight increase in Montana. In the "Market Offsets" case, impacts go from a high of 1 percent in North Dakota to a low of around five one-hundredths of a percent in states such as California, Florida, and Hawaii because of the product mixes in these states.

Figure ES.1

Impacts on Annualized GSP Growth Rates between 2005 and 2020



Impacts of the policy scenario on household consumption within each state, however, may not be tied solely to changes in employment. Divergences may occur because of the possibility that allocations of allowances to states can significantly redistribute income across the country. Allowance allocation can thus potentially be used to offset or equalize policy impacts on U.S. citizens. For example, assuming that an allowance is worth $7 per $MTCO_2e$, the total value of allowances available under the policy would be around $40 billion. Although the distribution of these

allowances will not have significant impacts for states' production activities, it does have important implications for household income and thus household consumption. One possible approach is to base allocations on states' historical emissions, which may compensate states experiencing larger than average changes for these economic adjustments through receiving additional allowances. Another approach might be to distribute allowances based on population. Such options need to be evaluated.

I. Introduction

Human-generated contributors to increasing atmospheric GHG concentrations arise from a wide range of economic activities. Among these emission sources are carbon dioxide (CO_2) from energy production and land-use change; methane (CH_4) from fuel production, landfills, and agriculture; nitrous oxide (N_2O) from agricultural and industrial activities, as well as fuel combustion; and perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6) from a variety of industrial processes. There is growing scientific consensus that these emissions, and the resulting rise in atmospheric GHG levels, have directly contributed to recent years being among the hottest on record. This warming appears already to be causing dramatic changes in local environments, including the melting of ice masses at the poles, the thawing of permafrost in northern latitudes, and the degradation of coral reef systems. Projections from climate models also indicate that, in the absence of changes in anthropogenic emissions trends, the current global warming will continue worsening over the next century (see Smith [2004] for a discussion of how these changes in climate may affect different regions and environments in the United States).

In response to these potential environmental impacts, policies have been, and continue to be developed, to curb the growth in GHG emissions. European nations are already engaged in reducing emissions through the European Union Emissions Trading System (EU-ETS) as a prelude to implementation of the Kyoto Protocol in participating Annex I countries. Within the United States, people at the national level and a large number of state and local governments[1] are interested in developing domestic policies to address GHG emissions. At the national level, a variety of bills have been proposed, with alternative elements including incentives for carbon capture and storage, renewable energy, automobile standards and even reengagement at the international level. A consistent element in most of these proposals however, is the inclusion of cap-and-trade system that allows the transfer of permits from firms with low cost of GHG controls to firms with higher costs. Accordingly, this report analyzes as a first step, the potential costs of a moderate national cap-and-trade policy that seeks to stabilize emissions at the level seen in the year 2000. The objective is to inform the debate about on types and magnitude of impacts that could be expected both at the national and regional level.

The objective of this report is to illustrate insights into alternative policy options and the potential impact nationally and explicitly at the state level associated with a modest GHG control policy. Differences in the structure of the economy across the United States are likely to cause these impacts to diverge from those estimated for the country

as a whole. Because acceptance of a national GHG policy is likely to depend on such state-level effects, an analysis such as this report is essential to understand the potential magnitudes of these impacts, their economic foundations, and how a policy may be designed to address them.

The subsequent sections in this report are organized as follows. Section II provides an overview of the key features of the policy analyzed in this report, describes the computable general equilibrium (CGE) model used in the analysis, and discusses how the macroeconomic model considers quantitative features of the illustrative policy considered. Section III presents estimated policy effects for the United States as a whole and for specific states, and Section IV summaries the main findings. Finally, Appendix A offers results of sensitivity analyses that have been conducted on various modeling assumptions, and Appendix B gives more information about the macroeconomic model.

II. Modeling of the Climate-Change Mitigation Policy

This section discusses features of the national policy scenario used in this report to provide analytical context information on the ADAGE CGE model, and to describe how the policy modeling is implemented.

A. Policy Features

A nationwide cap on GHG emissions is analyzed here similar in approach to that successfully used to reduce sulfur dioxide (SO_2) emissions under Title IV of the Clean Air Act Amendments of 1990 (Ellerman et al., 2000). Under this approach, affected entities can choose to reduce their emissions to meet the target, purchase allowances giving them the right to emit GHG from other entities covered by the policy, or sell allowances if they have low-cost opportunities to reduce emissions below the number of allowances they receive under the program. Thus, by including allowance trading, the policy evaluated ensures that the private sector has incentives to find the least-cost reductions across the economy.

The cap-and-trade system would cover the six GHGs considered by most of the bills proposed in the 110 Congress and by many international and domestic climate negotiations (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6). Aside from specific exemptions for households and agriculture, all sectors of the economy would be included under the emissions cap. Small entities within sectors, defined as those emitting less than 10,000 metric tons of GHGs per year as measured in CO_2 equivalents (CO_2-e), would also be exempt. However, petroleum products intended for transportation and manufacturing inputs leading to emissions of several types of GHGs (HFC, PFC, and SF_6) would be covered at the point where they are produced or imported. By including petroleum products at the refinery level, "indirect" emissions (sometimes referred to as upstream emissions) from personal transportation (and other forms of transportation) would be covered under the policy scenario examined here. Because emissions from transportation fuels were responsible for around 31% of U.S. CO_2 emissions in 2000 (U.S. EPA, 2005) and their share is expected to grow over time, this approach greatly enhances the coverage of an emissions cap. Similarly, "indirect" emissions associated with the electricity consumed by noncovered entities are covered because emissions from this electricity generation will be captured at the electric-utility level.

After considering exemptions for households, agriculture, and small entities, it is assumed that around 80 percent of U.S. GHG emissions would be included in the cap-and-trade system established by the policy. These

covered emissions would be capped at year 2000 levels, beginning in 2010. Allowances enabling entities to emit GHGs up to the level of the cap are considered in the model to be fully auctioned (and the revenue recycled to the economy in lumpsum). In reality it is more likely that some allowances would be auctioned and some given away, or "grandfathered," to incumbents or entities taking early action. In the Regional Greenhouse Gas Initiative – RGGI, for example, a minimum 25% of allowances must be auctioned for public benefit purposes that could include assisting affected workers and communities or providing affordable residential energy-efficient improvements. An examination of these uses of auction revenue and potential benefits, however, are beyond the scope of the current effort.

A variety of "flexibility mechanisms" are incorporated into the analyzed scenario to enhance its economic efficiency. One of the most important is the flexibility to trade allowances to take advantage of the cheapest reduction opportunities across sectors of the economy. Past analyses of GHG policies have demonstrated that expanding coverage of a trading system can significantly reduce costs of meeting emissions targets (see, for example, Weyant and Hill [1999]). Similarly, ongoing modeling efforts being conducted by participants in the Stanford Energy Modeling Forum[2] show that allowing trading across types of GHGs, rather than restricting consideration to CO_2 alone, provides additional cost-effective reduction opportunities (see, for example, Hyman et al. [2003] and the Special Issue of the *Energy Journal* (2006) on multigas abatement). The flexibility to overcomply and bank allowances for future use, and the ability to acquire up to 15 percent of total required allowances from sources outside the trading system: noncovered entities, international GHG markets (i.e., developed nations participating in the Kyoto Protocol), and sequestration of carbon in agricultural soils and forests is also included in the scenario evaluated.

B. The ADAGE Model

ADAGE is a dynamic CGE model capable of investigating effects of both international and U.S. domestic GHG policies (see Appendix B for additional information). To estimate policy effects, the ADAGE model combines a consistent theoretical structure with observed economic and energy data covering all interactions among businesses and households. Households are forward looking and thus can adjust their behavior today in response to future policy announcements. Decisions by households regarding the consumption of goods and the amount of labor to supply to businesses are made to maximize their overall welfare—estimates of labor-supply responses are taken from the literature to determine how employment may be affected by policies (see Ross [2005]). Firms are assumed to maximize profits subject to their manufacturing technologies (current and future). Equations and parameters in ADAGE

influencing how firms and households react to policies (e.g., feasible energy-efficiency improvements and fuel switching) are derived from existing CGE literature, notably, Babiker et al. (2001)—the Massachusetts Institute of Technology's Emissions Prediction and Policy Analysis (EPPA) model—and Balistreri and Rutherford (2004). This model structure, along with baseline projections of energy consumption and assumptions regarding economic growth and capital formation, will determine estimated abatement costs for CO_2 emissions.

An important feature of ADAGE for this analysis, along with covering CO_2 emissions from fossil-fuel consumption,[3] is its inclusion of the five types of non-CO_2 GHG emissions (CH_4, N_2O, HFCs, PFCs, and SF_6). Unlike CO_2, these gases are not emitted in fixed proportions to energy consumption, making the modeling of abatement costs more problematic. Rather than relying on abatement cost functions that are external to the model, and thus ignoring interactions among economic sectors, costs of reducing these five GHGs have been endogenized in the model using an innovative approach developed by Hyman et al. (2003).[4] Sector- and gas-specific abatement costs are also based on findings presented in this paper.[5]

The version of the ADAGE model used in this analysis is composed of two modules: "*International*" and "*US Regional*." Each module relies on different data sources and has a different geographic scope, but both have the same theoretical structure. The internally consistent, integrated framework connecting ADAGE's modules allows the *US Regional* component to use relevant policy findings from the *International* component and ensure that broad international effects of policies are considered by states, while avoiding computational issues that preclude solving for all U.S. states and world nations simultaneously. Within the *US Regional* module, states are combined using a flexible regional-aggregation scheme that allows an individual state of focus to be designated and modeled relative to other multi-state regions. Five primary regions (groups of neighboring states) and an individual state (modeled as a distinct sixth region) are included in each policy simulation. By running this scheme through all states of interest, findings can be obtained for multiple states in a computationally tractable, yet flexible and consistent, manner.[6]

A variety of economic and energy data sources are used to develop a balanced database for the ADAGE model that reflects all flows of commodities and productive inputs in the economy. International economic data come from the Global Trade Analysis Project (GTAP, Version 6 data), and U.S. state-level economic data are from the Minnesota IMPLAN Group. This information is combined with data on energy production, consumption, trade, and prices from the International Energy Agency (IEA) and the U.S. Energy Information Administration (EIA). BaU forecasts for

energy production, consumption, prices, and CO_2 emissions come from IEA's *World Energy Outlook 2004* and EIA's *Annual Energy Outlook 2004*. Historical and forecast emissions of non-CO_2 GHGs are from the Stanford Energy Model Forum (EMF).[7] These data are used to establish an initial model year of 2005 and subsequent baseline projections (in 5-year intervals) for the regions and industries shown in Table 1.

Table 1. Regions and Industries in ADAGE

International Regions	U.S. Regions	Industries
United States	Northeast	***Energy***
Canada	South	Coal
Europe[a]	Midwest	Crude Oil
Japan	Plains	Electricity: multiple types[c]
Russia	West	Natural Gas
China	Individual State[b]	Refined Petroleum
Rest of World		***Non-Energy***
		Agriculture
		Energy-Intensive Manufacturing
		Other Manufacturing
		Services
		Transportation

[a] The European region includes the EU-15, the European Free Trade Area, and countries in Eastern Europe that have ratified the Kyoto Protocol.

[b] For simulation purposes, an individual state is modeled as a distinct sixth region that is run concurrently with the five multi-state regions.

[c] Types of electricity generation vary slightly between the *International* and *US Regional* modules, depending on data availability.

Several nations including the United States are modeled separately, and others such as European countries are combined into broader regions. Within the United States in the *US Regional* module, five areas of the country are defined along state boundaries to capture important differences in regional electricity-generation technologies, and, as indicated above, individual states are modeled separately in each simulation. The same industrial sectors are defined in both the *International* and *US Regional* modules to maintain consistency when applying results for one model to the other. The industries selected focus on energy production, which will be affected by climate-change mitigation policies through their direct emissions of CO_2 and non-CO_2 GHGs and their indirect emissions of CO_2 when the fossil-fuel products are consumed. Agriculture is kept separate because it is an important source of non-CO_2 GHG emissions. Energy-intensive manufacturing industries (e.g., chemicals and paper) are distinguished from other types of manufacturing processes, as are transportation services that rely heavily on fossil fuels. Other industries less dependent on fossil fuels are aggregated together.

The *International* module is solved first using relevant global GHG policies. Findings from this module are used to provide information on world crude-oil and traded-goods prices to the *US Regional* module, which can then be used to estimate reactions in different parts of the United States that are consistent with the international policy (see Balistreri and Rutherford [2004] for a discussion of this modeling technique and its application in a climate-policy context). To ensure that economic reactions determined by the *International* module are comparable, and thus translatable, to those in the *US Regional* module, estimated allowance prices are compared across modules.

C. Policy Modeling

This discussion summarizes how key policy assumptions have been modeled in this analysis. It should be noted that, while many unique features are suggested in each policy proposal that has been put forward the majority have contained a provision to cap emissions and trade permits between firms and as such is the focus of the analysis. This report follows methodologies similar to those adopted in other, related analyses:[8]

- **Trading System**—The policy is modeled as an efficiently conducted cap-and-trade system covering emissions of six types of GHGs (CH_4, N_2O, HFCs, PFCs, and SF_6). Trading of allowances is permitted between gases, industries, and U.S. states, and agents in the model with flexibility to pursue the most cost-effective emission reduction opportunities. Banking of allowances for use in future years is also allowed, beginning in the year 2010 (i.e., businesses with low-cost reduction options can undertake additional actions to reduce emissions below their allotment today and save allowances for the future).

- **Excluded Entities and Sectors**—Emissions from households and agriculture are not included under the cap, although they may enter the trading system as allowance offsets if they provide cost-effective emissions reductions (up to the 15 percent limit on allowances from outside the system). CO_2 emissions from household and agriculture use of transportation fuels, however, are included in the system because they are covered at the refinery level. Emissions from all entities in the services sector of the economy (other than emissions from transportation fuels) are excluded, based on the assumption that many of these businesses will be under 10,000 metric-tons (the cut off imposed in this analysis).. As in similar analyses, this small-business exclusion is not applied to the manufacturing sector of the economy. While these assumptions have been adopted in other analyses, to the extent that some entities emit more than 10,000 metric tons, the estimated policy cap and its coverage will be too low.

- **Emissions Cap**—Within the United States, emissions of the six types of GHGs amounted to around 6,950 million metric tons of carbon dioxide equivalent ($MMTCO_2e$) in the year 2000. Based on these year 2000 emissions, and after considering the policy's exclusions for some sectors of the economy, the national cap on emissions for covered entities is estimated at 5,647 $MMTCO_2e$. This estimate is derived from information in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA, 2005) regarding U.S. historical

emissions in the year 2000 and additional information from EIA. This cap, which includes 81 percent of all GHG emissions in that year (see Appendix A), is applied beginning in the year 2010 and continues in perpetuity.

- **Allowance Distribution and Use**—Allowances are initially assumed to be distributed to states based on historical emissions in the year 2000. In policy scenarios, government spending is held constant in a nondistortionary fashion using lump-sum transfers between agents in the model.[9] These assumptions regarding allowance distribution and revenue use ignore any potential economic benefits associated with auctioning allowances and directing the revenues towards specific uses such as lowering taxes (known as "double dividends" if the benefits outweigh policy costs).[10]

- **Subnational GHG Policies**—The analysis assumes that states have not implemented any local or regional GHG policies. The EIA BAU forecasts on which the ADAGE model is based include only legislation enacted into law at the point the forecasts are generated. However, efforts in many states to enact policies would reduce GHG emissions in the absence of actions at the national level (see Pew Center [2004]). As these actions proceed, they would reduce the economic effects of a national policy by lowering the amount of emissions reductions necessary to meet a particular target.

- **International GHG Policies—**It is also assumed that countries that have ratified the Kyoto Protocol will proceed with this agreement. Kyoto emissions targets, initially applied in the model in 2010, are assumed to continue unchanged beyond 2012 (and no new countries enter the agreement). Trading of allowances is freely allowed among all Kyoto participants, and no restrictions are placed on countries' ability to meet emissions targets through trading versus through reductions accomplished by domestic actions. However, it is assumed that countries are unwilling to pay Russia for any excess allowances they have as the result of declines in energy consumption because targets were established based on 1990 emissions (i.e., Russian "hot air").[11] Thus, only real emissions reductions in Russia (as measured against BaU forecasts from IEA) are assumed to be eligible to create allowances that can be sold to other nations.[12]

Economic impacts associated with these policy assumptions will be influenced by the availability and cost of allowance offsets generated by emissions reductions outside the cap-and-trade system. This report follows previous analyses and addresses these uncertainties by establishing lower and upper bounds on estimated policy effects that depend on alternative assumptions about offsets:

- **"Free Offsets" Scenario**—In this lower-bound case, the full 15 percent of allowance offsets allowed by the policy are assumed to be available at no cost (this is done in the model by relaxing the emissions cap by 15 percent to around 6,494 $MMTCO_2e$). No additional offsets can be generated in this case from noncovered entities because the maximum quantity of offsets allowed by the scenario is reached. As noted in Paltsev et al. (2003), sequestration alone, depending on how net sequestration is calculated, could supply 15 percent of the emissions cap for this policy at no cost. Alternatively, offsets might be available

from international GHG markets at essentially no cost if significant quantities of Russian "hot air" are allowed (i.e., extra Kyoto credits available from Russia because their economy currently consumes fewer fossil fuels than when their Kyoto Protocol emissions target was established).

- **"Market Offsets" Scenario**—In this upper bound on estimated policy effects, offsets are only assumed to be available from emissions reductions made by noncovered entities located in the United States—at a market cost estimated within the model. For some types of emissions (e.g., N_2O from fuel combustion in motor vehicles), based on available data, it is assumed that there are no cost-effective reductions; thus, this case is relatively conservative regarding the amount of offsets obtainable. The case also does not allow for sequestration in agriculture/forest soils or timber stocks; consequently, to the extent that sequestration can occur for a low (or negative) cost, the model will overestimate allowance prices, understate offset supply and overstate associated macroeconomic effects.

Beyond the standard modeling assumptions discussed above, several detailed issues related to this type of climate-change mitigation policy do not lend themselves to quantitative analysis using a CGE model and are discussed below. In these instances, their exclusion will tend to make the report's findings more conservative, that is, resulting in higher projected policy costs, than if such issues were included (i.e., if they could be evaluated, estimated allowance prices and related macroeconomic effects would be lower):

- Although beyond the current scope, other work has evaluated the economic benefits to the United States of reducing climate change (see Jorgenson et al. [2004]). Inclusion of benefits from avoiding climate damages along with the mitigation costs would allow a more complete picture of the net costs to the economy but again is beyond the scope of this effort. Similarly, consideration of the health benefits associated with a reduction in criteria pollutants that result from reduced burning of fossil fuels is not considered in this study but could be expected to lower costs, because these pollutants will not need to be addressed by other policies.
- The modeling does not specifically consider potential effects of "induced technological change" (ITC)—improvements in technology brought about through the presence of a climate policy encouraging additional research on cost-effective emissions reductions (or, similarly, possible improvements from any designated climate research funds). Goulder (2004) has examined the implications of ITC and finds that its presence can lower the costs of achieving emissions reductions by stimulating additional technological change. However, because the ADAGE model already allows significant technology and energy-efficiency improvements to occur over time, this analysis does not include any additional ITC, beyond improvements implied by the overall model structure.
- The approach used to include abatement costs for non-CO_2 GHG rules out the possibility of "no regrets" reduction options—where engineering studies show that emissions reductions (e.g., capturing methane emissions from coal mines) could be done today with cost savings. However, while these cost-saving actions are not observed to be currently taking place and are not included in the model, the included abatement cost

curves (generally from Hyman et al. [2003]) do allow a significant portion of potential emissions reductions to occur at relatively low cost.

- The model includes some types of advanced electricity-generation technologies such as integrated gasification combined cycle electricity generation (IGCC) with carbon capture and storage. However, for allowance prices similar to those estimated for this policy, such technologies do not become cost-effective, compared with more traditional generation approaches. However, they will likely become important for policies with more stringent emissions targets over the longer term.
- As a general note, CGE models typically assume that, except for distortions caused by taxes, the economy is operating efficiently prior to instituting new policies. This assumption implies that, by definition, a new policy will impose costs on the economy because the policy moves it away from an efficient path. To the extent that is incorrect, either because of inefficiencies in the economy or factors such as ITC, costs may be overestimated.

III. Economic Implications of the Climate-Change Mitigation Policy

The ADAGE CGE model uses its combination of economic theory and data on production technologies and emissions abatement costs to evaluate how features of the policies described above may influence GHG emissions and the structure of the U.S. economy. Findings discussed in this section encompass reactions of businesses and households in U.S. states to the domestic climate-change mitigation policy that is the focus of this report, while considering the international context in which these policies are instituted.[13]

A. U.S. National Results

As a whole, model simulations indicate that the GHG policy is likely to have minimal impacts on economic activity in the United States. The national allowance prices estimated by ADAGE range from $4 to $8 per $MTCO_2e$ in 2010, rising to between $7 to $14 per $MTCO_2e$ by 2020. Imposition of these allowance prices, which reflect costs to the economy of abating emissions to meet the policy target, encourages businesses and households to take steps to reduce their GHG emissions. These adjustments have the following broad implications for the U.S. economy:

- **GDP**—Growth in GDP, which in the absence of the policy is expected to average 2.85 percent a year over the next 15 years, is between 2.83 and 2.84 percent a year with the GHG policy.
- **Household Consumption**—Growth under the policy over the 2005 to 2020 time period declines by around one to two one-hundredths of 1 percent a year.
- **Employment**—Growth under the policy is around 1.22 percent a year on an annualized basis between 2005 and 2020, compared to 1.23 percent growth expected in the model baseline.

The most direct economic impacts of a climate-change mitigation policy are generally experienced in energy markets. Although energy markets are a vital component of the U.S. economy, they represent a small share of overall production, which tends to limit the macroeconomic impacts of the GHG policy on GDP. Given the standard CGE modeling assumption that the economy was operating efficiently prior to a new policy being instituted, adjustments in energy markets lead to some declines in economic activity as production technologies and consumption patterns are altered. Table 2 summarizes these effects for the two offset scenarios, focusing on macroeconomic effects reported in similar analyses (GDP, household consumption, and employment).

When the policy scenario first takes effect in 2010, there are some very slight declines in GDP—between one and three one-hundredths of a percent—as the economy begins adjusting to lower-emissions methods of production and

new consumption patterns. These are accompanied by declines in the demand for labor by businesses on the order of one- to two-tenths of 1 percent. An initial increase in household consumption, driven by modifications in people's expectations that lead them to consume more initially and less in the future, helps alleviate any decreases in GDP. By 2020, after the policy has been in force for 10 years, there have been additional adaptations as the economy continues to grow, but emissions remain at the target (allowing for banking of allowances). Although the changes in GDP have increased by this time, the overall impact on U.S. economic growth is to change it from an expected average rate of 2.846 percent a year between 2005 and 2020 to a rate between 2.830 and 2.837 percent a year for the "Market" and "Free" offsets cases, respectively.[3] The annualized average growth rate in employment over this time period changes from 1.23 percent a year in the absence of a GHG policy to 1.22 percent a year under the policy. Household consumption declines somewhat by 2020 in response to the labor-market changes and increased prices of energy and other goods.

Table 2. Macroeconomic Results Across the United States

	Free Offsets		Market Offsets	
Macroeconomic Variable	**2010**	**2020**	**2010**	**2020**
Allowance Price ($/MTCO2e)	$4.3	$7.0	$8.4	$13.6
GDP (%)	-0.01%	-0.12%	-0.04%	-0.24%
Employment Change (1000s)	-110	-168	-232	-334
Employment Change (%)	-0.09%	-0.12%	-0.18%	-0.23%
Household Consumption ($)	$20	-$49	$20	-$113

One of the most significant determinants of these effects on the U.S. economy is the level of the emissions target compared to expected emissions in the absence of a GHG policy. If business-as-usual, or BaU, emissions are expected to growing rapidly, meeting the emissions cap requires more improvements in energy efficiency, switching out of carbon-intensive fuels, and reductions in overall energy consumption than if BaU emissions are expected to grow slowly. Figure 1 shows the BaU emissions projections in ADAGE, which are based on EIA forecasts for CO_2 and EMF forecast for non-CO_2 gases. In the *AEO 2004*, EIA projects CO_2 emissions growth of more than 1.5 percent per year between 2005 and 2025, leading to an overall growth in all GHG emissions in ADAGE of around 1.4 percent per year after including non-CO_2 GHGs. This is in contrast to historical GHG emissions growth in the United States of around 1 percent per year between 1980 and 2002 (EIA, *Annual Energy Review 2003*). The assumption of relatively rapid

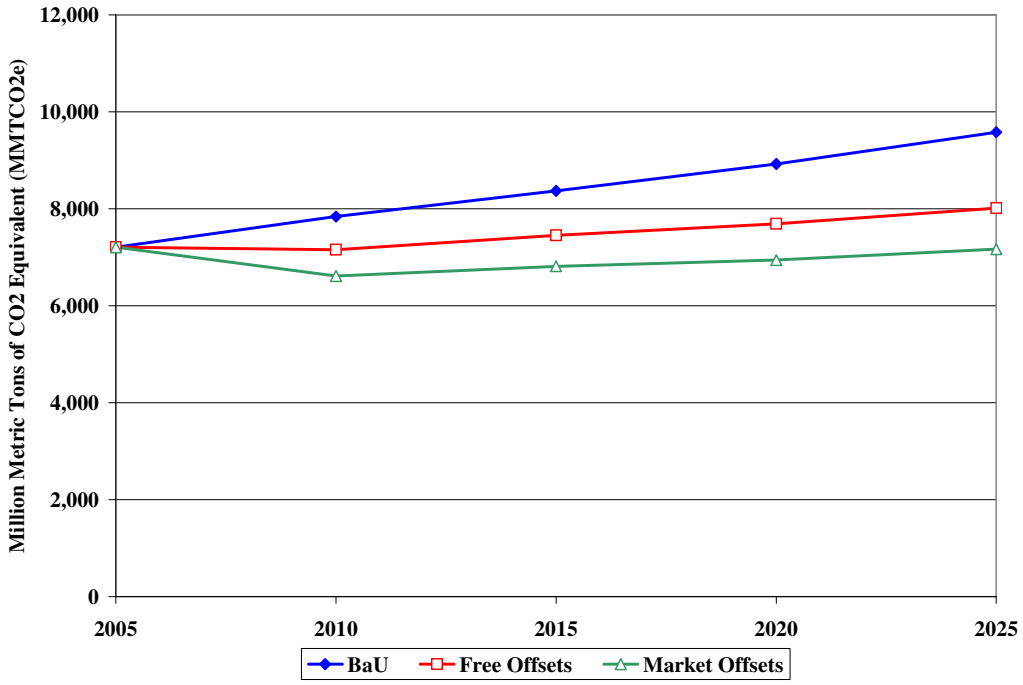
[3] The decimal place in these numbers is not used to suggest a high level of precision, but rather to illustrate any minimal impacts.

growth in emissions has implications for the model's estimated allowance prices and associated effects of the climate-change mitigation policy.

From this baseline projection, emissions are reduced by between 16 and 25 percent by 2025 to meet the policy target (depending on how many offsets are available and economic). As shown in the "Free" and "Market" offsets scenarios, emissions decline in 2010 to meet the target and also as businesses take advantage of cost-effective reductions to bank allowances for the future. Subsequently, emissions grow slightly as the result of increases from noncovered entities and as businesses use allowances saved in earlier years.

Figure 1

Total U.S. Greenhouse Gas Emissions

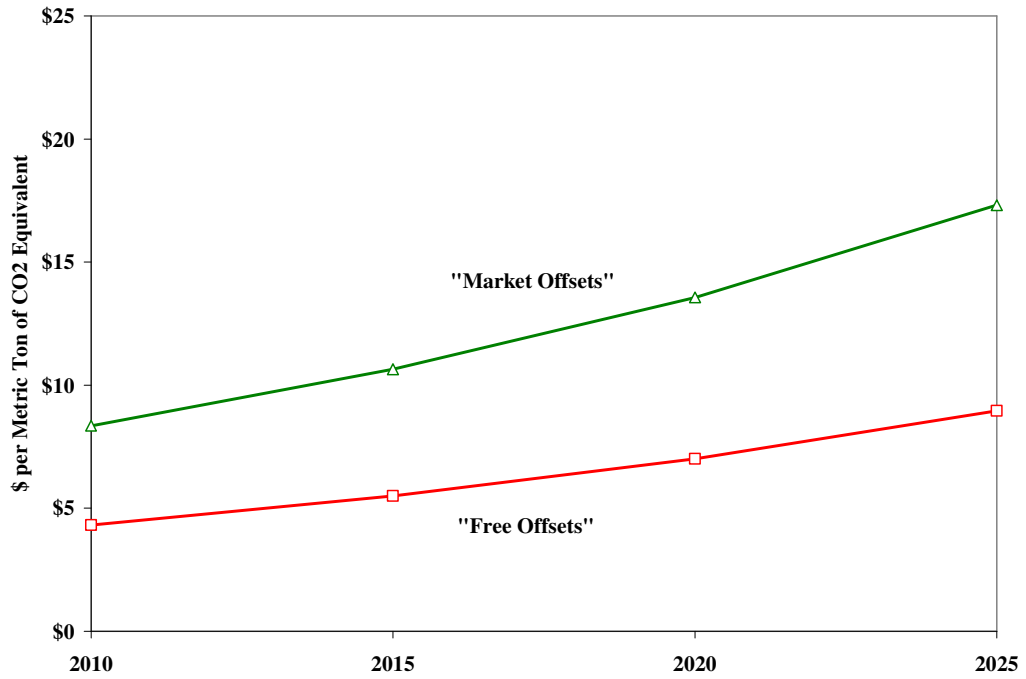


The price of an allowance will reflect the costs to the economy of abating emissions as necessary to meet the policy target. In the absence of banking, this price would equal the marginal cost of removing the last ton of emissions required to meet an emissions cap. Banking will tend to increase allowance prices in the initial years as people overcomply to save allowances for use in later years. However, looking across all years, banking will reduce costs of a policy by allowing the most cost-effective reductions to be made at the most cost-effective time.

Figure 2 shows allowance prices associated with the GHG policy scenario over time.[14] The exact point of prices within this range will depend on the availability and cost of offsets, with "Free" offsets providing a lower bound and "Market" offsets an upper bound on allowance prices.[15] Initial prices range from $4 to $8 per $MMTCO_2e$ and increase thereafter as the result of emissions growth and allowance banking (banking of allowances smoothes prices over time, but it increases initial allowance prices as additional, early reductions are made). To put these figures in context, based on carbon content, this would be roughly equivalent to between 3.8 and 7.3 cents per gallon of gasoline in 2010. At the allowance prices in the "Market Offsets" case, between 146 and 183 $MMTCO_2e$ of emissions reductions from noncovered entities in the United States are cost-effective. Consideration of these options by the ADAGE model lowers allowance prices by approximately 15 percent versus a scenario in which no offsets are allowed. Were non-CO_2 emissions excluded from a GHG policy, and CO_2 emissions of all sectors were capped at year 2000 levels (or 5,858 $MMTCO_2$), the allowance price would be by around 20 percent higher than in these simulations.

Figure 2

U.S. Allowance Prices



Note: All dollar figures presented in this analysis are in 2000$.

Establishing an allowance price encourages businesses and households to consider the effects of their actions on GHG emissions. This leads to adjustments in the economy as energy consumption decreases, people switch into

fuels such as natural gas that have a lower carbon content, and investments are undertaken to improve energy efficiency and otherwise reduce GHGs. Figures 3 and 4 show interactions between energy prices and demands, compared across types of energy. Units are expressed in British Thermal Units (Btu) or millions of Btus (MMBTU), where energy prices represent an average across all groups of consumers based on historical data and *AEO 2004* forecasts.

Box 1. An important note about the impact of recent energy price increases

The historical state-level data and IEA/EIA forecasts available at the time of the ADAGE model development do not fully reflect recent 2006 price developments in the natural gas and petroleum markets. In EIA's *Annual Energy Outlook 2006*, for example, natural-gas prices are 10 to 35 percent higher than those used in this analysis. However, coal prices are also around 20 percent higher, as are petroleum prices. These higher price forecasts reduce energy demands, resulting in baseline CO_2 emissions that are around 7 percent lower than those included in the model, which would make it easier to meet an emissions target and thus lower the costs of a GHG policy.

However, higher natural gas prices also encourage more coal consumption, especially by electric utilities, which would make it harder to lower overall emissions in the absence of new technology. In addition, the current emphasis on energy security and government investment in clean coal technology may also serve to promote the use of coal in comparison to other fuels, and as a result coal consumption could increase. See also Reilly and Paltsev (2005) for an evaluation of how higher energy prices may have affected model estimates for allowance prices in the EU-ETS.

According to this modeling, the modest policy considered here would not be sufficient on its own to trigger large investments in advance coal technology. However, anticipation of tighter GHG constraints outside the scope of the model in the future could drive firms to invest in more efficient coal plants and ultimately capture and store CO_2.

Coal, which has the highest carbon content per Btu of energy (the carbon content of natural gas is around 45 percent lower than coal and oil is around 32 percent lower), experiences the largest price increase in the model – between 50 and 100 percent by 2020. The growth in demand as people switch out of coal and oil leads to a natural gas price increase of between 8 and 16 percent by 2020. Prices for petroleum products also increase and are up by 3 to 5 percent in 2010 and 5 to 10 percent by 2020.[16] To put these increases in context, natural gas prices increased by 80 percent between 2000 and 2005, and motor gasoline prices increased by 50 percent during the same time period, yet U.S. real GDP rose by more than 13 percent in spite of these energy price increases and other macroeconomic forces (the average annualized growth rate in real GDP over these 5 years was 2.55 percent per year). Demands for natural gas and oil are modestly affected by the GHG policy. Oil demand falls in part as consumers drive less and businesses reduce consumption, while natural gas demand holds up as industries switch to this lower carbon fuel. Changes in demand for coal are largely controlled by reactions among electric utilities (discussed below), which consume around 90 percent of the coal in the United States.

Figure 3

Impacts on U.S. Energy Prices

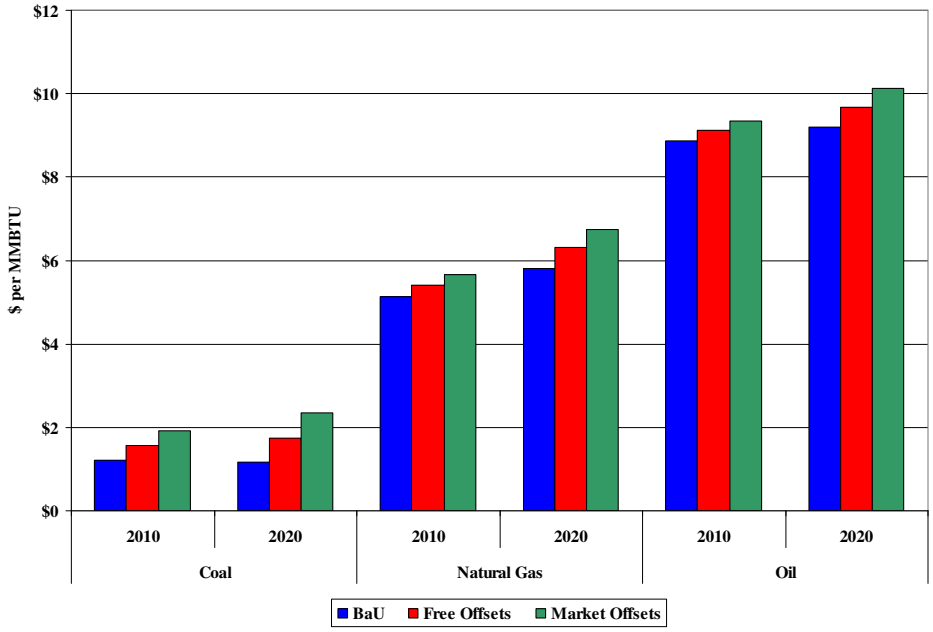
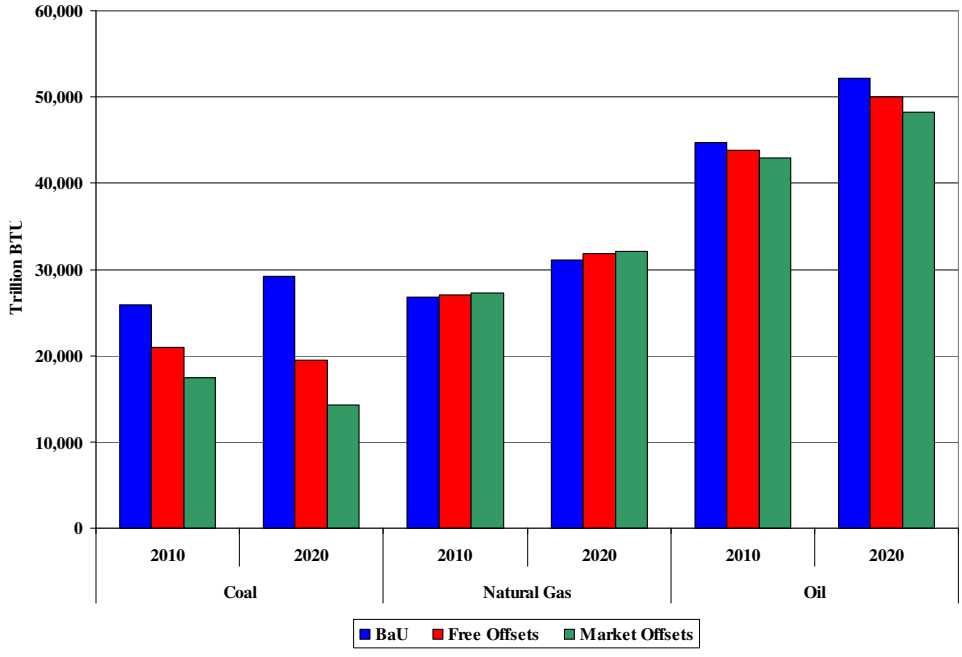


Figure 4

Impacts on U.S. Energy Use



One of the most significant factors determining how any GHG policy will affect the U.S. economy is the electricity-generation mix in the BaU forecast and assumptions about the ability of electric utilities to switch fuels. Reductions in coal consumption by utilities are generally expected to be one of the most cost-effective methods for lowering CO_2 emissions. Thus, although relying on coal-based generation in the BaU forecast will result in high emissions, it can also potentially provide low-cost reduction options, assuming that its major substitute, natural gas, has a low price. Figures 4 and 5 illustrate how the demand for coal (and other fossil fuels) has responded to changes in coal prices and improvements in energy efficiency at electricity utilities, based on the model's initial assumptions about the ease of fuel substitutions.

Figure 5 shows that by 2010 gas use has increased by 800 to 1,400 trillion Btu in the electricity industry, while coal use has fallen between 20 and 30 percent from the BaU forecast. By 2020, gas consumption is 1,500 to 2,400 trillion Btu higher than in the absence of the GHG policy. Along with an overall improvement in energy efficiency of utilities, coal consumption declines by 35 to 50 percent by 2020. Box 2 below discusses these changes and evaluates how different modeling assumptions would affect these shifts (the model's predictions of energy-efficiency improvements are also assessed in more detail in Section A.2).

It is important to note that this analysis assumes a modest short-term policy which will not require investment in capture and storage of CO_2 emissions from coal-generated electricity, based on current data about the costs of these options. Some firms, however, may choose to invest in capture-and-storage technology in anticipation of possible future reductions, especially as prices of advanced coal technologies decline over time. Clean coal technologies, like FutureGen, are currently receiving significant government investment, which will likely lower their capital costs in the future.

In the absence of these types of advanced technologies and given the current reliance of electricity generation on fossil fuels, electricity prices tend to respond under GHG policies in a fashion similar to other energy prices, especially those for natural gas. As shown in Figure 6, electricity prices rise between three- and five-tenths of one penny per kilowatt hour (kWh) in 2010 (or 4 to 9 percent) and between four- and eight-tenths of one penny per kWh in 2020 (or 7 to 12 percent). Electricity demand across the United States in 2010 falls between 2 and 5 percent and 4 to 7 percent in 2020, mainly as a result of these price increases.

Figure 5

Impacts on U.S. Fossil-Fuel Demand in Electricity Generation

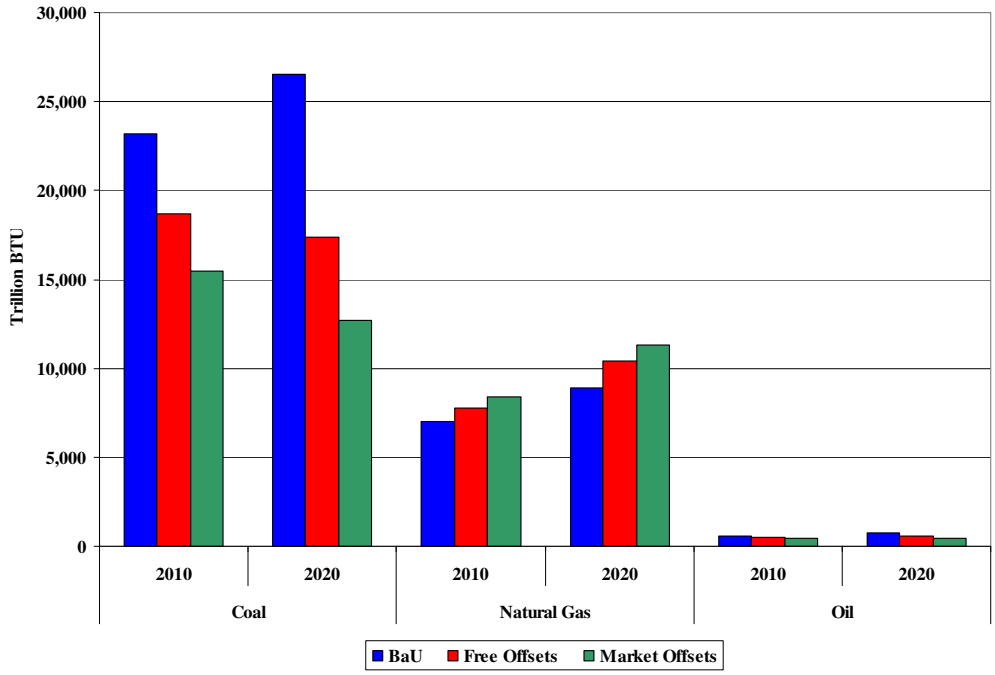
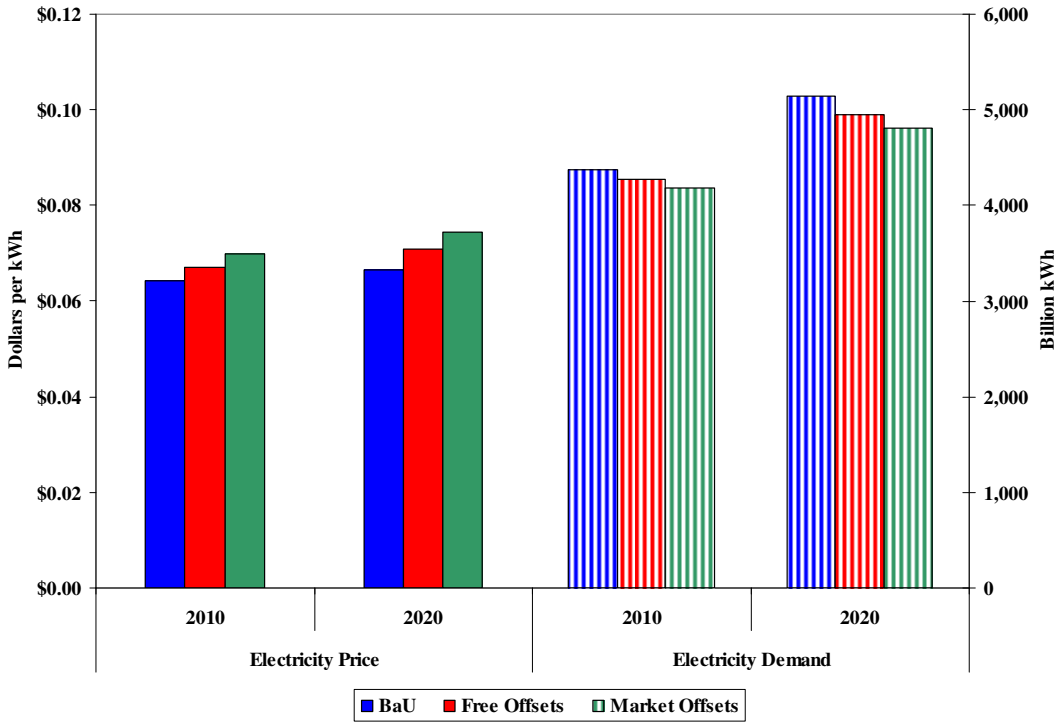


Figure 6

Impacts on U.S. Electricity Markets



Box 2. Fuel Switching

The ability of utilities to switch from coal-fired generation to natural gas will have a significant impact on adjustments required in the rest of the economy to meet a particular emissions target. If it is easy for utilities to switch from coal-fired to gas-fired generation, the emissions reductions in this industry will limit the need to lower emissions in other segments of the economy and hence will lead to lower overall allowance prices. Conversely, if such a switch is more difficult, other industries with more costly reduction opportunities will be required to reduce, and estimated allowance prices will be greater.

Electricity generation can be measured by "heat rates," or the number of Btus of energy input required to produce one kWh of electricity. In the results presented in the main report, BaU heat rates across all fossil-fuel generation are 9,690 Btu/kWh and 9,340 Btu/kWh in 2010 and 2020, respectively, based on the EIA forecasts used by the model. Switching from coal to natural gas leads to overall heat rates for the same years of 8,770 Btu/kWh and 7,700 Btu/kWh in the "Free Offsets" scenario and 8,140 Btu/kWh and 6,910 Btu/kWh in the "Market Offsets" scenario. These changes in heat rates underlie the declines in coal consumption and increases in gas consumption shown in Figure 6 (Appendix A.2 discusses an analysis of the adjustments underlying these heat rate improvements and changes in fuel consumption).

For comparison purposes, a sensitivity case was also run that lowered the ability of electric utilities to switch from coal to gas (see Appendix A.2 for discussion of the model run). As shown in the following table, by limiting the capabilities of the electricity industry to switch from coal to gas and reduce emissions reductions, allowance prices are around 30 percent higher than in the "Market Offsets" scenario. Despite this higher price, and thus higher coal prices, in 2020 coal consumption by utilities is 15 percent higher than in the "Market Offsets" scenario. Natural gas consumption is around 10 percent lower, and there is a smaller improvement in heat rates. As the result of additional production costs, electricity prices are somewhat higher and demand for electricity is lower.

Impacts of Assuming Less Coal-Gas Switching by Electric Utilities

		BaU		Less Fuel Switching		Market Offsets	
Variable		**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Allowance Price ($/MTCe)		--	--	$39	$64	$31	$50
GDP (%)		--	--	-0.08%	-0.35%	-0.04%	-0.24%
Electricity Fossil-Fuel Use	Coal	23.2	26.5	17.3	14.6	15.5	12.7
(Quad Btu)	Natural Gas	7.0	8.9	7.4	10.2	8.4	11.3
Electricity Markets	Price	$0.064	$0.066	$0.072	$0.077	$0.070	$0.074
($/kWh & billion kWh)	Generation	4,380	5,141	4,121	4,716	4,182	4,806
Heat rates (Btu per kWh)		9,687	9,338	8,608	7,336	8,142	6,908

The most direct economic impacts of a climate-change mitigation policy are generally experienced in energy markets, illustrated by the changes in industrial output in Figure 7. Under the assumptions discussed above (such as utilities' ability to easily substitute away from coal use), output of coal declines significantly in response to declining demand at electric utilities, which consume around 90 percent of coal used in the United States. In natural gas markets, additional consumption by utilities, along with higher demands in other segments of the economy, leads to an increase in natural-gas production. Aside from transportation services, which also rely on fossil fuels, effects in the rest of the economy are quite small. In revenue terms, the largest absolute changes are experienced by the services industry (equal to $50 to $100 billion, or 0.3 to 0.6 percent) because of its relative size in the economy, even though it does not

consume much energy per unit of output. Revenue impacts across manufacturing industries are larger than in services in percentage terms, although comparable in dollar values, because of their greater reliance on energy. Also, under the "Market Offsets" case, agriculture output tends to decline slightly as agricultural efforts are shifted from traditional production techniques to efforts that reduce non-CO_2 emissions—like reduced cultivation, in response to compensation for additional reductions in non-CO_2 emissions.

Figure 7

Impacts on U.S. Output Quantities in 2020

B. State-Level Results

Although a nationwide policy establishes an allowance price that encourages cost-effective actions to be taken across the country, individual states may experience economic effects that deviate substantially from U.S. averages. Among the most important characteristics of a particular state's economy controlling the impacts of climate-change mitigation policies are its initial energy efficiency, the mix of products manufactured, how electricity is generated, and the endowment of allowances it receives (which can either be used by businesses and households within the state or traded to other states). This section examines these features for the 28 states listed in Table 3 and then presents state-level impacts of the GHG policy, focusing on the year 2020 after the policy scenario has been in effect for 10 years

(impacts in earlier years will thus be lower than those shown). Individual state reports are available at http://www.pewclimate.org with additional information on these years, BaU estimates of output and energy consumption, and reactions of energy markets to the policy (changes in energy prices and consumption tend to be relatively uniform across states, and similar to the U.S. results, and thus are not discussed in detail here).

Table 3. States Analyzed in this Report

• Alaska (AK)	• Illinois (IL)	• Nebraska (NE)	• Ohio (OH)
• Arkansas (AR)	• Iowa (IA)	• New Hampshire (NH)	• Oregon (OR)
• California (CA)	• Kansas (KS)	• New Jersey (NJ)	• Pennsylvania (PA)
• Colorado (CO)	• Louisiana (LA)	• New Mexico (NM)	• South Carolina (SC)
• Florida (FL)	• Michigan (MI)	• New York (NY)	• Tennessee (TN)
• Hawaii (HI)	• Minnesota (MN)	• North Carolina (NC)	• West Virginia (WV)
• Idaho (ID)	• Montana (MT)	• North Dakota (ND)	• Wisconsin (WI)

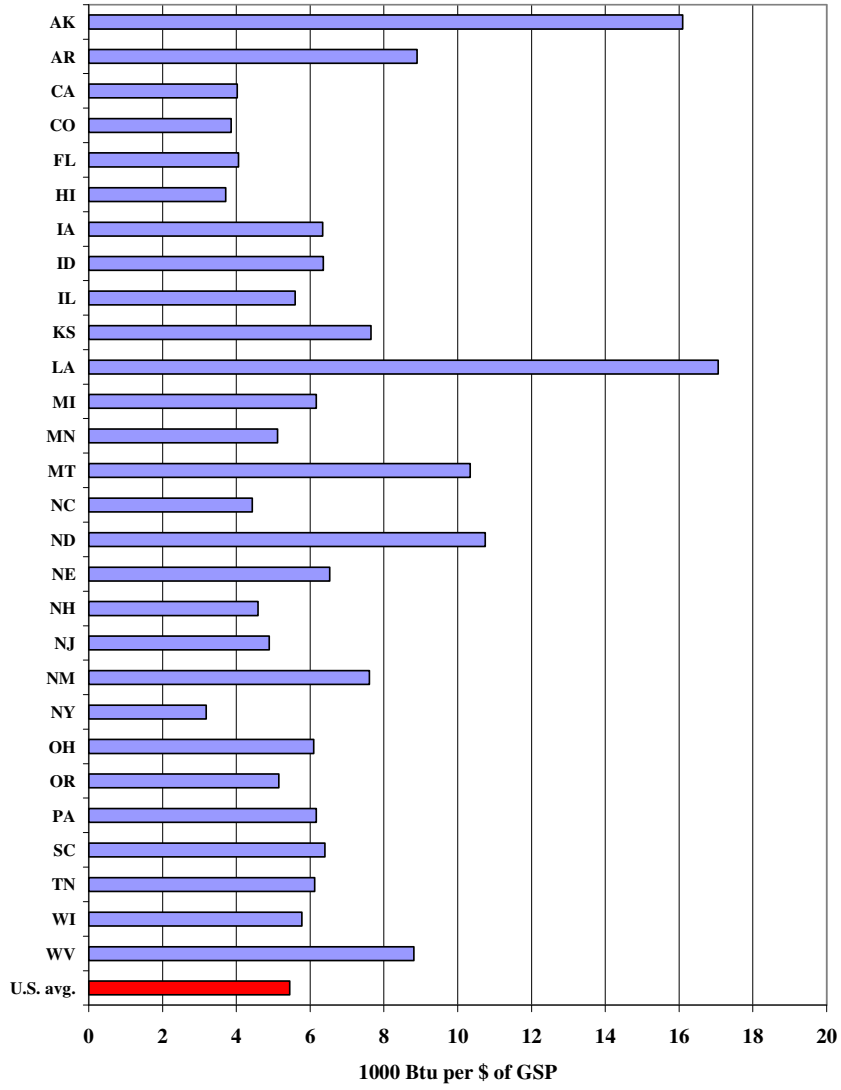
B.1 Business-as-Usual Energy Intensities of States

Overall energy intensity of a state, as measured in thousands of Btu of delivered energy consumed per dollar of GSP, is a convenient metric to summarize the general efficiency of its economy. Delivered energy includes electricity delivered to customers in a state, but not energy inputs to electricity generation, which need to be considered separately. However, all other energy use is captured by this measurement, such as manufacturing consumption and household transportation and heating use.

Figure 8 illustrates the initial energy intensity estimates per dollar of GSP in the model. Some states such as Alaska and Louisiana stand out as heavy energy consumers, mainly in their industrial and energy-production sectors. Others use significantly less energy than the U.S. average according to this metric. For example, California consumes more energy than any other state aside from Texas because of the size of its economy. However, in terms of energy use per dollar of GSP, it is among the lowest in the nation because the California economy is weighted toward the services industry, rather than manufacturing, and hence requires less fuel (see Figure 9). States such as Colorado, Florida, and New York are similarly below the U.S. average and will thus need to make fewer adjustments to their economies to reduce emissions than more energy-intensive states.

Figure 8

Business-as-Usual Energy Intensity in 2020 (delivered energy)



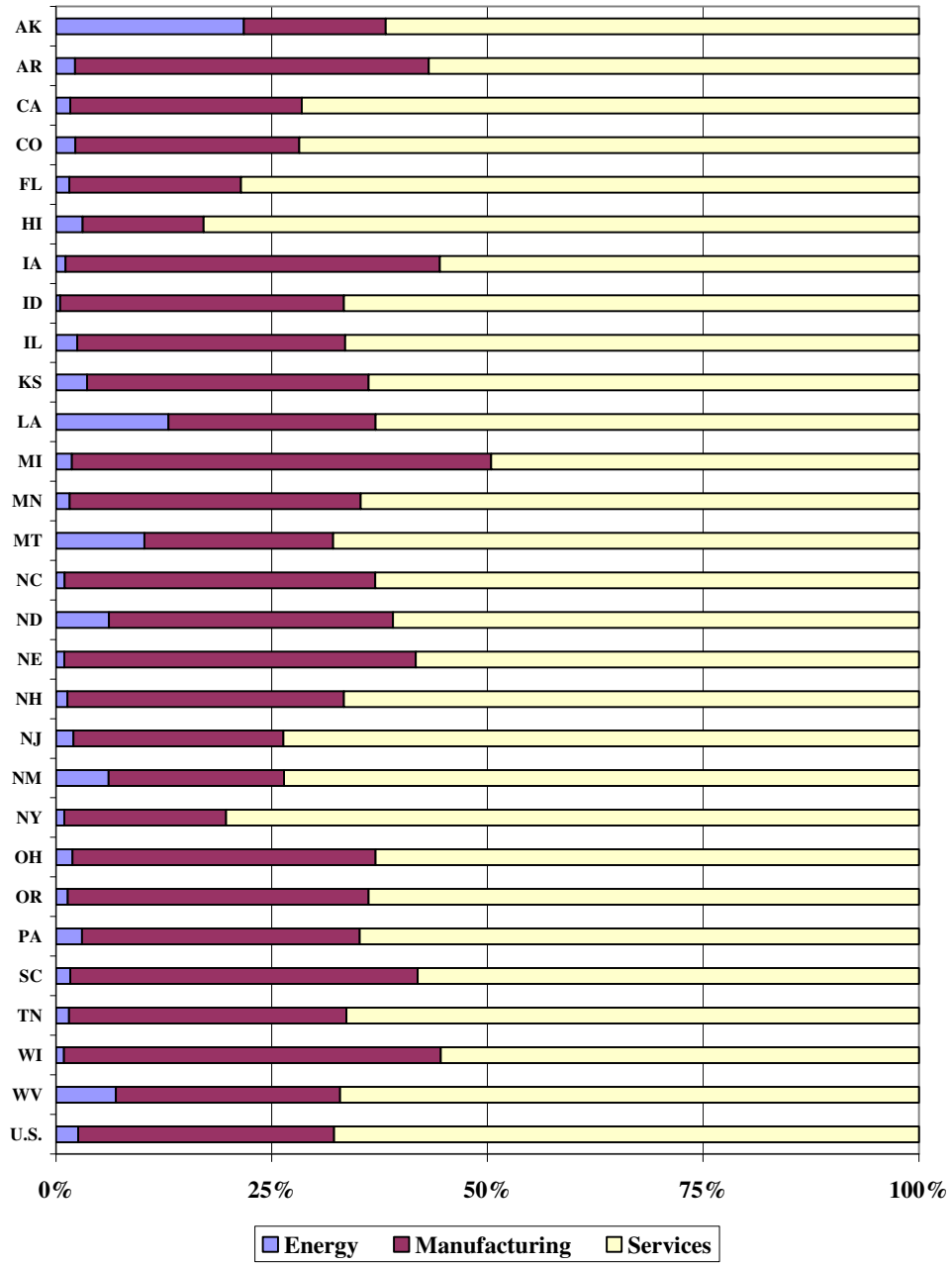
B.2 Business-as-Usual Output of States

Aside from household energy consumption for transportation and heating, energy intensities will largely be determined by the mix of commodities produced in each state, along with any differences in production techniques across the United States. Figure 9 presents the ADAGE model's BaU estimates of output revenue shares for states in 2020. Comparing these shares to the energy intensities in Figure 8, the correspondence between a large services sector and low energy consumption is clear, with the opposite holding true for energy-producing states. States with higher than average manufacturing shares such as Michigan (the blue and red portions of the bar showing that one-half of

Michigan's output is energy plus manufacturing) also tend to rely more on energy in their economies, which will influence their responses to a GHG policy.

Figure 9

Business-as-Usual Output Shares of States in 2020

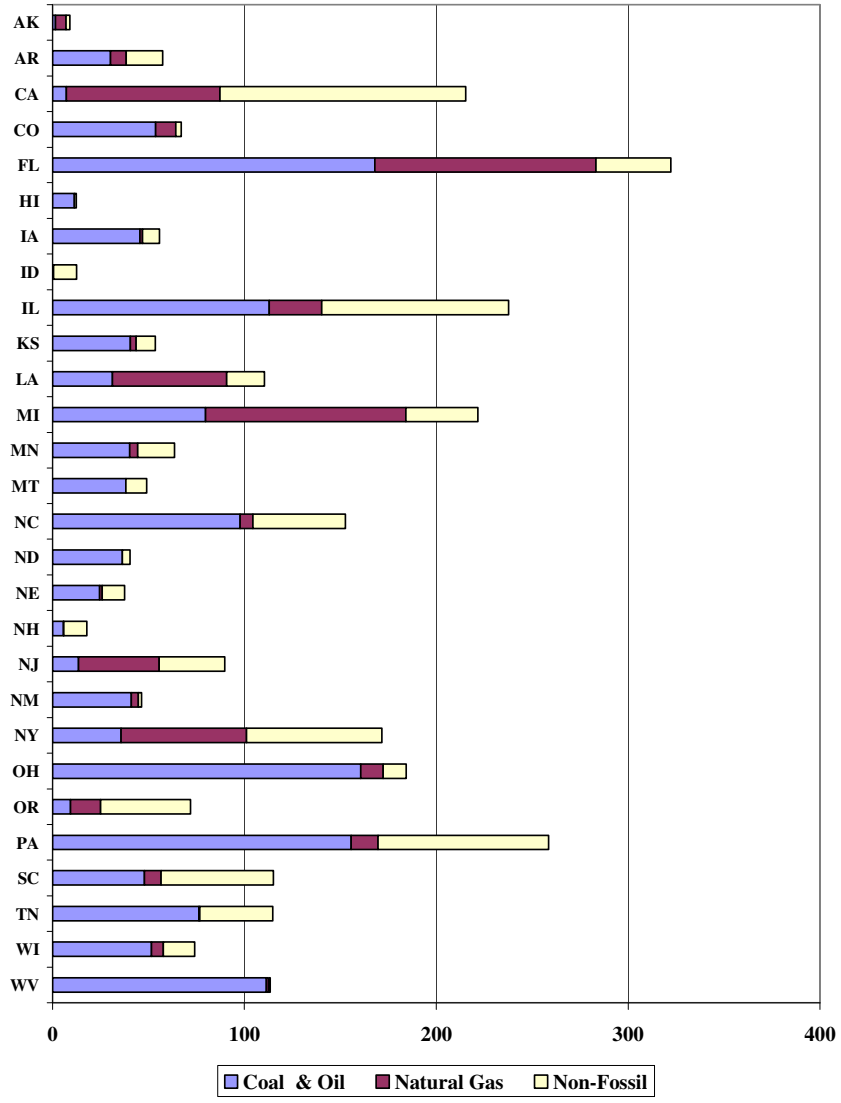


B.3 Business-as-Usual Electricity Generation of States

Many of the economic adjustments in response to GHG policies, such as the ones examined in this report, are expected to occur in the electric-utility industry. As discussed above, a switch from coal-fired to gas-fired generation can substantially reduce CO_2 emissions because coal has a much higher carbon content than natural gas, and gas-fired boilers are around 20 percent more energy efficient than coal-fired boilers. States containing utilities relying on coal will thus have higher emissions but more opportunities for low-cost reductions, if gas prices were to remain low. Figure 10 illustrates expected generation technologies in the absence of GHG policies for the year 2020, segmented into coal plus oil, natural gas, and nonfossil generation (nuclear, geothermal, municipal solid waste, solar, wind, and wood/biomass generation). Some states, such as Ohio and Pennsylvania, are forecasted to have significant amounts of coal-based generation, while others (e.g., Alaska, California, and Idaho) have almost none. It should be noted, however, that although states such as California, which rely mainly on gas-fired and nonfossil generation or electricity imports, have fewer emissions, they will also receive correspondingly fewer GHG allowances under a distribution scheme based on historical emissions (implications of this are discussed below).

Figure 10

Business-as-Usual Electricity Generation by Type in 2020 (billion kWh)[*]



[*] Note: In some states, California in particular, the amount of generation reported for the electricity industry, especially from coal, can vary depending on the definition of the industry. In ADAGE, the electricity industry covers electric utilities, independent power producers, and combined heat and power (CHP) intended for electric power. Energy use for CHP within industries is included in the overall energy consumption of those industries. Generation can also vary depending on which AEO forecast is used (e.g., this analysis uses *AEO 2004*, which shows no growth in Californian natural-gas generation by 2020).

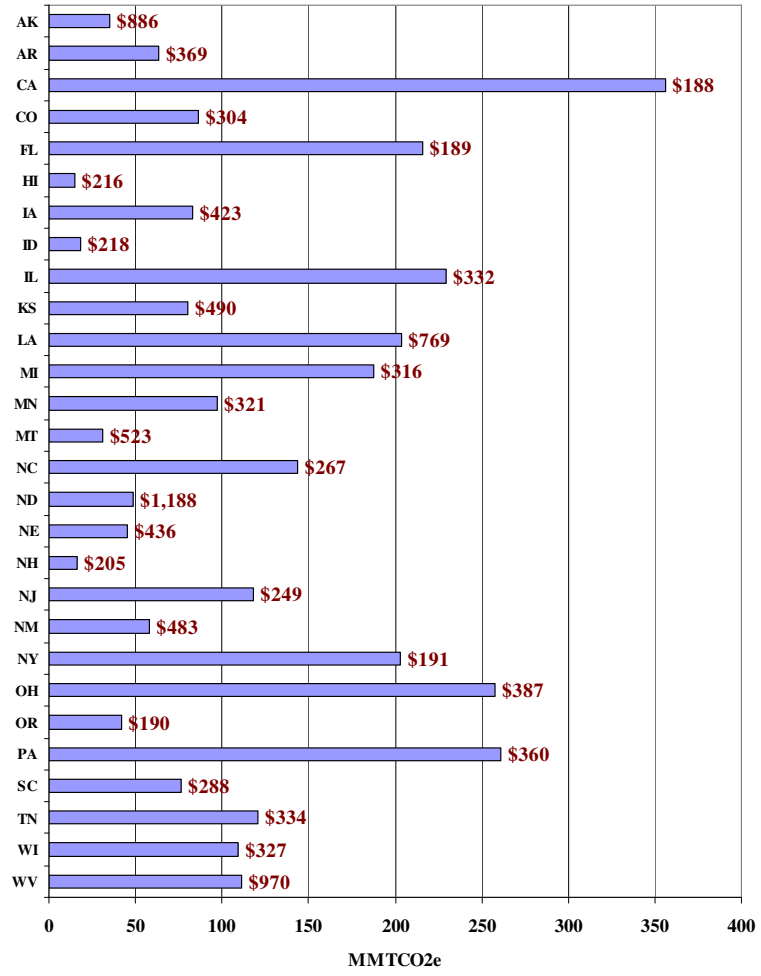
B.4 The Importance of Allocation to Model Results

Another critical determinant of economic impacts in each state is the distribution of allowance allocations across the United States. As a starting point, this analysis assumes that allowances will be distributed to states based on historical emissions in the year 2000. The distribution pattern will not particularly affect actions taken in the model by businesses and households to reduce emissions, because the policy's cap-and-trade system will ensure these are accomplished in the most cost-effective manner across the country. However, it can have important implications for household income and consumption and, to a lesser (and related) extent, changes in GSP. At the allowance prices estimated by the model, the associated value of allowance endowments can be fairly significant, implying that they may redistribute income among states—with more going to states having high initial energy consumption (these states are also those that will also experience the largest adjustments in response to the GHG policy).

Figure 11 shows the distribution of GHG allowances across the states used in this analysis (all states' endowments are shown in Table A-2), based on each state's historical emissions (model results are also discussed in Appendix A for an allocation scheme based on state population). At an average allowance price of $7/MTCO$_2$e, the total value of allowances distributed as part of the policy would be around $40 billion. On a per-household basis, this represents an average increase of around $330 per household across the United States. However, if allowances are distributed across states based on their historical emissions and this value is subsequently passed along to resident households, the value of the endowment received by each household in a state can diverge from this average of $330. For example, California had emissions from entities covered by the GHG policy of around 356 MMTCO$_2$e in 2000. At $7/MTCO$_2$e, these allowances would be worth $2.5 billion to the state. If the value of this endowment is distributed equally to households in California, it would represent an increase of around $188 per household. Conversely, North Dakota's emissions in 2000 were approximately 49 MMTCO$_2$e, which would be worth $340 million at $7/MTCO$_2$e. However, because North Dakota has a small population, this is a value equivalent to an increase of $1,188 per household. Such differences between the value of allowances allocated to each state and their respective populations have significant ramifications for the ultimate impact of the policy on household consumption, a metric typically used in analyses to examine GHG policies.

Figure 11

Distribution of GHG Allowances and the Value per Household at $7 per $MTCO_2e$



B.5 Impacts of the Policy on Gross State Product

Along with other aspects of states' economies such as household energy consumption and emissions of non-CO_2 GHG (mainly from the agricultural, coal-mining, and natural-gas industries), the four factors discussed above—allocation, BaU electricity generation, BaU energy intensity, and BaU state output—will largely control how impacts of the GHG policy are spread across the United States. Given that there is substantial variation among states in these features of their economies, it is to be expected that U.S.-level results will obscure many changes occurring at the state level. Figure 12 shows the magnitude of GSP change after the policy has been in effect for 10 years. Figure 13 illustrates this change in reference to each state's projected growth.

Figure 12

Impacts on Gross State Product in 2020

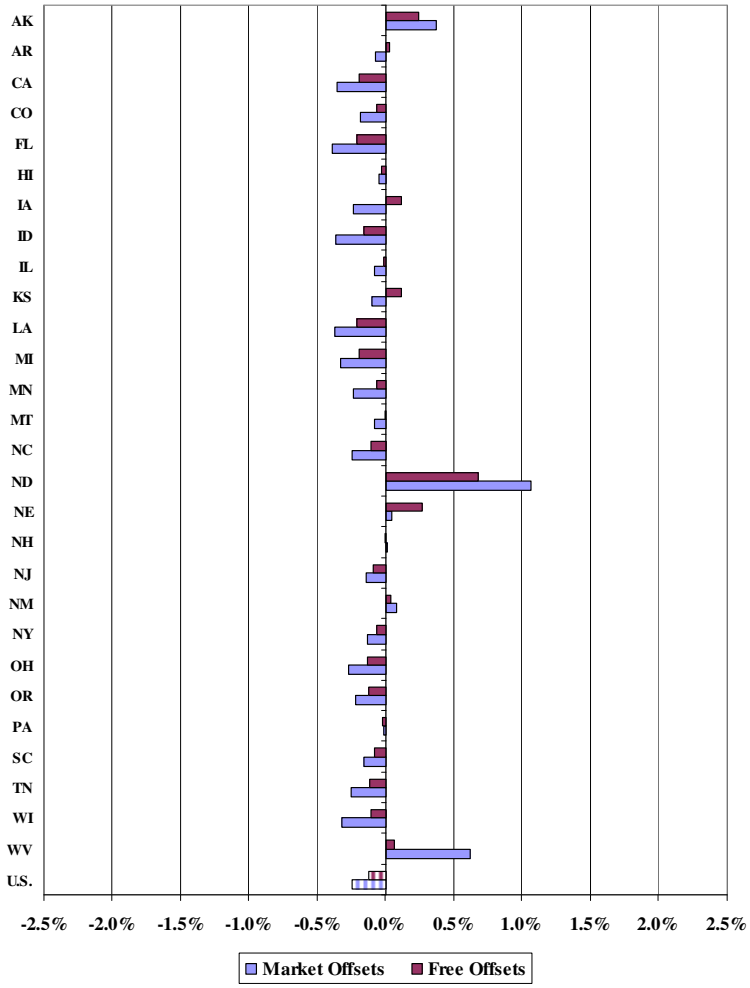
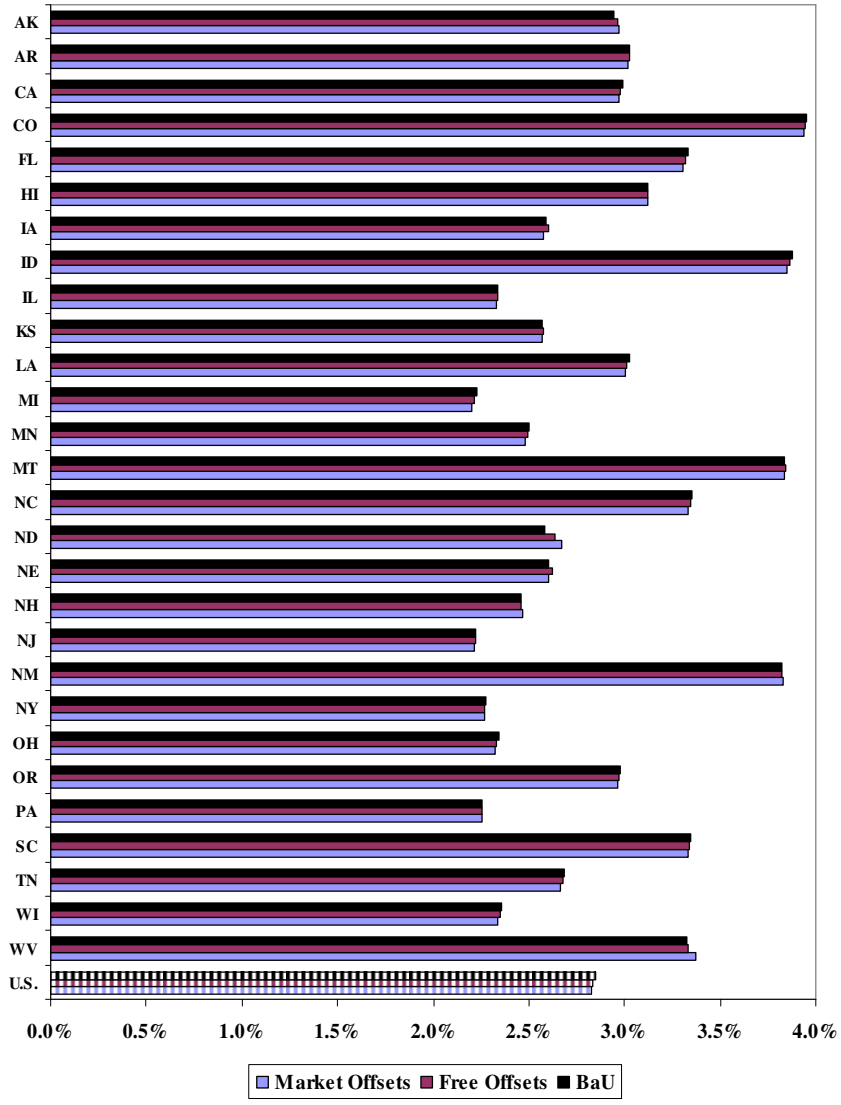


Figure 13

Impacts on Annualized GSP Growth Rates Between 2005 and 2020



Although there is a fair amount of variation across states, in general most impacts of this fairly modest reduction target are less than three-tenths of 1 percent in that year (as shown in Figure 13, these effects are nearly indistinguishable in terms of average growth rates over the next 15 years). States such as Alaska and New Mexico benefit from increased production of natural gas. In other states such as North Dakota and West Virginia, changes in GSP, which appear counterintuitive at first glance, are a function of the additional allowances they are allocated under a distribution scheme based on historical emissions and would tend to be reversed if alternative schemes were used (see Figures 14 and 15). Similarly, a state such as California that might be expected to do better than the U.S. average, based

on its low average energy consumption, is instead slightly worse off because its endowment of allowances is based on low historical emissions.

B.6 Impacts of the Policy and Allowance Distributions on State Household Consumption Spending

As shown in Figure 14, overall effects of the policy on growth in household consumption spending are extremely small. Impacts on spending in a particular year such as 2020, after the policy has been in effect for 10 years, are minor but can be used to compare results from this analysis to those of other climate-change mitigation policies. Figure 15 illustrates the impact per household and, as can be seen, these impacts vary significantly across states. Consumption impacts ranged from -$370 to +$1,580 for the most costly case ("Market Offsets") and, on average, reduced household consumption by around $50 and $110 for the United States for the "Free" and "Market" Offsets cases, respectively. Again, it is important to note that these results vary significantly across states and an important insight is that these are also highly dependent on the distribution of allowances adopted in the policy.

Impacts on household consumption spending combine changes in prices of consumption goods and changes in income from employment earnings with the effects of income received through endowments of GHG allowances. Findings shown in Figure 15 depend on the allocation scheme illustrated by Figure 11, in which states receive allowances based on their historical emissions patterns. As with GSP, the income received from these endowments leads to consumption patterns in states such as North Dakota, Louisiana, and West Virginia that are at odds with what might be expected because their economies are weighted more toward energy production than national averages. Similarly, states such as California, which have relatively low energy consumption, are somewhat worse off than the national average, as a function of receiving fewer allowances under a historical emissions approach to the allocations. Thus, even though with this allocation scheme the states likely to experience the largest aggregate impacts of a GHG policy are compensated for their economic adjustments through receiving additional allowances, the approach does not necessarily imply that impacts on households will be equalized across states.

Figure 14

Impacts on Annualized Growth Rates In Household Consumption Spending (2005 to 2020)

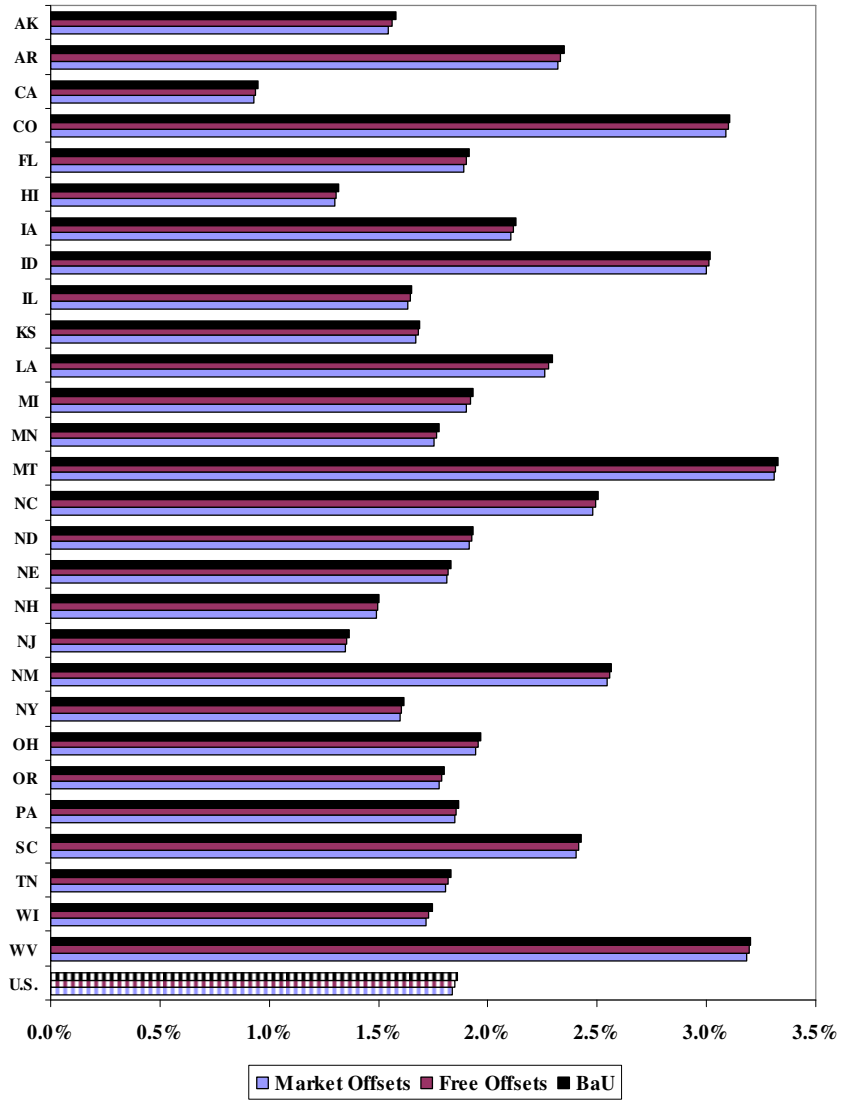
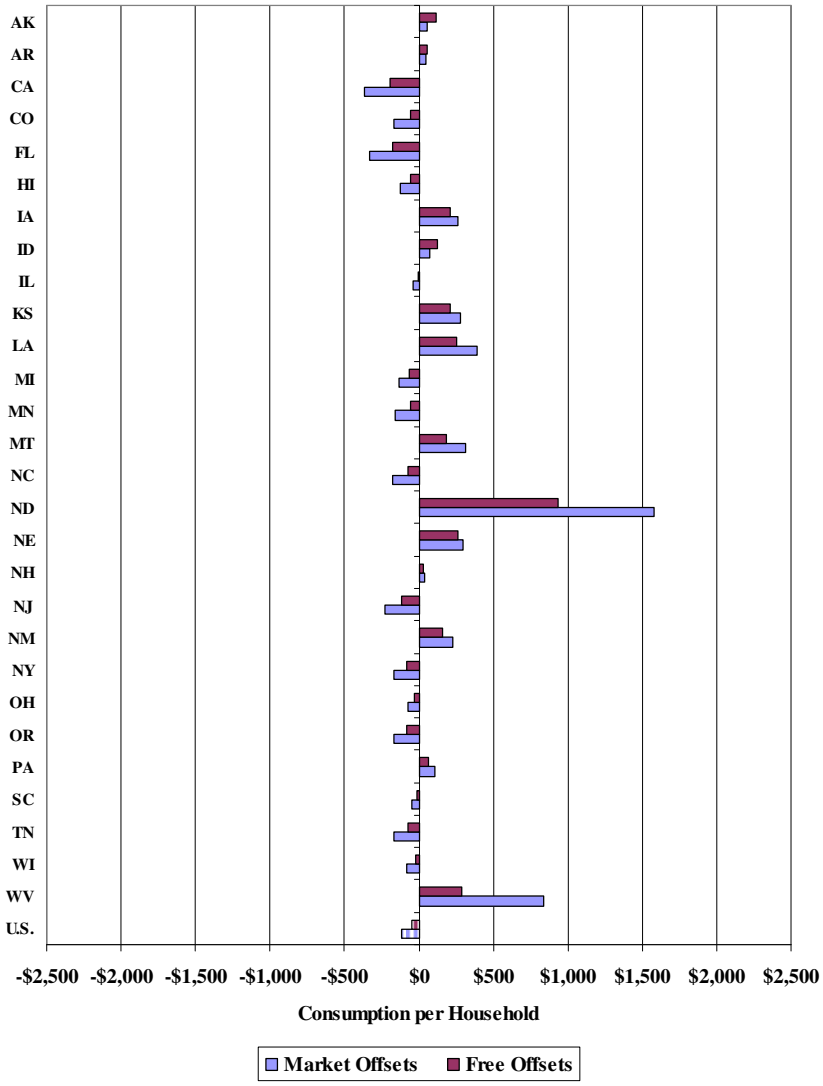


Figure 15

Impacts on Household Consumption Spending in 2020

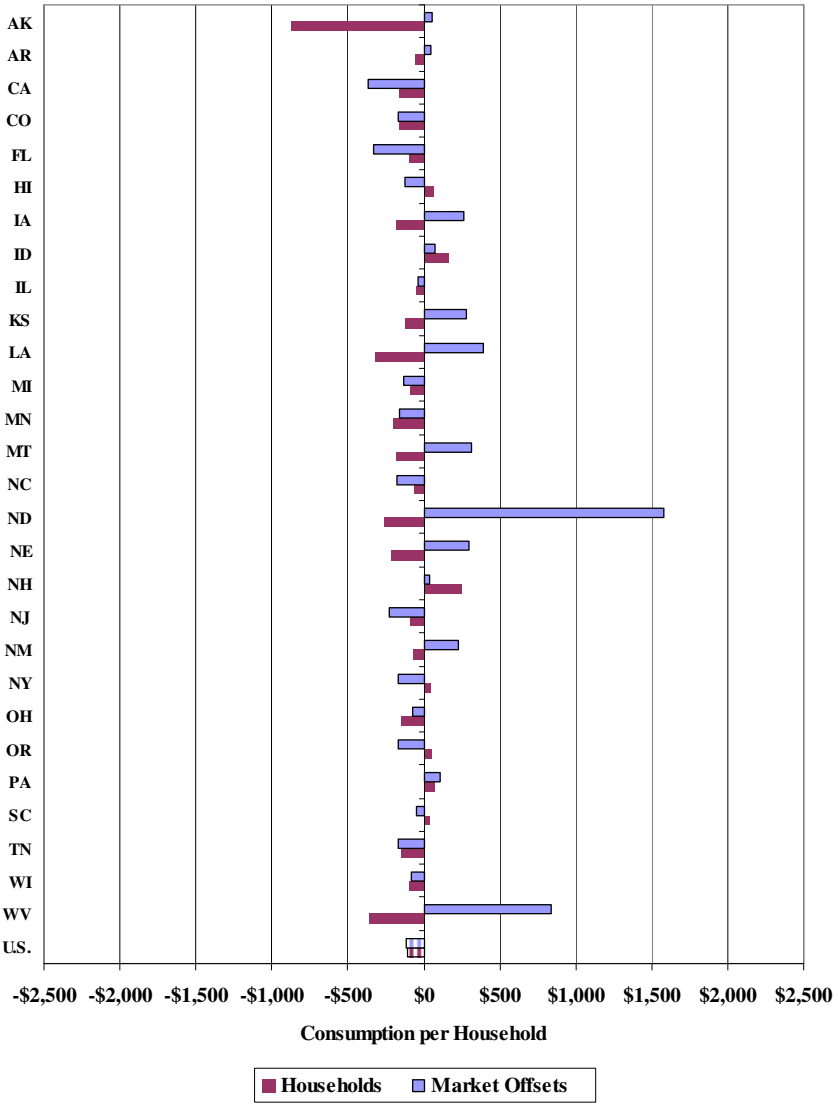


An alternative approach for distributing allocations might be to base them on the number of households in each state in a given year. Under this approach, states are not compensated according to their differing energy-consumption requirements but along the lines of their population. Figure 16 shows the implications of these results for consumption spending as the "Households" scenario and compares them with the "Market Offsets" results from Figure 15. States such as North Dakota and West Virginia, which experienced large consumption increases as the result of receiving more allowances per household than the national average under a historical emissions distribution, are now below the U.S. average. Other energy-producing states such as Alaska with more moderate consumption increases are now significantly worse off. Conversely, states with large populations and low initial energy consumption (and

emissions) such as California do better under an allowance distribution that depends on households, rather than emissions. Impacts on other states not at extremes of either energy consumption or population are less affected. Although neither of these approaches equalizes the impacts of the policy across households, the results indicate how allocations can be used to alleviate any costs associated with a GHG policy. In addition, as suggested by the RGGI approach, a certain portion of the allowance auction could be used for public benefit purposes and specifically to compensate specific disadvantaged groups of citizens, not unlike the initial assumption used in this report where states with larger impacts receive more allowances.

Figure 16

Impacts of an Alternative Allowance Distribution on Household Consumption Spending



B.7 Impacts of the Policy on State Output Revenues

Figures 17 and 18 show how output revenues of nonenergy industries (agriculture, manufacturing, and services) are expected to change across states; energy production is not included in the graph to isolate the effects of energy efficiency differences across states on potential changes in output. The revenue effects shown combine both changes in commodity prices and changes in quantities produced; consequently, the changes appear larger than GSP impacts shown in Figure 12. However, revenues provide a convenient method by which to merge results from different industries for comparison purposes. The results illustrate the inverse relationship between energy intensity per unit of output (see Figure 8) and responses of state economies to the GHG policy: as a general rule, states with high industrial energy use will experience larger adjustments than states with a service-oriented focus (Figure 9).

Figure 17

Impacts on Annualized Growth Rates In Industrial Output – Non-Energy (2005 to 2020)

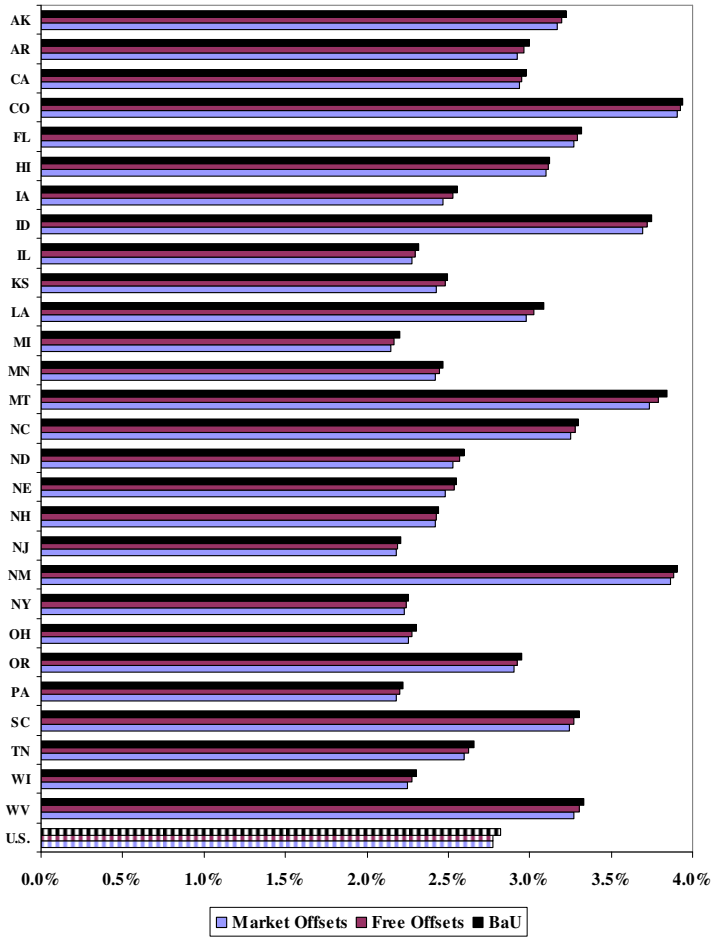
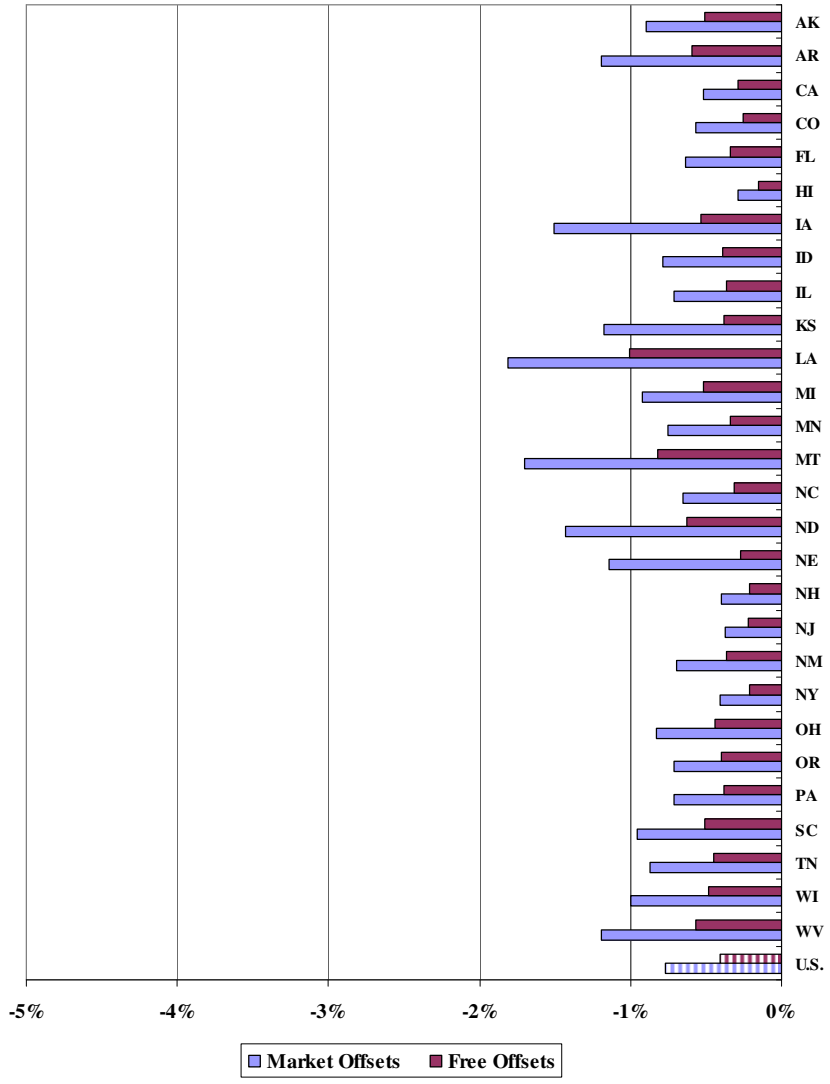


Figure 18

Impacts on Output Revenues of Nonenergy Industries in 2020



B.8 Impacts of the Policy on State Employment

Policy impacts on employment, which reduced overall employment growth in the United States from 1.225 percent a year to 1.215 percent over the 2005 to 2020 time frame, are spread across states in a pattern similar to changes in output revenues (see Figure 19). As shown in Figure 20, in 2020, after 10 years of the policy, employment effects range from essentially zero for states such as California, Florida, and Hawaii to between a quarter of a percent from the BaU projection for energy-producing states (recall that, in these same states, household consumption spending did not necessarily decline, depending on how allowances are distributed). Trends that might be expected in some

energy states, such as Alaska and Colorado, are offset by increases in employment in the natural-gas industries. In other states that are significant coal producers, such as West Virginia, some labor movements from the energy-producing industries into other parts of the economy are relatively unaffected by the GHG policy, such as services.

Figure 19

Impacts on Annualized Growth Rates In Employment (2005 to 2020)

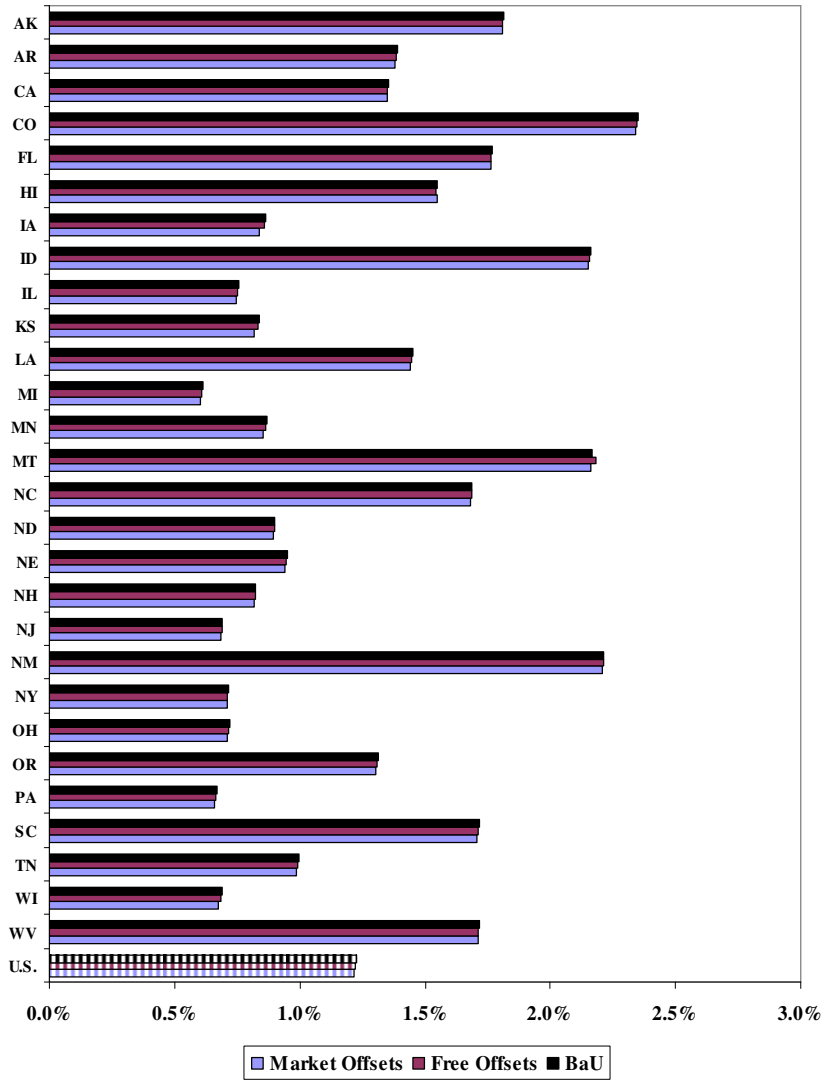
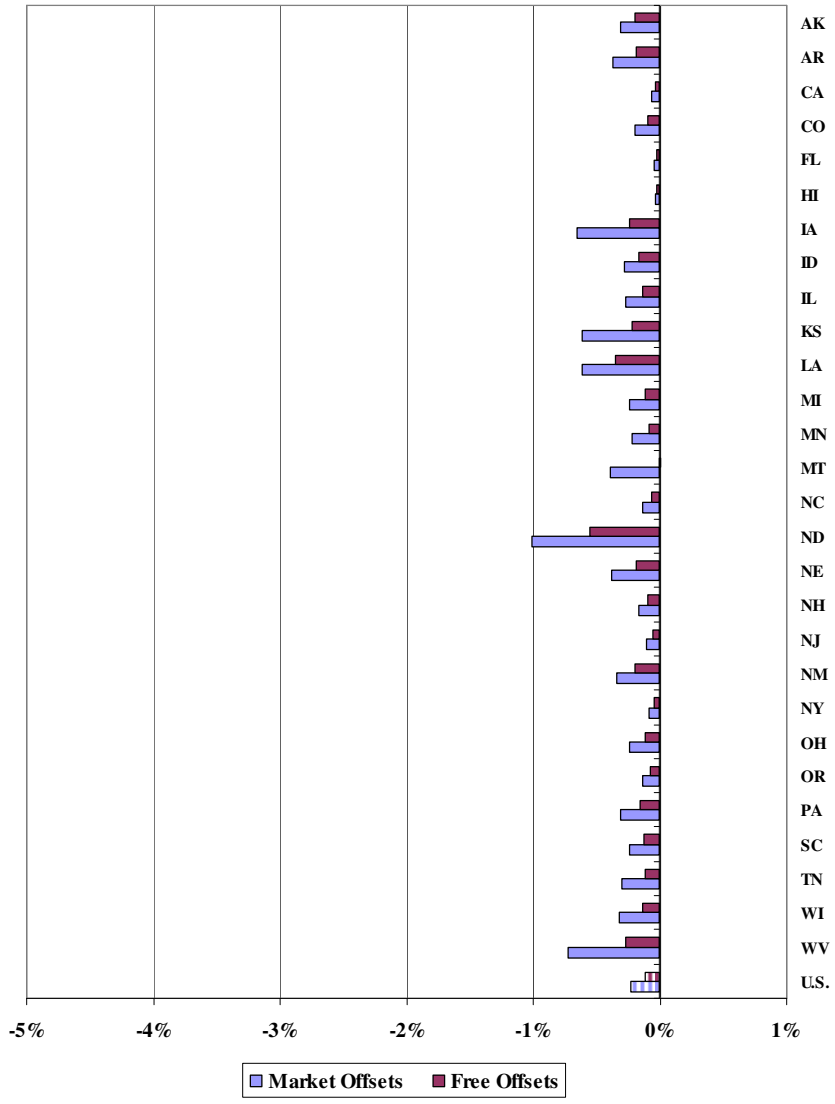


Figure 20

Impacts on Employment in 2020



IV. Conclusions

This analysis uses the ADAGE CGE model to estimate the economic impacts of a modest national climate-change mitigation policy and evaluate how these impacts might affect the economies of individual states. It is important to note that, although this modeling effort focuses on estimating costs associated with undertaking a policy to reduce GHG emissions, costs will also likely be associated with not taking action as increasing atmospheric levels of human-generated GHG contribute to further global warming, and these costs (or benefits from action) should be included in a more complete evaluation, but this is beyond the scope of the current effort.

Impacts of a climate-change mitigation policy on an individual state within the United States will depend on many factors. Among these are states' initial energy consumption, the types of manufacturing and service industries located there, how a state generates (or purchases) its electricity, and the endowment of allowances it receives under the policy. Relatively energy-efficient states, because of either their product mix or manufacturing technologies, will need to make fewer adjustments in their economies to reduce emissions than more energy-intensive states. Also, the techniques currently used to generate electricity and their fossil-fuel intensity will control how states adjust to a GHG policy as will the ability to develop markets and use new technologies and fuels. Finally, the distribution of allowances across states can have important implications for household income and consumption because the value of these allowances is potentially quite large, relative to the total cost of the policy.

This report finds that economic impacts of a policy that reduces GHG emissions to around the levels seen in the year 2000 are relatively small. Average annual GDP growth rates are estimated to be a few one-hundreds of a percent lower over the next 15 years. Similar implications are found for household spending and employment trends. Allowance prices, which range between $4 and $14 per $MTCO_2e$ over the next 15 years, and the economic adjustments associated with them, depend ultimately on assumptions used in the analysis. If there are low-cost, or free, opportunities for purchasing emissions offsets from sources outside the policy's trading system, allowance prices will be at the low end of the price range, while more restricted opportunities will increase prices. In addition, if the model used to analyze a GHG policy does not include options to achieve cost-effective reductions in non-CO_2 gases, or through trading with international or domestic emissions sources, the model's estimated allowance prices and associated economic impacts will be much higher.

Finally, the modeling discussed in this report indicates that, even under a uniform national policy, effects on states are likely to be distributed in a fairly heterogeneous fashion. However, opportunities exist to use the value embodied in GHG emissions allowances created under a cap-and-trade policy to help ameliorate impacts on states experiencing larger than average economic adjustments.

Endnotes

[1] For a discussion of ongoing state and regional GHG emissions reduction efforts see http://www.pewclimate.org/what_s_being_done/in_the_states/.
[2] See http://www.stanford.edu/group/EMF/home/index.htm.
[3] CO_2 emissions associated with calcination during cement production are not considered.
[4] For some types of GHG emissions, such as N_2O from fossil-fuel consumption, abatement opportunities are not considered because of difficulties in monitoring or assigning abatement costs.
[5] Abatement costs for CH_4 from coal mines are based on work by RTI International; however, these results are similar to the data presented in Hyman et al. (2002).
[6] A similar CGE structure was used in Andriamananjara et al. (2005) to examine state-level impacts of international trade policies. To the best of our knowledge, this aggregation methodology was originally conceived by Thomas Rutherford. See http://www.gams.com/solvers/solvers.htm#MPSGE for information on his work.
7 Stanford Energy Modeling Forum – EMF 21: Multi-Gas Mitigation and Climate Control (http://www.stanford.edu/group/EMF/home/index.htm).
[8] Massachusetts Institute of Technology Joint Program on the Science and Policy of Global Change at http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt97.pdf ; Charles River Associates at http://www.crai.com/pubs/pub_3694.pdf ; U.S. DOE Energy Information Administration at http://www.eia.doe.gov/oiaf/analysispaper/sacsa/index.html; and the forthcoming Pew Center on Global Climate Change analysis by Jorgenson, Goettle et al. using the IGEM model.
[9] As in the Smith et al. (2003) analysis of this policy, government spending is maintained under the policy (because the government is included as a separate agent in the model). Although their analysis accomplished this through raising personal income taxes, this analysis maintains government spending in a nondistortionary manner.
[10] The economics literature has examined how revenues from environmental policies might provide a "double dividend" benefit to the economy if they are used to lower existing distortions (see, for example, Bovenberg and Goulder [1996], Parry and Bento [2000], and Goulder and Williams [2003]). While these benefits can have important implications for the macroeconomic costs of policies, they are beyond the scope of this analysis. Thus, although it is assumed in this analysis that government purchases in the United States are maintained in a nondistortionary manner to ensure meaningful welfare results, allowances are allocated directly to states and not used to reduce existing taxes in the United States.
[11] Including countries in Eastern Europe such as Poland in the European region in the model implies that Kyoto participants will be willing to pay these countries for their excess allowances.
[12] If Russian "hot air" is included, based on IEA forecasts, none of the Kyoto participants would need to take action for a number of years to meet the overall Kyoto emissions target, similar to results mentioned in Paltsev et al. (2004), and allowance prices would be equal to zero (excluding effects of banking). Because this result does not agree with the current positive allowance prices in European trading markets, or comments by European leaders indicating they are unlikely to pay for "hot air," it was decided to remove it from the analysis.
[13] Although the international policy assumption of unrestrained trading of allowances among participants leads to low estimated prices for Kyoto Protocol participants, it is still essential to consider these global actions because they will have ramifications for economic effects of domestic policies. Among the most important of these are how worldwide declines in demand for crude oil will lower its price, thus providing an incentive to consume more petroleum and potentially making it more difficult to meet the emissions target. Similarly, the ADAGE model considers how international competitiveness may be influenced through changes in production costs of industries. Taking these reactions into account, a Kyoto allowance price of around $10 per metric ton of carbon equivalent is estimated for the year 2010, increasing at 5 percent a year thereafter. (Assuming that the United States bought offsets from Kyoto nations would increase the Kyoto allowance price by up to 100 percent, due to the reduction in amount of their allowances available for trade and use.) This leads to an initial drop in world crude-oil prices of around 1 percent, which declines to around one-quarter of a percent over the next 10 to 15 years. These changes, along with those in other traded goods, are then considered when determining U.S. reactions.
[14] Note on comparing module results: allowance prices estimated by the *US Regional* module of $30.63 and $49.73 per MTCe for the years 2010 and 2020, respectively, compare to results for the policy in the *International* module of $30.32 and $49.19 for the same years. We feel this shows a good correspondence between the two modules and indicates that responses in the *US Regional* module to changes in trade prices from the *International* module will provide an accurate representation of world reactions to the Kyoto Protocol and domestic GHG policy.

[15] As noted previously, the "Free Offsets" scenario might represent circumstances in which forest/soil sequestration proves to be capable of supplying 15 percent of the policy's emissions cap at no cost or, alternatively, if very cheap offsets are available from international GHG markets (e.g., if Russian "hot air" is allowed on these markets). Domestically generated offsets in the "Market Offsets" scenario come from reductions of non-CO_2 gases in agriculture, methane emissions from coal mines or landfills, HFCs from refrigerants or foam manufacturing, etc.

[16] The process used in ADAGE to develop state-level data and forecasts, which generally involves starting from historical state-level data and projecting it along AEO forecasts, leads to a slightly lower BaU estimate for U.S. petroleum prices than in AEO 2004.

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Appendix A: Additional Information and Analyses

This appendix presents additional information on calculating the emissions target used in this analysis. It also shows the estimated distribution of allowances across states and how an alternative distribution would affect model results. Finally, sensitivity analyses are conducted on various model assumptions controlling how energy consumption reacts to the climate-change mitigation policy.

A.1 Emissions Target Used in Analysis and States' Endowments of Allowances

The emissions target is established using data from EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (2005). For non-CO_2 emissions, sufficient detail is provided to distinguish emissions of noncovered entities in the agriculture, household, and services sectors of the economy. For CO_2 emissions, additional data from EIA are used to separate emissions related to transportation fuels, which are covered by the policy, from other emissions by noncovered entities.

Table A-1. Calculation of the National Emissions Target

Emission Type	All Emissions	Excluded Emissions			Covered Emissions
		Agriculture [2]	Households [3]	Service Industry [4]	
CO_2 [1]	5,858.2	8.3	379.1	234.7	5,236.2
CH_4	552.2	162.0	168.4	0.0	221.8
N_2O	402.0	282.2	69.2	0.0	50.6
HFC, PFC, SF_6	138.9	0.0	0.0	0.0	138.9
Total	6,951.3	452.5	616.7	234.7	5,647.0

[1] Excludes net CO_2 emissions from land-use change and forestry

[2] Excluded emissions of CO_2 from transporation fuels are calculated from AEO 2003, Table 32. Emissions of CH_4 and N_2O in agriculture from enteric fermentation, manure management, crop burning, rice cultivation, and soil management are excluded.

[3] Excluded emissions of CO_2 from transportation fuels are calculated from AEO 2003, Tables 2 and 34. All emissions of CH_4 and N_2O from mobile sources are assigned to households. Emissions of CH_4 and N_2O from landfills, wastewater treatment, mobile sources, and sewage/waste are excluded.

[4] All emissions of the services industry (EIA's Commercial Sector minus government) are excluded.

State-level CO_2 emissions by economic sector in the year 2000 are calculated using historical EIA data on states' energy consumption (see Ross [2005] for these data sources). Overall U.S. emissions of non-CO_2 gases by source are taken from the Stanford EMF 21 data on multigas abatement. Regional shares of EMF's U.S. emissions are assigned to states based on output and consumption of the relevant economic sectors from the IMPLAN and EIA data in the model. Table A-2 shows the results of these emissions estimates, which are described further below.

Table A-2. States' Endowments of Allowances Based on Estimated Emissions in Year 2000

State	Endowments Based on Emissions (MMTCe)							Endowment Value at $7/MTCO2e (in $million)	Endowment Value per Household in 2010
	CO_2	CH_4	N_2O	HFC	PFC	SF_6	Total		
Alabama	126.8	3.6	0.5	1.4	0.3	0.7	133.4	$933	$465
Alaska	33.0	1.6	0.1	0.1	0.0	0.0	34.8	$244	$886
Arizona	75.8	2.6	0.3	1.7	1.1	0.5	82.0	$574	$234
Arkansas	57.9	3.1	0.9	0.9	0.1	0.2	63.1	$442	$369
California	320.1	16.9	2.2	11.7	3.9	1.2	356.0	$2,492	$188
Colorado	76.0	7.3	1.0	1.6	0.2	0.2	86.3	$604	$304
Conneticut	30.9	1.2	0.2	1.4	0.1	0.2	33.9	$238	$175
Delaware	14.8	0.3	0.1	0.3	0.0	0.0	15.6	$109	$313
Florida	204.4	6.0	0.7	3.4	0.4	1.0	215.9	$1,511	$189
Georgia	148.9	3.3	0.7	3.0	0.3	0.6	156.7	$1,097	$304
Hawaii	14.3	0.6	0.1	0.2	0.0	0.1	15.2	$106	$216
Idaho	14.7	1.7	0.7	0.5	0.4	0.1	18.0	$126	$218
Illinois	214.1	6.4	3.2	4.3	0.4	1.1	229.6	$1,607	$332
Indiana	216.4	4.2	1.8	3.1	0.7	0.9	227.1	$1,590	$622
Iowa	73.1	4.8	3.3	1.0	0.4	0.2	82.9	$511	$423
Kansas	69.9	6.9	2.4	1.0	0.1	0.2	80.4	$563	$490
Kentucky	137.2	7.2	0.9	1.6	0.5	0.5	148.1	$1,036	$592
Louisiana	196.0	5.6	0.7	1.1	0.1	0.4	203.8	$1,427	$769
Maine	15.6	0.6	0.1	0.4	0.1	0.1	16.8	$244	$373
Maryland	68.7	2.3	0.4	1.2	0.1	0.3	73.0	$511	$234
Massachusetts	65.4	2.2	0.3	2.4	0.5	0.2	71.1	$498	$194
Michigan	173.4	5.2	1.3	6.7	0.4	0.7	187.6	$1,313	$316
Minnesota	88.2	4.1	2.5	2.0	0.2	0.3	97.3	$681	$321
Mississippi	53.7	1.9	0.4	0.9	0.1	0.2	57.1	$400	$341
Missouri	112.2	3.3	1.7	2.0	0.4	0.5	120.2	$841	$341
Montana	28.0	1.8	1.0	0.2	0.0	0.2	31.1	$218	$523
Nebraska	36.6	5.2	2.8	0.5	0.0	0.2	45.3	$317	$436
Nevada	39.3	0.8	0.2	0.6	0.0	0.3	41.2	$289	$307
New Hampshire	15.1	0.5	0.1	0.6	0.1	0.1	16.5	$115	$205
New Jersey	111.7	3.0	0.6	1.9	0.3	0.4	117.9	$825	$249
New Mexico	51.4	5.8	0.3	0.4	0.2	0.2	58.3	$408	$483
New York	188.3	7.7	1.4	4.3	0.6	0.8	203.2	$1,422	$191
North Carolina	134.0	4.1	0.8	3.9	0.2	0.6	143.6	$1,005	$267
North Dakota	45.8	1.1	1.4	0.2	0.0	0.2	48.6	$340	$1,188
Ohio	243.1	6.0	1.7	5.0	1.0	1.1	257.8	$1,804	$387
Oklahoma	88.6	9.0	0.9	0.9	0.0	0.4	99.8	$698	$454
Oregon	36.1	1.7	0.7	1.4	1.1	0.5	41.5	$291	$190
Pennsylvania	244.5	9.1	1.4	3.7	0.9	1.6	261.3	$1,829	$360
Rhode Island	9.5	0.3	0.0	0.3	0.1	0.1	10.4	$73	$168
South Carolina	72.0	1.5	0.3	1.6	0.2	0.5	76.0	$532	$288
South Dakota	13.0	1.8	1.8	0.2	0.1	0.0	17.0	$119	$363
Tennessee	114.5	2.6	0.7	2.3	0.4	0.6	121.0	$847	$334
Texas	653.7	26.4	3.3	6.8	1.9	2.1	694.3	$4,860	$548
Utah	58.4	2.5	0.3	0.7	0.0	0.3	62.3	$436	$514
Vermont	5.5	0.6	0.1	0.2	0.2	0.0	6.7	$47	$159
Virginia	108.2	4.3	0.7	2.3	0.4	0.4	116.3	$814	$268
Washington	73.0	3.3	0.9	2.2	0.6	0.6	80.5	$564	$214
West Virginia	103.3	6.9	0.2	0.3	0.2	0.5	111.4	$780	$970
Wisconsin	99.8	4.6	2.0	2.4	0.3	0.3	109.3	$765	$327
Wyoming	57.0	8.4	0.3	0.1	0.0	0.2	66.1	$463	$1,944
United States	5,235.6	221.8	50.6	96.8	19.2	22.9	5,647.0	$39,529	$330

Methane emissions from U.S. coal mines in the EMF 21 data are apportioned to underground and surface mines using EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. Net emissions, accounting for methane recovery, from these mines are assigned to states based on state-level coal production (with underground mines in the eastern states and surface mines in the west). Methane emissions associated with natural-gas transmission are assigned based on states' shares of national gas transmission, while emissions from petroleum products are determined by states' oil consumption. State-level agricultural emissions of methane from enteric fermentation, animal waste, rice cultivation, and crop residue burning are estimated based on state's shares of national agricultural production of the relevant commodities as shown in the IMPLAN data. Similar logic is applied to emissions from the iron and steel industry and chemical manufacturing. Methane emissions from landfills are assumed to be a function of each state's population as a share of national population. Emissions of N_2O from fuel combustion are based on the ADAGE state-level estimates of energy consumption. As with some types of methane sources, other N_2O emissions from agriculture and manufacturing depend on the IMPLAN production data. Similar logic is also applied to all HFC and PFC emissions and to SF_6 emissions related to magnesium production. SF_6 emissions from the electricity industry are based on the state-level estimates of electricity generation in ADAGE (in kWh).

A.2 Sensitivity Analyses

A.2.1 Energy Efficiency Improvements and Fuel Switching in Electricity Generation

To evaluate the feasibility of the heat rate improvements in the model, which are described in Box 2 of Section III.A, the authors conducted a spreadsheet analysis of these improvements and the changes in fuel consumption. Levelized costs of new advanced gas generators can be determined from the capital and operating costs in Tables 38 and 48 of EIA's *Assumptions to the Annual Energy Outlook*, along with natural gas prices and carbon content from the *Annual Energy Outlook*. Data on heat rates and capacities of existing coal-fired generating units are available from EPA's NEEDS database at http://www.epa.gov/airmarkt/epa-ipm/. This information can be combined with assumptions on fixed and variable operating costs for coal units (from the documentation of the Integrated Planning Model at the same Web site) to get levelized generation costs for existing coal units. This analysis indicates that, by 2020, based on the coal and natural gas prices in the model and the estimated allowance prices in the policy case, it would be economic to retire 120 gigawatts of current coal units and replace them with advanced gas technologies. Remaining coal units, running at a capacity factor of 85 percent, would be able to generate 1,260 billion kWh of electricity from the 12.7 quadrillion Btus of coal used in the electricity industry in the ADAGE model. From a total fossil-fired generation in the model of 3,530 billion kWh, this leaves around 2,200 billion kWh for natural-gas generation (after subtracting off a small amount for oil units). At an average capacity factor of 90.4 percent and with a heat rate of 4,960 Btu/kWh, 280 gigawatts of new advanced gas generators would be needed to consume the 11.3 quadrillion Btus of natural gas in the electricity industry in the model. This would generate the 2,200 billion kWh of electricity needed to match total electricity demand in the model. Combining these new gas units with the remaining existing coal and other units would give an overall heat rate for fossil generation of 6,920 Btu/kWh, which is equivalent to the estimate in ADAGE.

As discussed in Box 2, a sensitivity case was run in ADAGE regarding model assumptions about the ability of electric utilities to switch from coal to gas. This model parameter, which has a large impact on allowance prices and the economy's energy consumption, is the elasticity of substitution that controls the ability to undertake this fuel switching (see Figure 2-5 in Ross [2005]). In this sensitivity case, this elasticity is lowered from two to one, which restricts movements out of coal-fired generation and into gas-fired generation. As shown in Table A-3, by limiting the capabilities of the electricity industry to provide low-cost emissions reductions, the allowance price increases by

around 30 percent. Despite the increase in the allowance price, and thus the price of coal, in 2020 coal consumption by utilities is 15 percent higher than in the "Market Offsets" scenario. Natural-gas consumption is around 10 percent lower than before, and there is a smaller improvement in heat rates. As the result of additional production costs, electricity prices are somewhat higher and demand is lower.

Table A-3. Impacts of Assuming Less Coal-Gas Switching by Electric Utilities

		BaU		Less Fuel Switching		Market Offsets	
Variable		**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Allowance Price ($/MTCO2e)		--	--	$10.8	$17.5	$8.4	$13.6
Electricity Fossil-Fuel Use	Coal	23.2	26.5	17.3	14.6	15.5	12.7
(Quad Btu)	Natural Gas	7.0	8.9	7.4	10.2	8.4	11.3
Electricity Markets	Price	$0.064	$0.066	$0.072	$0.077	$0.070	$0.074
($/kWh & billion kWh)	Generation	4,380	5,141	4,121	4,716	4,182	4,806
Heat rates (Btu per kWh)		9,687	9,338	8,608	7,336	8,142	6,908

A.2.2 Energy-Efficiency Improvement in Manufacturing

One of the most important model parameters is the elasticity of substitution that controls energy-efficiency improvements in the manufacturing, services, and transportation industries (σ_{KLE} equal to 0.5 in Figure B-3). This sensitivity case involves raising the parameter to one, which allows additional switching between energy and value-added (capital and labor). Hence, there is more ability to invest in capital or use more labor to reduce the need for energy in production. Table A-4 shows the impacts of this change for the "Market Offsets" scenario (this scenario is used for comparison purposes because it shows more reactions than the "Free Offsets" scenario). Across the economy, the allowance price falls by around 20 percent as the result of these additional efficiency improvements. Coal consumption, which already declines by the largest amount, remains fairly constant. By 2020, however, consumption of the remaining types of energy falls by an extra 4 percent as the result of additional investments by manufacturers, even though allowance prices are lower than in the "Market Offsets" scenario.

Table A-4. Impacts of Assuming More Energy-Efficiency Improvements

		BaU		More Efficiency		Market Offsets	
Variable		**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Allowance Price ($/MTCO2e)		--	--	$6.7	$11.0	$8.4	$13.6
Manufacturing,	Coal	2.5	2.4	1.8	1.3	1.7	1.3
Services &	Electricity	7.1	8.6	6.7	7.7	6.8	8.1
Transport Energy	Natural Gas	10.5	12.0	9.9	10.7	9.9	11.1
Use (Quad Btu)	Petroleum	18.4	21.6	17.7	19.5	17.8	20.3

Appendix B: ADAGE Model Description

This appendix describes the general structure of the ADAGE model. See Ross (2005) for additional information.

B.1 Overview

RTI's ADAGE model is a dynamic CGE model capable of examining a wide range of economic policies and estimating how all parts of an economy will respond over time to policy announcements. Among the feasible set of policies are many types of economic, energy, environmental, and trade policies, which can be investigated at the international, national, U.S. regional, and U.S. state levels.[4] Of particular note is the ability of the ADAGE model to investigate climate-change mitigation policy issues affecting six types of GHG at a range of geographic scales.

To investigate implications of policies, the ADAGE model combines a consistent theoretical structure with observed economic data covering all interactions among businesses and households. These economic linkages include firms purchasing material inputs from other businesses and factors of production (labor, capital, and natural resources) from households to produce goods, households receiving income from factor sales and buying goods from firms, and trade flows among regions. Nested constant elasticity of substitution (CES) equations are used to characterize firm and household behaviors (which are intended to maximize profits and welfare, respectively), as well as options for technological improvements.

ADAGE uses a classical Arrow-Debreu general equilibrium framework to describe these features of the economy. Households are assumed to have perfect foresight and maximize their welfare (received from consumption of goods and leisure time) subject to budget constraints across all years in the model horizon, while firms maximize profits subject to technology constraints. Economic data in ADAGE come from the GTAP[5] and

[4] RTI gratefully acknowledges partial funding of model development related to regional U.S. policies by EPA's Office of Air Quality Planning and Standards (OAQPS). The OAQPS model was developed for analysis of nonclimate-related environmental policies under the name "EMPAX-CGE" (see Ross, Beach, Depro, and Murray [2005]). ADAGE relies on different data, assumptions, and model structure and is suitable for climate-change mitigation analyses at multiple levels of geographic disaggregation. All international and climate-related model development has been funded by RTI International. Development of state-level modeling capabilities has been largely being funded by the Pew Center on Global Climate Change. See http://www.pewclimate.org/ for information on their organization. Any opinions expressed in ADAGE policy analyses are those of the authors alone.

[5] See http://www.gtap.agecon.purdue.edu/ for information on the Global Trade Analysis Project.

IMPLAN[6] databases, and energy data and various growth forecasts come from the IEA and EIA of the U.S. Department of Energy.

ADAGE is composed of three modules: "*International*," "*US Regional*," and "*Single Country.*" Each module relies on different data sources and has a different geographic scope, but all have the same theoretical structure. The internally consistent, integrated framework connecting ADAGE's modules allows its components to use relevant policy findings from other modules with broader geographic coverage. This allows the model to estimate detailed regional and state-level results that incorporate international impacts of policies, while avoiding computational issues that preclude solving for all U.S. states and world nations simultaneously.

ADAGE incorporates four sources of economic growth: (1) growth in the available effective labor supply from population growth and changes in labor productivity, (2) capital accumulation through savings and investment, (3) increases in stocks of natural resources, and (4) technological change from improvements in manufacturing and energy efficiency. By means of these factors, a baseline growth forecast is established for ADAGE using IEA and EIA forecasts for economic growth, industrial output, energy consumption and prices, and GHG emissions. Starting from the year 2005, ADAGE normally solves in 5-year time intervals along these forecast paths, which are extended into the future as necessary for each policy investigation.[7]

B.2 Components of the ADAGE Model

The ADAGE modeling system is composed of three interconnected modules. As shown at the top of Figure B-1, this framework begins with the *International* module. This component of ADAGE allows the model to conduct international policy investigations on any set of nations included in its database (within computational limits on the total number of regions in the model). After the data and forecasts enter the model structure, policies can be examined. From these studies, findings on prices of traded goods and, in the case of climate-change mitigation policies, emissions permit prices can be passed to the *US Regional* and *Single Country* modules. By passing this information down to modules with additional regional disaggregation, ADAGE is able to incorporate effects of

[6] See http://www.implan.com/index.html for information on the Minnesota IMPLAN Group.
[7] Beyond the end of the model horizon (generally between 2050 and 2075), additional time periods are run to ensure that the model converges to a new steady-state equilibrium after a policy is imposed.

international policies in its regional simulations (see Balistreri and Rutherford [2004] for a discussion of this type of modeling structure and its application in a climate-policy context).

Within the *US Regional* module, states are combined using a flexible regional-aggregation scheme that allows an individual state of focus to be designated and modeled relative to other regions. Five primary regions (groups of neighboring states) and an individual state (modeled as a separate sixth region) are included in policy simulations. By running this aggregation scheme through all states of interest for a policy, findings can be obtained for multiple states in a computationally tractable, yet flexible and consistent, manner. A similar CGE structure was used in Andriamananjara et al. (2005) to examine state-level impacts of international trade policies.[8]

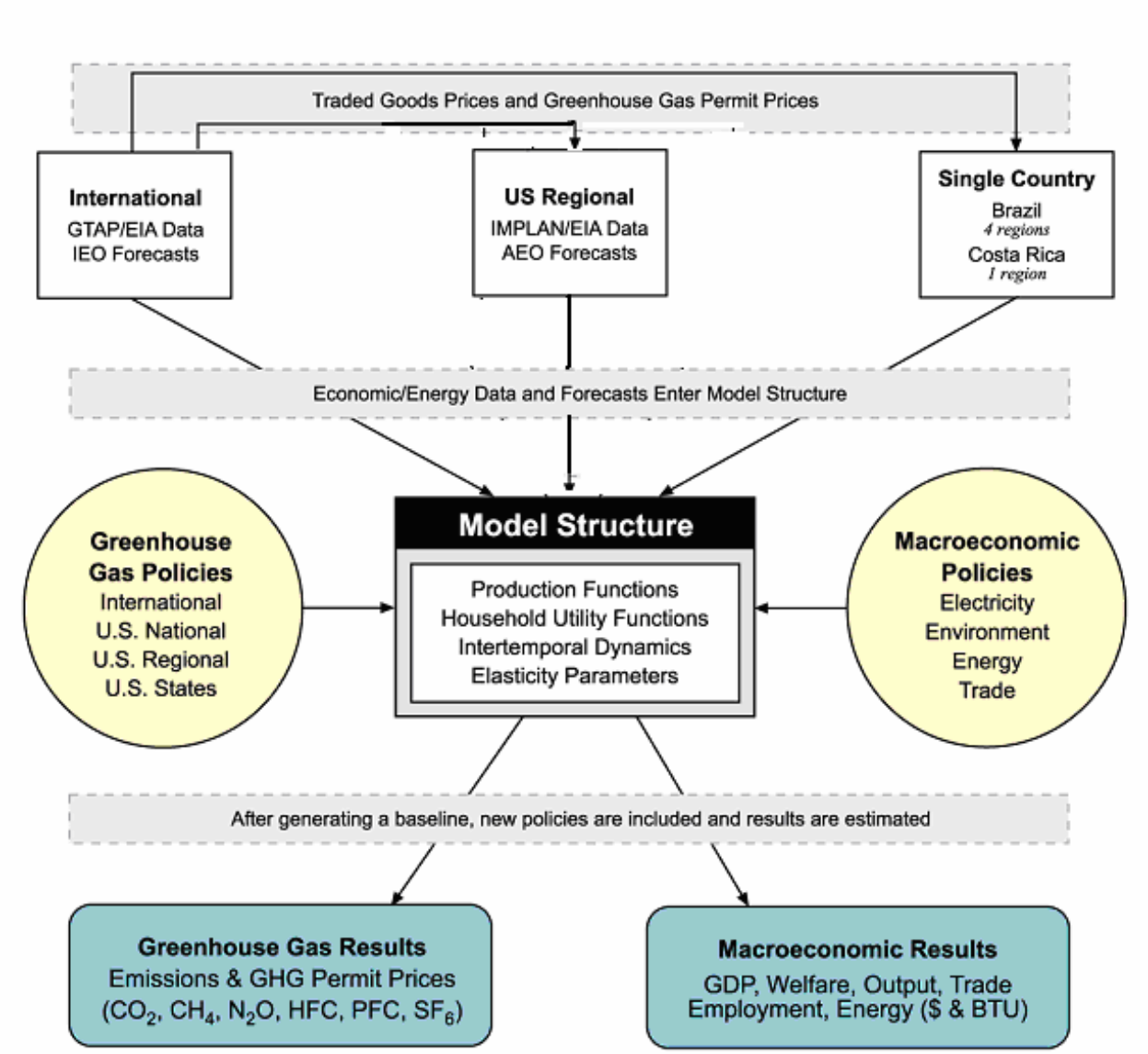
ADAGE uses a variety of economic, energy, and emissions data sources to characterize production and consumption decisions by firms and households. These data show current production technologies and demands by agents and are combined with economic growth forecasts and estimates of future energy production, consumption, and prices:

- ***International***—GTAP economic data, IEA energy production and consumption data, and *World Energy Outlook 2004* forecasts from IEA. Carbon dioxide (CO_2) emissions related to fuel consumption are from IEA. Non-CO_2 GHG emissions are from the Stanford Energy Modeling Forum (EMF 21).
- ***US Regional***—Economic data from the Minnesota IMPLAN Group, and energy data and forecasts from EIA: *Annual Energy Outlook 2004*, *Manufacturing Energy Consumption Survey 2002*, *State Energy Reports*, and various industry annuals. Fuel-related CO_2 emissions are from EIA, and non-CO_2 GHG emissions are from EMF 21.
- ***Single Country***—Individual country data where GTAP data are less comprehensive (currently for Brazil–International Food Policy Research Institute data[9] and Costa Rica).

This integrated modular design (along with the flexible regional aggregations for U.S. states and foreign nations) has been adopted to overcome computational constraints that limit the total size of nonlinear, intertemporally optimizing CGE models such as ADAGE.

[8] To the best of our knowledge, this aggregation methodology was originally proposed and developed by Thomas Rutherford. See http://www.gams.com/solvers/solvers.htm#MPSGE for information on his work.
[9] See http://www.ifpri.org/ for International Food Policy Research Institute (IFPRI) data and reports.

Figure B-1. The ADAGE Model: Integrated Framework of Connected Modules



ADAGE model development would not have been possible without the MPSGE software (Mathematical Programming Subsystem for General Equilibrium; Rutherford [1999]).[10] ADAGE is solved as a mixed complementarity problem (MCP) within the GAMS language (Generalized Algebraic Modeling System; Brooke et al. [1998]).[11] The GAMS/PATH solver is used to solve the MCP equations generated by the MPSGE software.

[10] See http://www.gams.com/solvers/solvers.htm#MPSGE for more information.
[11] See http://www.gams.com for more information.

B.3 Data in the ADAGE Modules

ADAGE combines multiple data sources to create a balanced social accounting matrix for each module. The data are used to generate a balanced SAM for the year 2005 consistent with desired sectoral and regional aggregations. Although developing a "base" year for the SAM that is different from the initial year of the GTAP and IMPLAN sources requires additional effort, it provides several advantages: first, the different modules should be as consistent as possible and begin in the same year; second, in a perfect-foresight model, agents will adjust their behavior in all time periods as soon as a policy is announced, so, if ADAGE began in the year 2000, policies under consideration today would show effects in that year; and finally, developing a SAM for the year 2005 outside of the model allows more opportunity to incorporate estimates of economic growth between the year of the data and the base year of ADAGE.

The *International* module of ADAGE relies on the GTAP Version 6 database. These economic data include balanced SAMs for 87 regions containing 57 sectors, with information for the year 2001. Within the bounds of the regional and sectoral disaggregation of these data, ADAGE is fully flexible in choosing regions and industries. For climate-change mitigation policy analyses, this information is combined with IEA data on historical and forecast energy production, consumption, and price data, types of electricity generation, and GDP growth.[12]

An international regional aggregation of the countries in GTAP is selected for an analysis based on the relevant international policy backdrop. In this case, it includes the following group of regions:

- United States
- Europe
- Canada
- Japan
- Russia
- China
- Rest of World

The *US Regional* module is based on state-level economic data from the Minnesota IMPLAN Group[13] and energy data from EIA. These data are used to define around five broad regions within the United States (regional

[12] The necessary energy production and consumption data have been gathered for 32 countries and 6 regions to cover the 87 regions included in GTAP.
[13] Programs from Rutherford (2004) are used to organize and aggregate the IMPLAN data.

definitions are flexible along state boundaries, the aggregation used in this analysis is shown in Figure B-2). To examine a particular state of interest, that state is modeled as a separate sixth region, which interacts simultaneously with the five broader regions. When examining energy/environmental policies, the broad regions within the United States are generally selected to capture important differences across the country in electricity-generation technologies and also to approximate electricity market regions defined by the North American Electric Reliability Council (NERC). Each region typically includes between 10 and 20 industries (the ones used in this analysis are shown below), where the total number of industries (aggregated from the IMPLAN data, which includes over 500 industries) are controlled by dimensional constraints.

Figure B-2. Potential U.S. Regional Aggregation (excluding specific states)

The *Single Country* module is designed to allow ADAGE to look at nations not covered by the GTAP data and/or look at regions within non-U.S. countries if data are available. International Food Policy Research Institute (IFPRI) publishes a four-region SAM for Brazil that has been adapted for use in ADAGE. Similarly, a Costa Rica SAM from Rodriguez (1994) is used to specify a module for that country, combined with World Bank data on

expected economic growth. These data sources are described in more detail in policy papers related to the specific countries in question and are not discussed here.

Industries represented in each module of ADAGE are aggregated from those in the underlying GTAP and IMPLAN databases to focus on the relevant economic sectors likely to be affected by the policy under investigation, while remaining within computational limits of CGE models. When using findings from one module in another, similar aggregations of industries are used across databases to ensure policy effects are translated accurately among modules. For example, when examining climate-change mitigation policies, data in each module are aggregated to five broad industries (with a focus on maintaining important distinctions in energy consumption and emissions) and five primary energy industries (with multiple forms of electricity generation):

- Agriculture
- Energy-Intensive Manufacturing
- Other Manufacturing
- Services
- Transportation
- Coal
- Crude Oil
- Electricity *(multiple technologies)*
- Natural Gas
- Refined Petroleum

ADAGE, however, is flexible across industries (and regions) contained in the databases underlying the SAMs for each region and can be reaggregated for particular policy investigations to include specific regions and industries of interest (where the total number of regions/industries is constrained by computational considerations).

For policy investigations related to energy and climate-change mitigation, procedures are used to integrate the relevant economic and energy data. Although the GTAP and IMPLAN economic data contain information on the value of energy production and consumption in dollars, these data are replaced with IEA and EIA data for several reasons. First, when the policies being investigated focus on energy markets, it is essential to include the best possible characterization of these markets in the model, and the economic data do not always agree with energy information collected by IEA and EIA. Second, physical quantities of energy consumed are required for ADAGE to accurately estimate GHG emissions. IEA and EIA report physical quantities, while the economic databases do not. Finally, the economic data sources reflect the years 2001 and 2000, respectively, while the initial base year for ADAGE is 2005. Thus, *World Energy Outlook* (WEO) and *Annual Energy Outlook* (AEO) energy production and consumption, output, and economic-growth forecasts for 2005 are used to adjust the economic data.

B.4 General ADAGE Model Structure

Figure B-3 illustrates the general framework of ADAGE, giving a broad characterization of the model and associated elasticities of substitution (noted by σ). At the top level, households in each region maximize intertemporal utility, or their overall welfare, across all time periods with perfect foresight. Within each time period, intratemporal household utility is a function of consumption and leisure. Below these utility functions, individual consumption goods are formed from domestic goods and foreign imports (plus regional domestic imports in the case of the *US Regional* module). At the bottom of the diagram, production technologies are specified that control how inputs can be substituted for each other. Although not illustrated in the figure, differences across industries exist in their handling of energy inputs, most notably between electricity generation and other manufacturing industries. In addition, agriculture and fossil-fuel industries contain equations that account for the use of natural resource inputs.

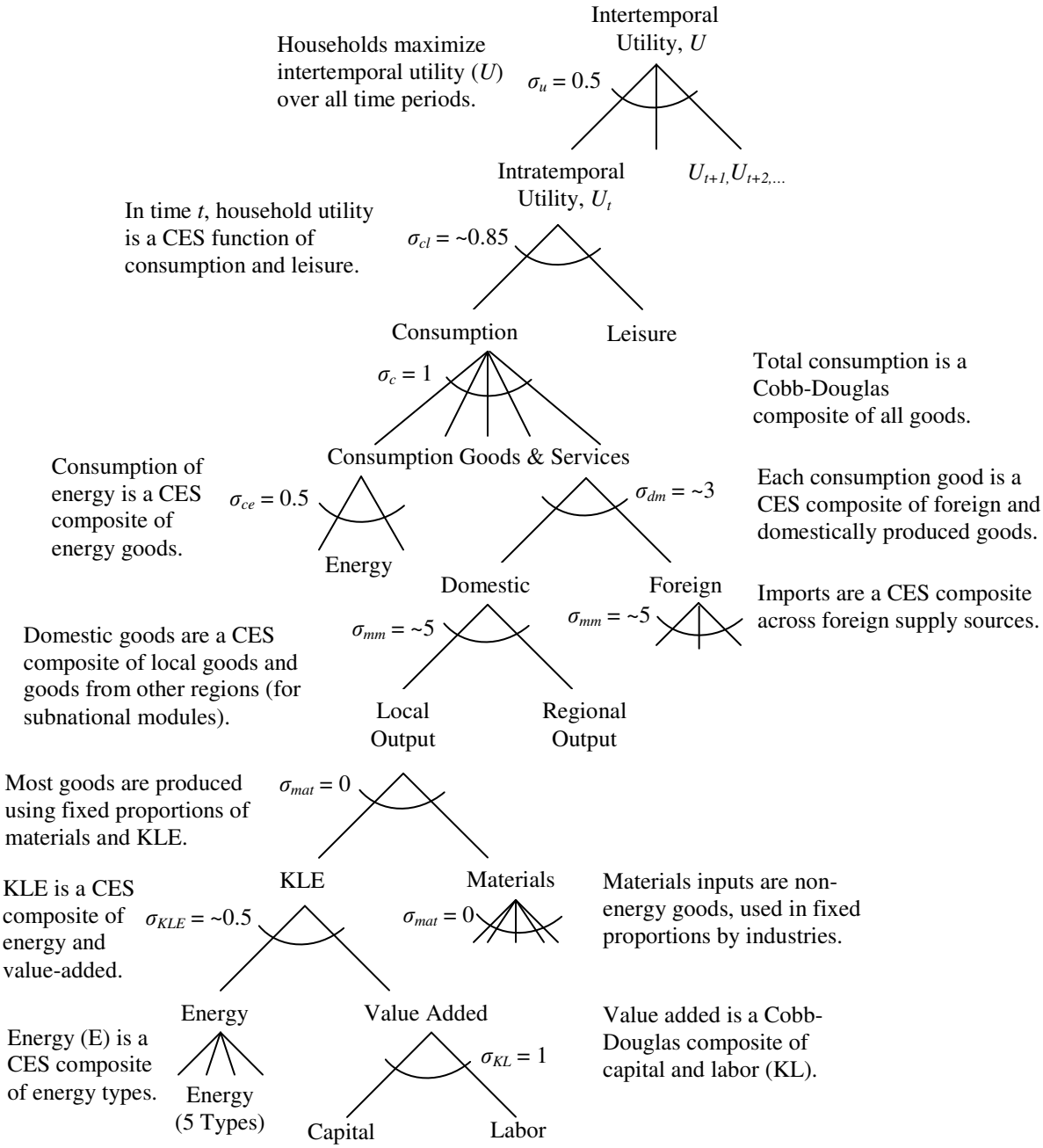
As shown at the top of the figure, each region in ADAGE contains a representative household, which maximizes intertemporal utility over all time periods in the model subject to budget constraints based on endowments of factors of production (labor, capital, natural resources, and land inputs to agricultural production). Income from sales of factors is allocated to purchases of consumption goods and to investment. Within each time period, intratemporal utility is received by households from consumption of goods and leisure. All goods, including total energy consumption, are combined using a Cobb-Douglas structure to form an aggregate consumption good. This composite good is then combined with leisure time to produce household utility. The elasticity of substitution between consumption goods and leisure, σ_{cl}, is controlled by labor-supply elasticities and indicates how willing households are to trade off leisure for consumption.

Factors of production owned by households are assumed to be intersectorally mobile within regions, but migration of productive factors is not allowed across regions so that changes in utility for representative households located in each region can be calculated.[14] It has also been assumed in the *International* and *Single Country* modules that the representative household in each country owns the natural resources located within it, as well as all capital stocks. For the *US Regional* module, ADAGE assumes that ownership of capital stocks and natural resources is spread across the United States through capital markets. Dynamics of capital formation are controlled through quadratic adjustment

[14] Migration among nations and across regions of the United States is included in baseline forecasts.

costs associated with installing new capital (Uzawa, 1969). These installation costs, which represent the frictions or additional costs associated with rapid increases in investment, are based on Bovenberg and Goulder (2000).

Figure B-3. Consumption, Trade, and Production Structures in ADAGE



As shown in the middle of Figure B-3, goods and services are assumed to be composite, differentiated "Armington" goods (Armington, 1969) made up of locally manufactured commodities and imported goods.[15] Within

[15] The one exception is crude oil, which is modeled as a homogeneous good that is identical across all regions and has the same baseline price across all regions and modules (from EIA price forecasts).

this basic framework in ADAGE, some differences across modules exist to accommodate the fact that goods produced in different regions within the United States are more similar than goods produced in different nations. In the *US Regional* module, output of local industries is combined with goods from other regions in the United States using the trade elasticity σ_{mm}. The high values for this elasticity indicates agents make relatively little distinction between output from firms located within their region and output from firms in other regions of the United States (i.e., they find them to be close substitutes). This module then aggregates domestic goods with imports from foreign sources using lower trade elasticities (σ_{dm}) to capture the fact that foreign imports are more differentiated from domestic output. The *International* (and some *Single Country*) modules skip the interregional step but include an aggregation across foreign supply sources.

Production technologies used by most industries and associated elasticities are illustrated in the bottom levels of Figure B-3. Within these technology constraints, each industry maximizes its profits. The nested CES structure of ADAGE allows producers to change the technology they use to manufacture goods. If, for example, petroleum prices rise, an industry can shift away from petroleum and into other types of energy. It can also choose to employ more capital or labor in place of petroleum, thus allowing ADAGE to model improvements in energy efficiency. The ease with which firms can switch among production inputs is controlled by the elasticities of substitution. Elasticities relating to energy consumption are particularly important when investigating environmental policies. If, for instance, an industry is able to substitute away from energy with relative ease, the price of its output will not change much when energy prices vary.

With the exception of electricity generation, the general nesting structure of production activities and associated elasticities have been adapted from the Emissions Prediction and Policy Analysis (EPPA) model developed at the Massachusetts Institute of Technology (MIT), a well-known CGE model designed to investigate energy and GHG policies (Babiker et al. [2001]). Researchers at MIT derived their CES nesting structures and elasticity estimates from a variety of empirical literature, expert elicitations, and "bottom-up" engineering studies. Figure B-3 shows broadly how these equations control production technologies. A capital-labor-energy composite good (KLE) is combined with materials inputs to produce final output. The assumption that this is done in fixed proportions ($\sigma_{mat} = 0$) implies that businesses must either invest in more capital goods (i.e., new equipment) or hire more workers to achieve energy efficiency improvements. The elasticity σ_{KLE} controls these improvements by

specifying how value added (the combination of capital and labor) can be substituted for energy. The bottom level in Figure B-3 then determines how capital and labor can be substituted for each other and, in the other nest, specifies energy substitution possibilities.

Taxes have been included in ADAGE because of the critical role that the existing tax structure can play in determining costs of a policy. If taxes drive a wedge between the cost of producing a good and the price paid by that good, producer and household behaviors are distorted, giving rise to an excess burden beyond the revenue raised by the tax. The *International* module incorporates taxes from the GTAP and IEA data, and the *Single Country* module include any tax rates from their data sources. For the *US Regional* module, a variety of additional tax information has been integrated with the IMPLAN economic database, including marginal income tax rates from the NBER TAXSIM model. ADAGE also contains a user cost of capital formulation based on Fullerton and Rogers (1993), which estimates marginal effective capital tax rates as a function of their important components, most notably personal income and corporate tax rates.[16]

Distortions associated with taxes are a function of both marginal tax rates and labor-supply decisions of households. Thus, ADAGE includes a labor-leisure choice—how people decide between working and leisure time. Labor-supply elasticities related to this choice determine, to a large extent, how distortionary taxes are in the model. Based on a literature survey by Russek (1996) and estimates used in other CGE models, ADAGE uses 0.35 for compensated and 0.15 for uncompensated labor-supply elasticities. These values give an overall marginal excess burden (MEB) of approximately 0.31 and a marginal cost of funds of around 1.22 in the *US Regional* module, measured at the baseline solution for the model.

In ADAGE, economic growth comes from four sources: growth in the available labor supply (encompassing both population growth and changes in labor productivity), capital accumulation through investment, increases in stocks of natural resources, and technological change associated with improvements in manufacturing and energy efficiency. Labor force expansions, economic growth rates, and industrial output are based on IEA and EIA forecasts. Savings, which provide the basis for capital formation, are motivated through households' expectations about future needs for capital. The GTAP and IMPLAN datasets provide details on the types of goods and services used to produce the investment goods underlying each economy's capital stocks. Dynamics associated with formation of capital are

[16] Marginal income tax rates and industry-specific marginal capital tax rates are around 40 percent.

controlled through the use of quadratic adjustment costs associated with installing new capital (these imply that real costs are experienced in order to build and install new capital equipment). Expected changes in energy consumption per unit of output are modeled as exogenous autonomous energy efficiency improvements (AEEI). These AEEIs are used to replicate energy consumption forecasts by industry and type of fuel from IEA and EIA forecasts, which also provide the growth rates for electricity generation, natural resource production, and energy prices.

Prior to investigating policy scenarios, a baseline growth path is established for ADAGE that incorporates these economic growth and technology changes expected to occur in the absence of any new policy actions. Beginning from the initial balanced SAM dataset, a "steady-state" growth path is first specified for the economy to ensure that the model remains in equilibrium in future years, assuming all endowments and output grow at a constant rate. Next, this assumption of constant growth is replaced by forecasts from IEA and EIA. Upon incorporating these forecasts, ADAGE is solved to generate a baseline consistent with them, after which it is possible to run "counterfactual" policy experiments.

To investigate energy and GHG-emissions policies, the ADAGE model tracks fuel consumption in physical units (British thermal units or BTUs), based on IEA and EIA forecasts. Because CO_2 emissions from fuel use are tied to combustion of fossil fuels, the model is able to determine emissions levels in terms of millions of metric tons of carbon dioxide ($MMTCO_2$). Substitution options for and the costs of replacing energy inputs to production are controlled by the CES equations and substitution elasticities in the model. Households also have the ability to switch fuels, lower overall consumption, and improve energy efficiency.

ADAGE has also endogenized emissions abatement costs associated with five non-CO_2 gases (CH_4, N_2O, HFCs, PFCs, and SF_6), based on the approach used in the EPPA model (Hyman et al., 2002). Unlike CO_2, these gases are not emitted in fixed proportions to energy consumption, making the modeling of abatement costs more problematic. Rather than relying on exogenous marginal abatement cost functions, which ignore interactions among the economic sectors, emissions of non-CO_2 gases are modeled directly as an input to production. This allows specification of abatement cost curves representing industry-specific costs associated with achieving reductions. National baseline emissions of these gases are matched to EMF forecasts. Regional shares of EMF's national emissions for the United States are based on regional output and consumption from the IMPLAN and EIA data.

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