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Carbon Emission Offsets and Criteria Pollutants:

A California Assessment

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Executive Summary

This report provides an economy-wide assessment of how the use of offsets within a California cap-and-trade system may affect criteria pollutants. We used the Berkeley Energy and Resources (BEAR) macro-economic model to simulate Scoping Plan implementation and consider five offsets scenarios and their impact on criteria pollutants.

This is the first economy-wide assessment of how the Global Warming Solutions Act will affect criteria pollutants in California. Assuming that AB32 is implemented according to the climate action measures recommended in the proposed Scoping Plan and offsets are not used, most criteria emissions in the state will be reduced. Even though the policies within the scoping plan are targeted at reducing global warming emissions, this suite of policies simultaneously reduce reactive and toxic co-pollutants like methane,,benzene, carbon monoxide, smog-forming nitrogen oxides (NOx.

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However, if AB32 implementation includes the use of offsets from out of state, these criteria pollutant reductions are decreased and in at least one case reversed. In other words, offsets can lead to increases in criteria pollutants. Thus a policy (offsets) that may be globally CO2-neutral will sustain or even intensify local pollution in California.

If offsets are limited to emission reduction projects occurring within the state, mitigation of Total Organic Gas toxins can be further reduced as, for example, global warming emission reduction efforts are shifted to the methane-intensive agriculture and landfill sectors, but nitrogen oxide (NOx) emissions will increase against baseline emissions because AB32 policies expand demand for transport services.

The Western Climate Initiative and the AB 32 Scoping Plan propose that in California, out-of-state offsets be allowed to substitute for up to 49% of the total global warming emission reductions below 2012 cap level under the regional cap-and-trade program. This could mean that more than half of the emission reductions expected to be achieved in California by the cap and trade program could come from offsets. The results of this study show that if out-of-state offsets are permitted at a 50% or higher level, AB32 mitigation of criteria pollutants will be seriously undermined, and in some cases completely reversed.

For instance, while AB 32 implementation without offsets reduces Carbon Monoxide by more than 1,917 tons per year, allowing 50% of the cap and trade reductions to come from out-of-state offsets actually increases CO by more than 2,500 tons per year, wiping out the gains from AB 32 and intensifying smog-forming pollution in California. Similarly, fine particle pollution caused by combustion of fossil fuels (PM 2.5) is reduced by more than 63 tons per year if AB 32 is implemented with in-state offsets. When 50% of the cap-and-trade reductions are allowed to be achieved through out-of-state offsets, PM 2.5 increases by over 200 tons per year.

If out-of-state offsets are allowed to substitute for 100% of the California emission reductions expected from the cap-and-trade program, CO and PM 2.5 emissions are expected to rise by more than 5,000 tons and 300 tons per year respectively above the AB 32 baseline.

Out of state offsets substitute reductions elsewhere for in-state reductions, effectively exporting the in-state benefits. These include co-pollution effects accompanying offset GHG emissions, as well as more complex collateral effects of mitigation shifting. Generally speaking, however, offsets repress incentives to invest in mitigation technologies in California.

From an environmental perspective, offsets forsake the opportunity to reduce local pollution, which often is toxic and represents substantive local public health risk and environmental damage. The costs of such effects and, just as important, the benefits of local mitigation, are not usually considered in the global efficiency argument. They need to be estimated and included, however, if local stakeholders are to fairly compare offsets with in-state global warming pollution reductions. Outsourcing climate action through offsets ultimately outsources innovation and its rewards.

The full implications for the state of relying on offsets to meet global warming emission reduction goals are only partially understood. Some industry stakeholders strenuously advocate offsets because they may reduce short-term adjustment costs. To achieve a balanced appraisal of this approach, more evidence is needed. At this critical moment of policy debate, we all need to better understand the benefits and costs of offsets.

1 Introduction

California's response to rising Greenhouse Gas (GHG) emissions has drawn the world's eighth largest economy into an unprecedented policy dialogue that will influence energy and environmental decisions around the world. Within the state, it is widely acknowledged that GHG policies already implemented and under consideration will have far reaching economic consequences. State institutions have expressed an urgent interest in strengthening research capacity in this area.

In response to this, research economists are developing assessment tools to support more effective policy design, implementation, and assessment. One of the most advanced examples of this policy research capacity is the Berkeley Energy and

Resource (BEAR) model. BEAR is a detailed and dynamic economic simulation model that traces the complex linkage effects across the California economy as these arise from changing policies and external conditions. BEAR has already been used to produce estimates for the California Environmental Protection Agency, and the same agency now wants to extend the scope and depth of these findings. This paper reports on efforts to build out BEAR's capacity and address a central issue in the state's climate policy formulation: the implications of California GHG policies for criteria pollutants. These pollutants are of considerable relevance to local public health and other state environmental issues, yet their linkage to GHG policies and emissions are only partially understood. This research will advance BEAR's ability to analyze the criteria pollutant emission effects due to policy, and will apply this new capability to the question of how offset policy design could affect the accumulation of clean air benefits in California.

The last round of BEAR analysis was broadly in accord with the state's findings and buttressed the public interest in legislative discussion of Assembly Bill 32. In the next phase of climate action dialogue, more specific policies and effects will be subjected to intensive public and private scrutiny. Criteria pollutants have received less attention because of larger geographic and institutional issues in the climate debate, but their health and habitat significance will draw them more deeply into the debate as the state's implementation policies emerge. For this reason, the basis of evidence for constructive policy dialogue on this issue needs to be strengthened.

California's path-breaking GHG initiatives, as enunciated in the Global Warming Solutions Act, will be implemented with a combination of regulatory and market-oriented GHG mitigation strategies. In every case, policy objectives focus on cost-effective reductions in GHG emissions, without explicit standards for mitigation or measurement of emissions of other types of pollution. Because several categories of criteria pollutants are collateral to GHG production, these emissions will change also, but in complex ways. Also, some criteria pollution levels will be affected indirectly by GHG policies, as the latter induce structural change in production and consumption patterns. Thus GHG mitigation measures could either decrease or increase net criteria pollution, and the level itself is a complex empirical question.

To elucidate such economy-wide linkages between GHG policy and criteria pollution, the BEAR model was used for ex ante assessment of a range of climate policies, evaluating their individual and combined contributions to criteria pollution levels by type of economic activity. That is to say that the anticipated criteria pollutant reductions were estimated for individual policies and cumulatively under the latest policy package being contemplated by CARB, the implementing agency for AB32.

2 Offsets and Climate Policy in Context

As the world awakens to the reality of climate change, policy makers are scrambling to reconcile the need to reduce global warming pollution with traditional economic priorities such as growth, employment, and technological progress. Fortunately, a growing body of research suggests a way forward, though the challenges are enormous: transitioning to a low-carbon future without having to sacrifice living standards will require path breaking commitments to innovation. The opportunities this presents are just as significant as the challenges, and the rewards may rival those of history's most robust industrial and technological booms.

Rising global warming pollution has drawn California, the world's eighth largest economy, into an unprecedented policy dialogue that will influence energy and environmental decisions around the world. Among many other climate action initiatives, pollution offsets are being intensively discussed—particularly in the context of market-based incentive schemes like carbon trading—yet their full implications for the state are only partially understood. Some industry stakeholders strenuously advocate offsets because they can reduce short-term adjustment costs. To achieve a balanced appraisal of this approach, outsourcing climate action, more evidence is needed. At this critical moment of policy debate, we all need to better understand the benefits and costs of offsets.

Short Term Challenges, Long Term Opportunities

Because the dispersion of global warming pollutants is a worldwide phenomenon, there is in principle no reason not to "recognize"—that is, account for—mitigation wherever it occurs. Indeed, many advocates of offsets argue that mitigation can be achieved at lower cost outside the geographic boundaries of the trading scheme (e.g., outside California) and that climate risk can thus be reduced more efficiently with offsets. For example, a U.S. company might invest in, sell, or give a more efficient power plant to a Chinese counterpart in exchange for some contractual arrangement specifying that the transaction results in lower global warming pollution than would otherwise have been emitted. These contracted reductions would then be credited to the U.S. investor. Although there are extra transactions expenses, such a deal could reduce global GWP at lower cost than that of inventing and adopting entirely new technology at home.

Countering this simple intuition are many uncertainties—including the challenges of measurement, verification, and "additionality" (defined below)—as well as environmental and economic objections. From an environmental perspective, offsets forsake the opportunity to reduce local pollution, which often is toxic and represents substantive local public health risk and environmental damage. The costs of such effects and, just as important, the benefits of local mitigation, are not usually considered in the global efficiency argument. They need to be estimated and included, however, if local stakeholders are to fairly compare offsets with in-state global warming pollution reductions.

Offsets also forsake the opportunity for innovation, and for higher-income technology-intensive economies like California this may be their most serious drawback. The primary drivers of the state's superior growth experience over recent decades have been education and innovation, which together have made the state a knowledge-intensive leader in the global economy. First in information and communication technology (ICT), then in biotech, California's R&D supply chain has delivered solutions for the most dynamic and profitable sectors of modern times. And now the Next Big Thing has arrived, as is apparent from the venture community's rapid initiatives to capture the opportunities it presents.

New Markets will Belong to Innovators

That Next Big Thing is efficient and clean energy use; today's innovators in this field will be tomorrow's new technology barons.[2] Because energy consumption accounts for over 80 percent of CO_2 emissions, energy efficiency is a cornerstone of climate action. By revenue, energy is also the world's largest industry. Because this product so

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[2] Clean and green technologies are the most rapidly growing segment of new-venture investment, totaling several billion dollars annually in California alone.

pervades the modern economy, efficiency can do for energy what ICT did for management and logistics—deliver innovation that revolutionizes traditional practices around the world. Such innovation will save money in the production of every single modern good and service; and in an era of escalating energy prices, demand for efficiency would grow robustly over the coming decades even *without* climate action. These considerations, together with the additional demand induced by local environmental regulation, will create an enormous global market in new energy-use technologies that range from compact fluorescent light bulbs to hybrid vehicles.

These markets will be dominated by innovators, not those who defer innovation. While it is a laudable goal to reduce pollution in poor countries, doing so with today's technology merely substitutes short-term solutions elsewhere for long-term solutions and opportunities both at home and in rapidly emerging global technology markets. For example, even though the U.S. electric power systems are more efficient than those of many other countries, they remain far less efficient than they needs to be in order to meet our long-term needs for decarbonization. Meanwhile, the so-called "additionality" problem is a serious conundrum for offset advocates. Simply put, how do we know that an investment we make in lower pollution elsewhere would not have been made anyway—especially in dynamic emerging markets, where spontaneous rates of innovation and technology adoption are very high? Such an investment would not only be a false economy but also would imply significant opportunity costs. China, for example, is facing some the world's fastest-growing energy prices, as domestic fuel subsidies have become unsustainable and the country has moved, in a single decade, from being a small net exporter of oil to the world's second-largest importer. These price pressures will do much more to stimulate long-term energy efficiency than a short-term opportunity to export pollution rights. Consider that China, which was once the ultimate labor-intensive economy, is today the fastest-growing market for industrial robotics. Why? Even the most expensive technologies become profitable in the face of rising wages and the desire for higher product quality. In much the same way, rising energy prices and a rapidly increasing public desire for environmental quality will drive emerging markets toward pollution mitigation.

Other challenges related to offsets arise from unwelcome secondary effects that are socioeconomic in nature. For example, if we pay for environmental mitigation in fast-growing economies through offsets, what incentive do they have to establish and maintain their own standards? If these countries have a given level of pollution tolerance, would we not just be subsidizing more energy use, increasing resource scarcity? What happens when offsets arouse conflict between home and overseas regulatory regimes or complicate salient social issues (such as labor standards, biofuel-food tradeoffs, or biodiversity)? Clearly, offsets can lead to a host of new and difficult policy challenges.

Offsets can also dispel the momentum of climate action into profit making by middlemen marketing uncertain projects and financial instruments. By putting a price on carbon, mechanisms like cap and trade share the burden of adjustment, using markets to identify real efficiency and reward innovation. Creating a market for surrogate pollution reduction invites intermediaries to package emerging market technology adoption and sell it to more affluent bidders. Like the current mortgage securitization mess, contracting for far-away emission cuts creates uncertain agency relationships that increase transactions costs and risk. These schemes create real profit for matchmakers, but information and incentive problems multiply as the principals become farther and farther removed from each another. Verifiability, enforceability, and sustainability of such contracts all become more tenuous across space and time, and the short-term cost advantage and efficacy of offsets decline accordingly.

Finally, we need to recognize that offsets forsake opportunities to reduce long-term energy costs by leaving us vulnerable to ever-rising energy prices. Rapidly emerging economies might be happy to accept our technology while we defer innovation, but they will not pay our energy bills. As the costs of electricity, gasoline, and all the goods that use them continue to escalate, we pay more for every day we drag our feet on improving energy efficiency at home.

Outsourcing climate action through offsets ultimately outsources innovation and its rewards. Energy technology should take its rightful place among California’s knowledge-intensive industries, establishing new global standards at home for climate security and sustained prosperity. California should say no to offsets and accept the challenge to innovate.

3 Scenario Description and Results

To elucidate the relationship between the state's primary climate policy initiative and criteria pollutants, we used the BEAR model (described in Annex 1) to simulate the economywide effects of AB32, taking account of endogenous changes in eight criteria pollutant categories: TOG, ROG, CO, NOX, SOX, PM, PM10, and PM25 (also defined in Annex 1). Criteria emissions are very unequally distributed across economic activities and around the state, and they are only partially correlated with CO_2 and CO_2e emissions. For these reasons, it is difficult a priori to predict how policies targeting the latter will affect criteria emissions. For example, although carbon fuel consumption (e.g. vehicles and electric power) is associated with both CO_2 and NOx, policies targeting the former may not induce technological changes that mitigate both pollution categories. As we shall see below, the interaction between GHG policies like AB32 and criteria emissions is ultimately an empirical question. Intuition may suggest the direction of certain relationships, but the magnitudes and their ultimate significance must be estimated.

For these reasons, we use the BEAR model to simulate AB32 policies, considering a few generic variants with respect to offset policy. These scenarios are summarized in Table 3.1, including a baseline designed in accordance with the policies recommended for implementation of AB32 by the Proposed Scoping Plan (October 15, 2008). To this basic climate action package we add five alternative offset programs in rotation. The first is an in-state scheme, mainly recognizing non- CO_2 sources.[3] When external offsets are considered (S2-5), statewide offsets are excluded. Combining the two approaches would lead to results intermediate between those reported here. This is then extended to recognize offsets based on emission reduction efforts outside of the state, first nationally and then internationally. We consider allowing 50% of cap-and trade abatement over expected business as usual to be met by offsets, either from a national or international market, using offset prices from independent estimates.[4] Finally, we evaluate a 100% out-of-state offset program, sourced from either the national or international markets..

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[3] As currently framed, the recommended Scoping Plan policies intend for the scope of cap-and-trade to cover both stationary and mobile CO2 sources.

[4] See EPA (2008).

It is very difficult to predict what future offset prices will be – these will depend on future emission reduction commitments and the global supply of reductions. To capture this uncertainty, we sought to model a range of offset prices. We suppose that offsets from the US but outside the state of California, what we are calling "national offsets" would be available at $29/ton of CO2e by (e.g.) 2020, the lower price predicted for compliance under the EPA analysis of Lieberman-Warner.[5] The rationale is that the modeling is supportive $29/ton represents the marginal cost of a reduction in the US. The international offset price is $12/ton in 2020, reflecting the US EPA's forecast. For the purpose of this analysis, the important thing is not the level of certainty attributable to these prices, but to explore low and high out-of-state offset prices to understand the sensitivity of in-state air quality improvements to external offset prices.

Table 3.1: AB32 and Offset Scenarios

	Description
S0	AB32 Implementation according to the Scoping Plan
S1	C&T, Statewide Offsets
S2	C&T, 50% High Price (National estimate) Offsets
S3	C&T, 50% Low Price (International estimate) Offsets
S4	C&T, 100% High Price (National estimate) Offsets
S5	C&T, 100% Low Price (International estimate) Offsets

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[5] In fact, we are using a series of annual offset prices estimated by EPA.

Table 3.2: Cap and Trade Coverage Groups

Sectors Covered by the Cap in Proposed Scoping Plan

Primary Emitters

A04DistElc	Electricity Suppliers
A17OilRef	Oil and Gas Refineries
A20Cement	Cement
A34GndTrns	Ground Transport Services
A35WatTrns	Water Transport Services
A36TrkTrns	Truck Transport Services
A37PubTrns	Pubic Transport Services

Second-tier Emitters

A04Forest	Forestry, Fishery, Mining, Quarrying
A05OilGas	Oil and Gas Extraction
A06OthPrim	Other Primary Activities
A08DistGas	Natural Gas Distribution
A09DistOth	Water, Sewage, Steam
A10ConRes	Residential Construction
A11ConNRes	Non-Residential Construction
A12Constr	Construction of Transport Infrastructure
A13FoodPrc	Food Processing
A14TxtAprl	Textiles and Apparel
A15WoodPlp	Wood, Pulp, and Paper
A16PapPrnt	Printing and Publishing
A18Chemicl	Chemicals
A19Pharma	Pharmaceuticals
A21Metal	Metal Manufacture and Fabrication
A22Aluminm	Aluminium Production
A23Machnry	General Machinery
A24AirCon	Air Conditioner, Refridgerator, Manfacturing
A25SemiCon	Semiconductors
A26ElecApp	Electrical Appliances
A27Autos	Automobiles and Light Trucks
A28OthVeh	Other Vehicle Manufacturing
A29AeroMfg	Aeroplane and Aerospace Manufacturing
A30OthInd	Other Industry
A31WhlTrad	Wholesale Trade
A32RetVeh	Retail Vehicle Sales and Service
A33AirTrns	Air Transport Services
A38RetAppl	Retail Appliances
A39RetGen	General Retail Services
A40InfCom	Information and Communication Services
A41FinServ	Financial Services
A42OthProf	Other Professional Services
A43BusServ	Business Services
A46Educatn	Educational Services
A47Medicin	Medical Services
A48Recratn	Recreation and Cultural Activity
A49HotRest	Hotel and Restaurant Services
A50OthPrSv	Other Private Services

Sectors Covered in State-Based Offset Scenario (S1): Non-CO2 Emissions

A01Agric	Agriculture
A02Cattle	Cattle Production
A03Dairy	Dairy Production
A44WstServ	Waste Services
A45LandFill	Landfill

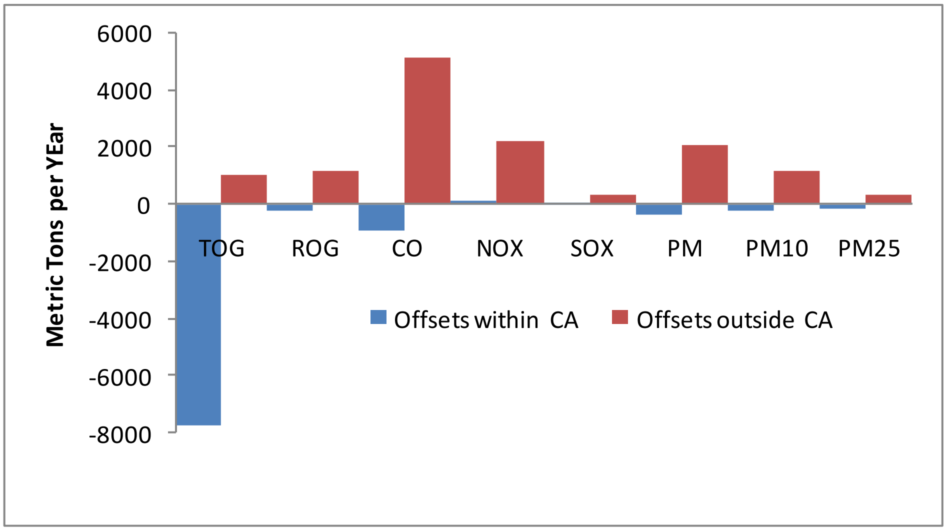
The basic scenario results are presented in Table 3.3. When interpreting them, it should be emphasized that criteria pollutants will be falling over the period under consideration because of a variety of other regulatory measures. Unfortunately, however, these results indicate that the use of offsets within a California cap-and-trade system will have a mixed effect on those gains, in some cases reducing criteria pollution further, but actually increasing it in most of the cases considered. Given the importance of adverse public health impacts from these emissions, this unintended consequence deserves further reflection.

Table 3.3: Scenario Results
(change in emissions, 2020)

	Tons per Year	TOG	ROG	CO	NOX	SOX	PM	PM10	PM25
S0	AB32 (Baseline)	-32,137	-15,601	-1,917	354	-5,124	9,533	4,661	64
S1	In-State Offsets	-7,821	-211	-895	93	51	-338	-211	-137
S2	50% Hi Offsets	-2,421	634	2,891	1,439	242	1,208	661	159
S3	50% Low Offsets	-2,704	559	2,598	1,325	223	1,065	583	136
S4	100% Hi Offsets	1,552	1,284	5,733	2,460	393	2,383	1,323	381
S5	100% Low Offsets	1,042	1,143	5,182	2,245	358	2,111	1,174	338

Notes: *S0 expressed as 2020 difference from Baseline.*
S1-S5 results expressed as differences from S0.

Figure 3.1: Criteria Emissions Resulting from Offsets
(change from AB32 trend in 2020)



A number of significant policy conclusions are suggested by this analysis.

1. Even though it is targeted at CO_2 and CO_2e (CO_2 equivalent), AB32 (Scenario 0) achieves significant mitigation in several criteria pollution categories.[6] This result is new to the AB32 policy dialogue, and strengthens the case for the state's approach to climate action.
2. In-state offsets reduce most types of criteria pollution (vis-à-vis AB32), but out-of-state offsets increase pollution in all criteria categories.The differences on all cases are significant. In particular, out-of-state offsets (see figure 3.1):
    a. reverse mitigation that would result from in-state offsets in six criteria categories
    b. raise NOx and SOx many times more than in-state offsets
    c. increase CO and PM2.5 substantially, reversing gains from AB32
3. The source and (percent) quantity of available offsets is apparently more important than the price in these scenarios.

Thus the impact of in-state offsets is somewhat mixed, but does facilitate a variety of environmental objectives. Out-of-state offsets, by contrast, are environmentally damaging in all criteria categories, and will actually make the state worse off in at least one category (carbon monoxide) despite improvements from AB32.

In the baseline, emissions in some criteria categories are on downward intensity trends because of separate standards and other measures. These include significant NOx reductions for trucking, maritime, and rail transport, as well as higher PM standards already committed for future construction and transport sector activity. In addition to these, the semiconductor sector has adopted voluntary HFC mitigation measures and a variety of building standards are already under way with respect to home heating, window glazing, and PV adoption. All these measures are outside of AB32, and help to flatten but not reverse baseline emissions growth.

Although these results make it clear that offsets can intensify non-CO2 pollutants, it is important to acknowledge their economic efficiency effects. Table 3.4 lists

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[6] An important exception are particulates of all three kinds, which rise because AB32 expands demand for transport services in response to building standards and other growth oriented policy components.

macroeconomic impacts of the scenarios in terms of real Gross State Product (GSP), Consumption, and employment. Here we see quite modest differences between the scenarios, although offsets do appear to confer efficiency gains, and more so with more generous allocation or lower priced offsets. Both these results are consistent with intuition, but the differences are quite small (less than a tenth of one percent per year in most cases). These amounts may be of much greater significance to individual sectors, but such gains must be balanced against the costs of higher criteria pollution levels.

Table 3.4: Macroeconomic Results
(percent change in 2020)

		Real GSP	Real Cons	Emp
S0	**AB32 (Baseline)**	**.33**	**.28**	**.40**
S1	**In-State Offsets**	**.11**	**.13**	**.15**
S2	**50% Hi Offsets**	**.12**	**.13**	**.16**
S3	**50% Low Offsets**	**.18**	**.22**	**.20**
S4	**100% Hi Offsets**	**.18**	**.22**	**.21**
S5	**100% Low Offsets**	**.23**	**.30**	**.24**

Notes: *S0 expressed as 2020 difference from Baseline.*
S1-S5 results expressed as differences from S0.

Examining the in-state offset results in more detail (Scenario 1), we see that they make agriculture and landfill activities eligible for indirect cap-and-trade coverage, and both of these sectors are relatively intensive in Total Organic Gas (TOG) emissions—namely, methane, which can be sequestered and converted to local power. When they can sell offsets, we get the same CO_2e reduction, but the average TOG-intensity of GSP can decline substantially. Indeed, most criteria pollutants are reduced by use of in-state offsets. Indeed, bringing agriculture and landfill under the cap actually reverses increases in PM2.5 from AB32. The only other criteria pollutants that increased were NOx and SOx, both of whose AB32 mitigation is very slightly reduced. It should also be borne in mind that including agriculture in mitigation schemes has collateral benefits, including soil and water conservation, reduced agro-chemical use, and a variety of other environmental services.

The situation is dramatically worsened when out of state offsets are available. By outsourcing emission reductions, offsets deprive California of in-state mitigation potential, both for CO_2 and criteria pollution. We consider four out-of-date offset scenarios, and in every one every criteria emission level is above the AB32 baseline.

These results clearly demonstrate that outsourcing climate action may be GHG neutral on a global basis, but California will be forced to deal with higher levels of criteria pollutants when CO_2 mitigation credits are purchased here in exchange for the right to continue polluting. Because criteria pollutants can have significant local health and environmental toxicity effects, the GHG neutrality of carbon offsets should not be seen as environmentally neutral. Offsets also confer efficiency gains since they will only be used if they provide less expensive GHG mitigation, but the macroeconomic gains we see from this are very small in percentage terms, and are difficult to compare to the inclusive costs of higher criteria pollution. To make real empirical comparisons would require integrating dose response, morbidity and mortality, and actuarial cost data with the model to assess net social gains from in or out of state mitigation strategies.

4 Decomposition Analysis of Offset-induced Emissions

Simulation results of the last section indicate that offset policies may have unintended adverse consequences if they stimulate other types of pollution. The reasons for this are complex, but it is important to elucidate such linkages because:

- Offsets are usually justified on efficiency grounds, but these calculations do not include the negative externality of collateral criteria emissions (what has been called, in the context of the AB 32 implementation debate, a concern about lost co-benefits).

- Anticipating collateral criteria and toxic air pollution effects makes it possible to design complementary measures that counter them.

- Such complementary policies can be integrated with CO_2 reduction measures, and their (public) costs compared to the (private) savings expected from offsets. If the latter exceed the former, offsets could be taxed to pay to prevent collateral emissions. This approach would essentially shift induced innovation from CO_2 emission technology to criteria emission technology.

In this section, we propose a pollution accounting method that can support deeper insights into the sources of emissions and the mechanisms of their interaction. Moreover, this approach makes more clear the important relationship between emissions and economic growth, and will support policies that can more effectively reconcile environmental and growth objectives.

Emissions that arise from economic activity are driven by three distinct forces, aggregate economic growth, changing economic structure, and whatever technology is producing the emissions in a given process of production or consumption. Because each of these factors is structurally and behaviorally different, a real understanding of economy-environment interactions, and polices dealing with them, requires a clear understanding of each. We now explain formal method for decomposing these three drivers of emissions, and then illustrate its use with an analysis of how AB32 affects criteria pollutant.

Consider a simplified case where there are only two sectors in the economy, producing individual goods A and B, as well as a common pollutant whose emissions E arise from linear emission technologies, $E_A = \alpha A$ and $E_B = \beta B$. This can be thought of as generating economywide emissions from total output Y=A+B as follows

$$E = \varepsilon Y = \varepsilon_A A + \varepsilon_B B$$

where

$$\varepsilon = \frac{E}{Y} = \varepsilon_A w_A + \varepsilon_B w_B$$

Thus economywide emissions intensity (ε) is the average of sector emissions intensities, weighted by sector shares w_A, w_B of total output (Y, GDP, GSP, etc.). From this simple framework, we can express the change in total pollution ΔE as the sum of the three components already mentioned. In particular, consider the expression

$$\begin{aligned}\Delta E &= \Delta(\varepsilon Y) = \varepsilon \Delta Y + \Delta \varepsilon Y \\ &= \varepsilon \Delta Y + \left[\Delta \varepsilon_A w_A + \varepsilon_A \Delta w_A + \Delta \varepsilon_B w_B + \varepsilon_B \Delta w_B\right] Y \\ &= \varepsilon \Delta Y + \left[\varepsilon_A w_A \hat{w}_A + \varepsilon_B w_B \hat{w}_B\right] Y + \left[\varepsilon_A w_A \hat{\varepsilon}_A + \varepsilon_B w_B \hat{\varepsilon}_B\right] Y\end{aligned}$$

where a caret (^) denotes percent change, yielding

$$\Delta E = E\hat{Y} + \left[E e_A \hat{w}_A + E e_B \hat{w}_B\right] + \left[E e_A \hat{\varepsilon}_B + E e_B \hat{\varepsilon}_B\right]$$

where e_A and e_B denote sector shares of emissions, E_A/E and E_B/E, respectively, and finally we have

$$\hat{E} \quad = \quad \hat{Y} \quad + \quad \left[e_A \hat{w}_A + e_B \hat{w}_B\right] \quad + \quad \left[e_A \hat{\varepsilon}_A + e_B \hat{\varepsilon}_B\right]$$

Emissions Growth = Aggregate Growth + Composition + Technology

Thus the percentage change in total emissions consists of three components, as indicated above. Aggregate growth represents how aggregate expansion would increase emissions, assuming the sector composition and technology remained constant. For most pollution categories, this of course has a positive sign. The second term is more ambiguous, representing the composite effects of sectoral pollution intensity (base emission shares e_A and e_B) and structural change (percent change of market shares w_A and w_B). Thus the sign of the composition effect depends on the inequality

$$e_A \hat{w}_A <> e_B \hat{w}_B$$

If economic growth favors one sector over the other, the former will contribute more to the average change in economywide emissions. Assume sector A is more pollution intensive than B (i.e. $\varepsilon_A > \varepsilon_B$). In this case, A-biased growth will increase A's market share w_A, but reduce that of B (w_B). In this case, the composition term will have a positive sign and the composition effect increases aggregate emissions. If, on the other hand, growth is B-biased, the net composition effect can be negative (if the change in market share offsets the difference in emission intensity between A and B). As the previous equation suggests, the interaction of all four variables will determine the ultimate sign of the composition effect.[7]

The third and final component takes account of opportunities for technical change, the most popular source of mitigation when trying to reconcile growth and environmental

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[7] As a practical example of the composition effect, evidence suggests that NAFTA had a greening effect on Mexico because the economic structure shifted away from relatively non-competitive heavy industry and toward less pollution-intensive light manufacturing.

objectives. For example, clean and green innovation are intended to reduce sectoral pollution intensities, i.e.

$$\hat{\varepsilon}_{\mathrm{A}} < 0, \hat{\varepsilon}_{B} < 0$$

with the ultimate result depending on the magnitudes of these reductions and the emissions scale of their activities (e_A and e_B).

To see the implications of the emissions decomposition for our analysis of offsets, we have produced estimates of all the above components for California and the sectoring scheme of the BEAR model. To do this, we first generalized the emissions decomposition for n=50 sectors as follows

Emissions Growth	=	Aggregate Growth	+	Composition	+	Technology

$$\hat{E} = \hat{Y} + \sum_{i=1}^{n} e_i \hat{w}_i + \sum_{i=1}^{n} e_i \hat{\varepsilon}_i$$

To identify component effects, we need detailed information about the state's source inventory of criteria pollutants and production structure. These are both summarized in Tables 3.1 and 3.2 below, which show sectoral total emissions and emission shares for eight leading criteria pollutants and shares of real output, detailed according to the 50 sectors of the BEAR model. Criteria pollutant definitions and information regarding the sources and development of this data are discussed in greater detail in the Annex to this report.

Table 4.1: Sectoral Inventory of California Criteria Emissions (Tons per day, 2006)

	TOG	ROG	COT	NOX	SOX	PM	PM10	PM25
A01Agric	1266.44	125.64	115.28	110.48	1.89	292.42	147.63	42.02
A02Cattle	52.90	5.25	4.81	4.61	0.08	12.21	6.17	1.76
A03Dairy	138.86	13.78	12.64	12.11	0.21	32.06	16.19	4.61
A04Forest	34.12	3.98	12.90	3.13	0.05	8.82	5.02	2.19
A05OilGas	129.04	77.66	3.78	5.38	0.53	0.30	0.29	0.29
A06OthPrim	6.03	4.89	41.40	53.50	19.94	95.66	52.64	20.33
A07DistElec	48.50	8.41	101.18	67.93	5.15	18.93	15.07	13.46
A08DistGas	26.03	3.09	16.57	17.78	1.70	1.59	1.53	1.58
A09DistOth	0.13	0.06	0.03	0.03	0.01	0.00	0.00	0.00
A10ConRes	0.00	0.00	0.00	0.00	0.00	96.08	47.01	4.70
A11ConNRes	0.00	0.00	0.00	0.00	0.00	45.94	22.48	2.25
A12Constr	0.00	0.00	0.00	0.00	0.00	275.98	135.04	13.50
A13FoodPrc	17.66	15.86	36.44	28.74	2.56	20.35	12.15	6.55
A14TxtAprl	0.53	0.15	2.29	3.67	0.55	0.24	0.24	0.23
A15WoodPlp	2.01	1.36	2.82	4.64	0.63	7.92	5.23	3.45
A16PapPrnt	19.88	17.77	9.54	14.58	2.17	1.21	1.17	1.13
A17OilRef	311.30	94.03	25.87	30.06	57.92	7.43	5.84	5.41
A18Chemicl	590.75	526.70	7.03	10.94	5.27	5.91	5.25	5.01
A19Pharma	0.53	0.15	2.29	3.68	0.55	0.24	0.24	0.23
A20Cement	3.15	2.14	5.55	16.10	3.62	13.99	9.60	6.69
A21Metal	1.56	0.71	5.59	8.02	1.07	1.71	1.34	1.06
A22Aluminm	0.28	0.13	1.00	1.44	0.19	0.31	0.24	0.19
A23Machnry	0.48	0.14	2.06	3.31	0.49	0.22	0.21	0.20
A24AirCon	0.06	0.02	0.27	0.43	0.06	0.03	0.03	0.03
A25SemiCon	3.55	1.31	12.83	20.62	3.08	1.38	1.33	1.28
A26ElecApp	0.32	0.12	1.17	1.88	0.28	0.13	0.12	0.12
A27Autos	0.24	0.07	1.03	1.65	0.25	0.11	0.11	0.10
A28OthVeh	0.34	0.10	1.46	2.35	0.35	0.15	0.15	0.15
A29AeroMfg	0.52	0.15	2.22	3.57	0.53	0.24	0.23	0.22
A30OthInd	115.01	42.72	12.04	12.34	2.01	14.63	10.20	6.39
A31WhlTrad	1.56	0.37	2.42	3.84	0.21	0.37	0.38	0.38
A32RetVeh	0.63	0.15	0.98	1.56	0.09	0.15	0.16	0.16
A33AirTrns	38.71	34.19	265.52	53.36	3.56	9.00	8.76	8.66
A34GndTrns	21.10	17.47	88.02	205.97	8.40	725.51	380.09	55.87
A35WatTrns	19.36	15.65	46.55	329.81	153.61	26.36	25.47	24.66
A36TrkTrns	457.78	408.24	3232.80	1838.90	13.98	1594.18	870.22	181.35
A37PubTrns	0.02	0.00	0.02	0.04	0.00	0.00	0.00	0.00
A38RetAppl	0.15	0.04	0.24	0.38	0.02	0.04	0.04	0.04
A39RetGen	1.67	0.39	2.58	4.10	0.23	0.39	0.41	0.41
A40InfCom	0.84	0.20	1.30	2.07	0.11	0.20	0.21	0.21
A41FinServ	3.96	0.93	6.15	9.75	0.54	0.93	0.98	0.97
A42OthProf	2.74	0.64	4.24	6.73	0.37	0.64	0.67	0.67
A43BusServ	1.05	0.25	1.64	2.59	0.14	0.25	0.26	0.26
A44WstServ	195.43	76.96	1172.09	28.10	2.61	115.18	109.38	99.98
A45LandFill	1227.59	8.38	0.97	0.97	0.43	1.39	0.59	0.41
A46Educatn	0.24	0.06	0.38	0.60	0.03	0.06	0.06	0.06
A47Medicin	1.64	0.39	2.54	4.03	0.22	0.39	0.40	0.40
A48Recratn	0.26	0.06	0.40	0.63	0.03	0.06	0.06	0.06
A49HotRest	0.57	0.13	0.89	1.41	0.08	0.13	0.14	0.14
A50OthPrSv	0.61	0.14	0.95	1.51	0.08	0.14	0.15	0.15
HH	944.67	810.36	7184.04	618.36	8.32	201.69	184.87	159.15
Total	5690.79	2321.37	12454.83	3557.68	304.24	3633.25	2086.06	679.09

Table 4.2: Sectoral Shares of Criteria Emissions and Total Output (percent in baseline, 2006)

	TOG	ROG	COT	NOX	SOX	PM	PM10	PM25	Output
A01Agric	22.25	5.41	.93	3.11	.62	8.05	7.08	6.19	1.80
A02Cattle	.93	.23	.04	.13	.03	.34	.30	.26	.07
A03Dairy	2.44	.59	.10	.34	.07	.88	.78	.68	.20
A04Forest	.60	.17	.10	.09	.02	.24	.24	.32	.06
A05OilGas	2.27	3.35	.03	.15	.17	.01	.01	.04	.90
A06OthPrim	.11	.21	.33	1.50	6.55	2.63	2.52	2.99	.42
A07DistElec	.85	.36	.81	1.91	1.69	.52	.72	1.98	.53
A08DistGas	.46	.13	.13	.50	.56	.04	.07	.23	.42
A09DistOth	.00	.00	.00	.00	.00	.00	.00	.00	.06
A10ConRes	.00	.00	.00	.00	.00	2.64	2.25	.69	.44
A11ConNRes	.00	.00	.00	.00	.00	1.26	1.08	.33	.41
A12Constr	.00	.00	.00	.00	.00	7.60	6.47	1.99	1.76
A13FoodPrc	.31	.68	.29	.81	.84	.56	.58	.97	2.70
A14TxtAprl	.01	.01	.02	.10	.18	.01	.01	.03	.54
A15WoodPlp	.04	.06	.02	.13	.21	.22	.25	.51	.38
A16PapPrnt	.35	.77	.08	.41	.71	.03	.06	.17	1.66
A17OilRef	5.47	4.05	.21	.84	19.04	.20	.28	.80	1.13
A18Chemicl	10.38	22.69	.06	.31	1.73	.16	.25	.74	1.23
A19Pharma	.01	.01	.02	.10	.18	.01	.01	.03	1.04
A20Cement	.06	.09	.04	.45	1.19	.38	.46	.99	.26
A21Metal	.03	.03	.04	.23	.35	.05	.06	.16	1.11
A22Aluminm	.00	.01	.01	.04	.06	.01	.01	.03	.09
A23Machnry	.01	.01	.02	.09	.16	.01	.01	.03	.54
A24AirCon	.00	.00	.00	.01	.02	.00	.00	.00	.08
A25SemiCon	.06	.06	.10	.58	1.01	.04	.06	.19	3.81
A26ElecApp	.01	.01	.01	.05	.09	.00	.01	.02	.25
A27Autos	.00	.00	.01	.05	.08	.00	.01	.02	.32
A28OthVeh	.01	.00	.01	.07	.12	.00	.01	.02	.33
A29AeroMfg	.01	.01	.02	.10	.18	.01	.01	.03	.15
A30OthInd	2.02	1.84	.10	.35	.66	.40	.49	.94	1.04
A31WhlTrad	.03	.02	.02	.11	.07	.01	.02	.06	2.52
A32RetVeh	.01	.01	.01	.04	.03	.00	.01	.02	1.21
A33AirTrns	.68	1.47	2.13	1.50	1.17	.25	.42	1.28	.45
A34GndTrns	.37	.75	.71	5.79	2.76	19.97	18.22	8.23	.98
A35WatTrns	.34	.67	.37	9.27	50.49	.73	1.22	3.63	.23
A36TrkTrns	8.04	17.59	25.96	51.69	4.60	43.88	41.72	26.70	.55
A37PubTrns	.00	.00	.00	.00	.00	.00	.00	.00	.02
A38RetAppl	.00	.00	.00	.01	.01	.00	.00	.01	.30
A39RetGen	.03	.02	.02	.12	.07	.01	.02	.06	3.16
A40InfCom	.01	.01	.01	.06	.04	.01	.01	.03	4.17
A41FinServ	.07	.04	.05	.27	.18	.03	.05	.14	26.50
A42OthProf	.05	.03	.03	.19	.12	.02	.03	.10	4.77
A43BusServ	.02	.01	.01	.07	.05	.01	.01	.04	3.76
A44WstServ	3.43	3.32	9.41	.79	.86	3.17	5.24	14.72	.20
A45LandFill	21.57	.36	.01	.03	.14	.04	.03	.06	.05
A46Educatn	.00	.00	.00	.02	.01	.00	.00	.01	.73
A47Medicin	.03	.02	.02	.11	.07	.01	.02	.06	3.53
A48Recratn	.00	.00	.00	.02	.01	.00	.00	.01	1.07
A49HotRest	.01	.01	.01	.04	.03	.00	.01	.02	1.97
A50OthPrSv	.01	.01	.01	.04	.03	.00	.01	.02	1.70
HH	16.60	34.91	57.68	17.38	2.73	5.55	8.86	23.44	18.41
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

We assume now the emissions technologies are the same in the baseline, with or without offsets, i.e. the Technology term above does not change. In fact, offsets are likely to reduce innovation incentives, limiting efficiency improvements that might occur if permits to pollute are more expensive. We know from the simulation results that all pollution categories will share the aggregate Growth component of emissions, but this will vary between scenarios but not across pollutant in a given scenario.

In any case, the decomposition offers very revealing information about detailed adjustment responses to the policy scenarios. We give a few examples here, but tables 4.3-4.11 reward more careful examination for those interested in shifting patterns of sector emissions and how more targeted policies might improve aggregate outcomes. In each table below, we present the composition effect of individual sectors to total criteria emissions, followed at the bottom by the aggregate growth effect (Y). It should be noted that the aggregate growth effect is significant and positive, the perverse environmental cost of expanded economic activity. Composition effects can reinforce, reduce, or even reverse this, as we will see in the examples below.

Consider first Total Organic Gases (Table 4.3). Here, as mentioned in the discussion of aggregate results, we see significant mitigation with AB32, led by the petroleum fuels sectors. This is partially offset by co-pollutant increases in natural gas, construction, and transport, but the net effect is still significantly negative. In-state offsets actually improve the outcome in this category by bringing Agriculture and Landfill into the C&T system (at least indirectly). Both are highly TOG-intensive, and assignment of offset to them reduces statewide TOG significantly. The worst case, however, occurs with out-of-state offsets, which facilitate increased in-state TOG emissions in many sectors, undoing a substantial portion of mitigation from AB32. The story for ROG is analogous, as would be expected from an allied emission category, but in this case the in-state offset lead to a small increase in TOG because Agriculture and Landfill are less ROG-intensive than several C&T covered industrial processes.

In Carbon Monoxide, sector heterogeneity matters a great deal. There are very large reductions from the Oil and Gas sector, but these are almost completely offset by increases from Construction and Transport. CO emissions from Construction, it should be noted, are also largely from transport services used in this sector. This AB32's potential for CO co-pollutant reduction falls short of its potential because of stimulus to transport services. The net result of AB32 is still estimated to reduce total CO, but in-state or (especially) out-of-state offsets would reverse this outcome. Because of their linkage in the petroleum product life cycle, the results for NOx largely parallel those for CO.

In the case of SOx, oil refining is the sector “hot spot” for the decomposition results (Table 3.8). Here we see substantial co-pollutant mitigation with AB32, but more SOx pollution in California when offsets are available from either in-state or out-of-state sources. Nearly every sector increases SOx emissions when offsets are incorporated in cap-and-trade.

Now consider the complex particulates group (Tables 4.9-4.11). In this context AB32 leads to mixed results. Both PM and PM10 increase across the state, although some sectors increase emissions and others reduce them. In the absence of offsets, increases outweigh mitigation and total emissions rise. The sector intensity of these two criteria pollutants is similar, so their compositional effects are likewise. Basically, PM and PM10 increases from transport and construction services offset AB32 co-pollutant mitigation elsewhere. For these two pollutants, offsets of any kind make matters worse, but the source of the offsets makes a big difference in the extent of this adverse affect. In-state offsets are marginal in this respect, increasing PM and PM10 by only 98 and 27 tons annually (respectively). When offsets come from outside California, however, PM increases over 33 times more and PM10 emissions increase over 70 times more. Obviously, complementary policy consideration would be warranted for these pollutants.

The final category, PM2.5, is reduced by AB32, and even more so by in-state offsets. Out-of-state offsets, however, increase PM2.5 emissions by more than the AB32 benefit, leading to net increase in this health threatening atmospheric pollutant.

Suggest adding discussion on NOx and suggest adding more discussion for key pollutants like NOx and PM 2.5.

Table 3.4: Aggregate and Sector Components of Induced TOG Emissions (Metric Tons, 2020)

Sector	No Offsets	In-state	Out-of-state	Difference
A01Agric	-2,272	-1,717	35	1,752
A02Cattle	-35	-75	5	80
A03Dairy	261	-532	-81	451
A04Forest	47	5	35	30
A05OilGas	-9,615	23	149	126
A06OthPrim	-15	2	9	7
A07DistElec	-112	55	272	218
A08DistGas	1,866	1	2	1
A09DistOth	0	0	0	0
A10ConRes	0	0	0	0
A11ConNRes	0	0	0	0
A12Constr	0	0	0	0
A13FoodPrc	-82	-6	-8	-2
A14TxtAprl	0	0	0	0
A15WoodPlp	3	0	1	1
A16PapPrnt	39	1	0	-1
A17OilRef	-29,702	38	411	373
A18Chemicl	-1,086	80	661	581
A19Pharma	1	0	0	0
A20Cement	-5	2	9	7
A21Metal	-1	0	2	2
A22Aluminm	-1	0	0	0
A23Machnry	1	0	0	0
A24AirCon	-1	0	1	1
A25SemiCon	29	0	2	1
A26ElecApp	0	0	0	0
A27Autos	2	0	0	0
A28OthVeh	1	0	0	0
A29AeroMfg	2	0	0	0
A30OthInd	79	11	30	19
A31WhlTrad	7	0	0	0
A32RetVeh	6	0	0	0
A33AirTrns	-4	8	39	31
A34GndTrns	514	5	26	21
A35WatTrns	21	4	22	18
A36TrkTrns	-94	58	552	494
A37PubTrns	0	0	0	0
A38RetAppl	1	0	0	0
A39RetGen	4	0	-1	-1
A40InfCom	6	0	0	0
A41FinServ	-5	0	-2	-2
A42OthProf	11	0	0	0
A43BusServ	2	0	0	0
A44WstServ	-230	-217	26	243
A45LandFill	8,216	-5,567	-1,153	4,414
A46Educatn	4	0	0	0
A47Medicin	-9	0	-1	-1
A48Recratn	3	0	0	0
A49HotRest	2	0	0	0
A50OthPrSv	4	0	0	0
Y	25	25	32	7
Total	-32,137	-7,821	1,042	8,863

Table 3.5: Aggregate and Sector Components of Induced ROG Emissions (Metric Tons, 2020)

Sector	No Offsets	In-state	Out-of-state	Difference
A01Agric	-225	-170	4	174
A02Cattle	-3	-7	0	8
A03Dairy	26	-53	-8	45
A04Forest	5	1	4	3
A05OilGas	-5,787	14	90	76
A06OthPrim	-12	1	7	6
A07DistElec	-19	9	47	38
A08DistGas	221	0	0	0
A09DistOth	0	0	0	0
A10ConRes	0	0	0	0
A11ConNRes	0	0	0	0
A12Constr	0	0	0	0
A13FoodPrc	-74	-6	-7	-2
A14TxtAprl	0	0	0	0
A15WoodPlp	2	0	1	1
A16PapPrnt	35	1	0	0
A17OilRef	-8,972	11	124	113
A18Chemicl	-969	71	590	518
A19Pharma	0	0	0	0
A20Cement	-3	1	6	5
A21Metal	-1	0	1	1
A22Aluminm	0	0	0	0
A23Machnry	0	0	0	0
A24AirCon	0	0	0	0
A25SemiCon	11	0	1	0
A26ElecApp	0	0	0	0
A27Autos	1	0	0	0
A28OthVeh	0	0	0	0
A29AeroMfg	1	0	0	0
A30OthInd	29	4	11	7
A31WhlTrad	2	0	0	0
A32RetVeh	1	0	0	0
A33AirTrns	-3	7	35	27
A34GndTrns	181	2	9	8
A35WatTrns	17	3	18	14
A36TrkTrns	-36	22	209	188
A37PubTrns	0	0	0	0
A38RetAppl	0	0	0	0
A39RetGen	1	0	0	0
A40InfCom	1	0	0	0
A41FinServ	-1	0	0	0
A42OthProf	3	0	0	0
A43BusServ	0	0	0	0
A44WstServ	-90	-86	10	96
A45LandFill	56	-38	-8	30
A46Educatn	1	0	0	0
A47Medicin	-2	0	0	0
A48Recratn	1	0	0	0
A49HotRest	0	0	0	0
A50OthPrSv	1	0	0	0
Y	9	9	12	2
Total	-15,601	-211	1,143	1,354

Table 3.6: Aggregate and Sector Components of Induced CO Emissions (Metric Tons, 2020)

Sector	No Offsets	In-state	Out-of-state	Difference
A01Agric	-207	-156	3	159
A02Cattle	-3	-7	0	7
A03Dairy	24	-48	-7	41
A04Forest	18	2	13	11
A05OilGas	-282	1	4	4
A06OthPrim	-103	11	60	49
A07DistElec	-234	114	568	454
A08DistGas	1,187	1	1	0
A09DistOth	0	0	0	0
A10ConRes	0	0	0	0
A11ConNRes	0	0	0	0
A12Constr	0	0	0	0
A13FoodPrc	-170	-13	-17	-4
A14TxtAprl	0	0	0	0
A15WoodPlp	5	0	2	2
A16PapPrnt	19	0	0	0
A17OilRef	-2,468	3	34	31
A18Chemicl	-13	1	8	7
A19Pharma	4	0	0	0
A20Cement	-8	3	15	12
A21Metal	-4	1	7	6
A22Aluminm	-2	0	1	1
A23Machnry	2	0	1	0
A24AirCon	-3	1	3	2
A25SemiCon	103	1	6	5
A26ElecApp	-2	0	0	0
A27Autos	10	0	-1	-1
A28OthVeh	6	0	1	0
A29AeroMfg	8	0	2	1
A30OthInd	8	1	3	2
A31WhlTrad	10	0	0	0
A32RetVeh	9	0	0	0
A33AirTrns	-25	57	270	213
A34GndTrns	2,146	21	110	90
A35WatTrns	51	10	52	42
A36TrkTrns	-666	407	3,896	3,488
A37PubTrns	0	0	0	0
A38RetAppl	1	0	0	0
A39RetGen	7	0	-1	-1
A40InfCom	10	0	0	0
A41FinServ	-8	0	-3	-3
A42OthProf	17	0	0	0
A43BusServ	3	0	0	0
A44WstServ	-1,377	-1,304	154	1,457
A45LandFill	6	-4	-1	3
A46Educatn	6	0	0	0
A47Medicin	-14	0	-2	-2
A48Recratn	4	0	0	0
A49HotRest	3	0	0	0
A50OthPrSv	6	0	0	0
Y	55	55	70	14
Total	-1,917	-895	5,182	6,077

Table 3.7: Aggregate and Sector Components of Induced NOX Emissions (Metric Tons, 2020)

Sector	No Offsets	In-state	Out-of-state	Difference
A01Agric	-198	-150	3	153
A02Cattle	-3	-7	0	7
A03Dairy	23	-46	-7	39
A04Forest	4	0	3	3
A05OilGas	-401	1	6	5
A06OthPrim	-134	15	78	63
A07DistElec	-157	77	382	305
A08DistGas	1,274	1	1	1
A09DistOth	0	0	0	0
A10ConRes	0	0	0	0
A11ConNRes	0	0	0	0
A12Constr	0	0	0	0
A13FoodPrc	-134	-10	-14	-3
A14TxtAprl	-1	0	0	0
A15WoodPlp	8	1	3	3
A16PapPrnt	29	1	0	0
A17OilRef	-2,868	4	40	36
A18Chemicl	-20	1	12	11
A19Pharma	7	0	-1	-1
A20Cement	-24	9	44	36
A21Metal	-6	2	10	9
A22Aluminm	-3	0	2	2
A23Machnry	4	0	1	1
A24AirCon	-4	1	4	4
A25SemiCon	166	2	10	7
A26ElecApp	-3	0	0	-1
A27Autos	16	0	-2	-2
A28OthVeh	10	0	1	1
A29AeroMfg	13	1	3	2
A30OthInd	9	1	3	2
A31WhlTrad	16	0	0	0
A32RetVeh	14	0	0	0
A33AirTrns	-5	11	54	43
A34GndTrns	2,525	24	130	106
A35WatTrns	363	72	370	299
A36TrkTrns	-190	116	1,114	998
A37PubTrns	0	0	0	0
A38RetAppl	1	0	0	0
A39RetGen	11	0	-2	-2
A40InfCom	15	0	-1	-1
A41FinServ	-12	0	-4	-4
A42OthProf	27	0	0	0
A43BusServ	4	0	0	0
A44WstServ	-33	-31	4	35
A45LandFill	7	-4	-1	4
A46Educatn	10	0	0	0
A47Medicin	-23	0	-3	-3
A48Recratn	7	0	0	0
A49HotRest	5	0	0	0
A50OthPrSv	9	0	0	0
Y	11	11	14	3
Total	354	93	2,245	2,152

Table 3.8: Aggregate and Sector Components of Induced SOX Emissions (Metric Tons, 2020)

Sector	No Offsets	In-state	Out-of-state	Difference
A01Agric	-3	-3	0	3
A02Cattle	0	0	0	0
A03Dairy	0	-1	0	1
A04Forest	0	0	0	0
A05OilGas	-39	0	1	1
A06OthPrim	-50	5	29	24
A07DistElec	-12	6	29	23
A08DistGas	122	0	0	0
A09DistOth	0	0	0	0
A10ConRes	0	0	0	0
A11ConNRes	0	0	0	0
A12Constr	0	0	0	0
A13FoodPrc	-12	-1	-1	0
A14TxtAprl	0	0	0	0
A15WoodPlp	1	0	0	0
A16PapPrnt	4	0	0	0
A17OilRef	-5,526	7	76	69
A18Chemicl	-10	1	6	5
A19Pharma	1	0	0	0
A20Cement	-6	2	10	8
A21Metal	-1	0	1	1
A22Aluminm	0	0	0	0
A23Machnry	1	0	0	0
A24AirCon	-1	0	1	1
A25SemiCon	25	0	1	1
A26ElecApp	0	0	0	0
A27Autos	2	0	0	0
A28OthVeh	1	0	0	0
A29AeroMfg	2	0	0	0
A30OthInd	1	0	1	0
A31WhlTrad	1	0	0	0
A32RetVeh	1	0	0	0
A33AirTrns	0	1	4	3
A34GndTrns	205	2	11	9
A35WatTrns	169	33	173	139
A36TrkTrns	-3	2	17	15
A37PubTrns	0	0	0	0
A38RetAppl	0	0	0	0
A39RetGen	1	0	0	0
A40InfCom	1	0	0	0
A41FinServ	-1	0	0	0
A42OthProf	1	0	0	0
A43BusServ	0	0	0	0
A44WstServ	-3	-3	0	3
A45LandFill	3	-2	0	2
A46Educatn	1	0	0	0
A47Medicin	-1	0	0	0
A48Recratn	0	0	0	0
A49HotRest	0	0	0	0
A50OthPrSv	0	0	0	0
Y	1	1	2	0
Total	**-5,124**	**51**	**358**	**306**

Table 3.9: Aggregate and Sector Components of Induced PM Emissions (Metric Tons, 2020)

Sector	No Offsets	In-state	Out-of-state	Difference
A01Agric	-525	-396	8	405
A02Cattle	-8	-17	1	18
A03Dairy	60	-123	-19	104
A04Forest	12	1	9	8
A05OilGas	-23	0	0	0
A06OthPrim	-239	26	139	113
A07DistElec	-44	21	106	85
A08DistGas	114	0	0	0
A09DistOth	0	0	0	0
A10ConRes	419	24	141	117
A11ConNRes	1,914	1	-12	-12
A12Constr	1,441	90	437	347
A13FoodPrc	-95	-7	-10	-2
A14TxtAprl	0	0	0	0
A15WoodPlp	13	1	5	4
A16PapPrnt	2	0	0	0
A17OilRef	-709	1	10	9
A18Chemicl	-11	1	7	6
A19Pharma	0	0	0	0
A20Cement	-21	8	39	31
A21Metal	-1	0	2	2
A22Aluminm	-1	0	0	0
A23Machnry	0	0	0	0
A24AirCon	0	0	0	0
A25SemiCon	11	0	1	0
A26ElecApp	0	0	0	0
A27Autos	1	0	0	0
A28OthVeh	1	0	0	0
A29AeroMfg	1	0	0	0
A30OthInd	10	1	4	2
A31WhlTrad	2	0	0	0
A32RetVeh	1	0	0	0
A33AirTrns	-1	2	9	7
A34GndTrns	7,437	71	382	311
A35WatTrns	29	6	30	24
A36TrkTrns	-138	84	808	723
A37PubTrns	0	0	0	0
A38RetAppl	0	0	0	0
A39RetGen	1	0	0	0
A40InfCom	1	0	0	0
A41FinServ	-1	0	0	0
A42OthProf	3	0	0	0
A43BusServ	0	0	0	0
A44WstServ	-135	-128	15	143
A45LandFill	9	-6	-1	5
A46Educatn	1	0	0	0
A47Medicin	-2	0	0	0
A48Recratn	1	0	0	0
A49HotRest	0	0	0	0
A50OthPrSv	1	0	0	0
Y	10	10	13	3
Total	9,533	-338	2,111	2,450

Table 3.10: Aggregate and Sector Components of Induced PM10 Emissions (Metric Tons, 2020)

Sector	No Offsets	In-state	Out-of-state	Difference
A01Agric	-265	-200	4	204
A02Cattle	-4	-9	1	9
A03Dairy	30	-62	-9	53
A04Forest	7	1	5	4
A05OilGas	-21	0	0	0
A06OthPrim	-132	15	77	62
A07DistElec	-35	17	85	68
A08DistGas	110	0	0	0
A09DistOth	0	0	0	0
A10ConRes	205	12	69	57
A11ConNRes	937	0	-6	-6
A12Constr	705	44	214	170
A13FoodPrc	-57	-4	-6	-1
A14TxtAprl	0	0	0	0
A15WoodPlp	9	1	4	3
A16PapPrnt	2	0	0	0
A17OilRef	-557	1	8	7
A18Chemicl	-10	1	6	5
A19Pharma	0	0	0	0
A20Cement	-15	5	27	21
A21Metal	-1	0	2	1
A22Aluminm	0	0	0	0
A23Machnry	0	0	0	0
A24AirCon	0	0	0	0
A25SemiCon	11	0	1	0
A26ElecApp	0	0	0	0
A27Autos	1	0	0	0
A28OthVeh	1	0	0	0
A29AeroMfg	1	0	0	0
A30OthInd	7	1	3	2
A31WhlTrad	2	0	0	0
A32RetVeh	1	0	0	0
A33AirTrns	-1	2	9	7
A34GndTrns	3,896	37	200	163
A35WatTrns	28	6	29	23
A36TrkTrns	-75	46	441	395
A37PubTrns	0	0	0	0
A38RetAppl	0	0	0	0
A39RetGen	1	0	0	0
A40InfCom	2	0	0	0
A41FinServ	-1	0	0	0
A42OthProf	3	0	0	0
A43BusServ	0	0	0	0
A44WstServ	-128	-122	14	136
A45LandFill	4	-3	-1	2
A46Educatn	1	0	0	0
A47Medicin	-2	0	0	0
A48Recratn	1	0	0	0
A49HotRest	0	0	0	0
A50OthPrSv	1	0	0	0
Y	6	6	8	2
Total	**4,661**	**-211**	**1,174**	**1,385**

Table 3.11: Aggregate and Sector Components of Induced PM25 Emissions (Metric Tons, 2020)

Sector	No Offsets	In-state	Out-of-state	Difference
A01Agric	-75	-57	1	58
A02Cattle	-1	-3	0	3
A03Dairy	9	-18	-3	15
A04Forest	3	0	2	2
A05OilGas	-22	0	0	0
A06OthPrim	-51	6	30	24
A07DistElec	-31	15	76	60
A08DistGas	113	0	0	0
A09DistOth	0	0	0	0
A10ConRes	20	1	7	6
A11ConNRes	94	0	-1	-1
A12Constr	70	4	21	17
A13FoodPrc	-31	-2	-3	-1
A14TxtAprl	0	0	0	0
A15WoodPlp	6	0	2	2
A16PapPrnt	2	0	0	0
A17OilRef	-516	1	7	6
A18Chemicl	-9	1	6	5
A19Pharma	0	0	0	0
A20Cement	-10	4	18	15
A21Metal	-1	0	1	1
A22Aluminm	0	0	0	0
A23Machnry	0	0	0	0
A24AirCon	0	0	0	0
A25SemiCon	10	0	1	0
A26ElecApp	0	0	0	0
A27Autos	1	0	0	0
A28OthVeh	1	0	0	0
A29AeroMfg	1	0	0	0
A30OthInd	4	1	2	1
A31WhlTrad	2	0	0	0
A32RetVeh	1	0	0	0
A33AirTrns	-1	2	9	7
A34GndTrns	573	5	29	24
A35WatTrns	27	5	28	22
A36TrkTrns	-16	10	92	82
A37PubTrns	0	0	0	0
A38RetAppl	0	0	0	0
A39RetGen	1	0	0	0
A40InfCom	2	0	0	0
A41FinServ	-1	0	0	0
A42OthProf	3	0	0	0
A43BusServ	0	0	0	0
A44WstServ	-117	-111	13	124
A45LandFill	3	-2	0	1
A46Educatn	1	0	0	0
A47Medicin	-2	0	0	0
A48Recratn	1	0	0	0
A49HotRest	0	0	0	0
A50OthPrSv	1	0	0	0
Y	2	2	3	1
Total	**64**	**-137**	**338**	**475**

5 Conclusions and Extensions

This report is the first to examine California's Global Warming Solutions act strictly from the perspective of criteria pollutants. While GHG emissions are the primary focus of the Act, its historical precedence makes it an important landmark for environmental policy, and in that context its fullest implications need to be understood. While the Act achieves dramatic gains in reduction of global warming pollution, its effects on other categories of emissions will depend on specifics of policy implementation. From a tocics and public health perspective, criteria pollutants are an important category of such collateral emissions. Since AB32 is not directly targeted at these, the effects of its approach to GHG reduction may have unintended consequences. This study provides the first detailed evidence to support policy dialogue on this issue.

Using a dynamic economic forecasting model, we evaluate AB32 implementation options set forth in the Scoping plan, with particular reference to cap and trade offset policies and their effects on criteria pollution levels over the medium term of AB32 (to 2020). Our findings suggest that the choice of offset level and origin will have important impacts on critiera pollution in California. In particular, we find that AB32 reduces most criteria pollution via co-pollutant mitigation, and in-state offsets can actually achieve further criteria mitigation in the majority of emission categories. However, if offsets are made available outside California, criteria pollution levels will be higher in every category. For these reasons, it is very important that offset policy be carefully considered and designed, including the use parallel criteria mitigation policies if out-of-state offsets are contemplated.

This work was undertaken to strengthen a relatively weak basis of evidence on an important public health issue: criteria pollution in the context of climate policy. Much work could profitably be done to inform public and private stakeholders about more detailed aspects of this issue, including more detailed industry analysis, local emissions and regulatory options, and "closing the loop" to examine economy-environment-public health cost feedbacks that should be informing long term environmental policy. California's leadership in climate policy offers a unique opportunity to broaden public awareness of these complex issues, to design more sophisticated and forward looking policies, and to set global standards for a new generation of integrated environmental policies.

Background Annexes

Annex 1 - The BEAR MODEL

The Berkeley Energy and Resources (BEAR) model is a constellation of research tools designed to elucidate economy-environment linkages in California. The schematics in Figures 2.1 and 2.2 (below) describe the four generic components of the modeling facility and their interactions. This section provides a brief summary of the formal structure of the BEAR model.[8] For the purposes of this report, the 2003 California Social Accounting Matrix (SAM), was aggregated along certain dimensions. The current version of the model includes 50 activity sectors and ten households aggregated from the original California SAM. The equations of the model are completely documented elsewhere (Roland-Holst: 2005), and for the present we only discuss its salient structural components.

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economywide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

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[8] See Roland-Holst (2005) for a complete model description.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to the new California SAM estimated for the year 2003.[9] The result is a single economy model calibrated over the fifteen-year time path from 2005 to 2020.[10] Using the very detailed accounts of the California SAM, we include the following in the present model:

Production

All sectors are assumed to operate under constant returns to scale and cost optimization. Production technology is modeled by a nesting of constant-elasticity-of-substitution (CES) functions.

In each period, the supply of primary factors — capital, land, and labor — is usually predetermined.[11] The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be

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[9] See e.g. Meeraus et al (1992) for GAMS. Berck et al (2004) for discussion of the California SAM.

[10] The present specification is one of the most advanced examples of this empirical method, already applied to over 50 individual countries or combinations thereof.

[11] Capital supply is to some extent influenced by the current period's level of investment.

partially mobile, reflecting differences in the marketability of capital goods across sectors.[12]

Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply conditions in all markets.

Consumption and Closure Rule

All income generated by economic activity is assumed to be distributed to consumers. Each representative consumer allocates optimally his/her disposable income among the different commodities and saving. The consumption/saving decision is completely static: saving is treated as a "good" and its amount is determined simultaneously with the demand for the other commodities, the price of saving being set arbitrarily equal to the average price of consumer goods.

The government collects income taxes, indirect taxes on intermediate inputs, outputs and consumer expenditures. The default closure of the model assumes that the government deficit/saving is exogenously specified.[13] The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

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[12] For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium prices to be determined by the model.

[13] In the reference simulation, the real government fiscal balance converges (linearly) towards 0 by the final period of the simulation.

Trade

Goods are assumed to be differentiated by region of origin. In other words, goods classified in the same sector are different according to whether they are produced domestically or imported. This assumption is frequently known as the *Armington* assumption. The degree of substitutability, as well as the import penetration shares are allowed to vary across commodities. The model assumes a single Armington agent. This strong assumption implies that the propensity to import and the degree of substitutability between domestic and imported goods is uniform across economic agents. This assumption reduces tremendously the dimensionality of the model. In many cases this assumption is imposed by the data. A symmetric assumption is made on the export side where domestic producers are assumed to differentiate the domestic market and the export market. This is modeled using a *Constant-Elasticity-of-Transformation* (CET) function.

Dynamic Features and Calibration

The current version of the model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in the model originate in three sources: i) accumulation of productive capital and labor growth; ii) shifts in production technology; and iii) the putty/semi-putty specification of technology.

Capital accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

The putty/semi-putty specification

The substitution possibilities among production factors are assumed to be higher with the new than the old capital vintages — technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (e.g. the imposition of an emissions fee), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

Figure A.1: Component Structure of the Modeling Facility

BEAR is being developed in four areas and implemented over two time horizons.

Components:

1. Core GE model
2. Technology module
3. Emissions Policy Analysis
4. Transportation services/demand

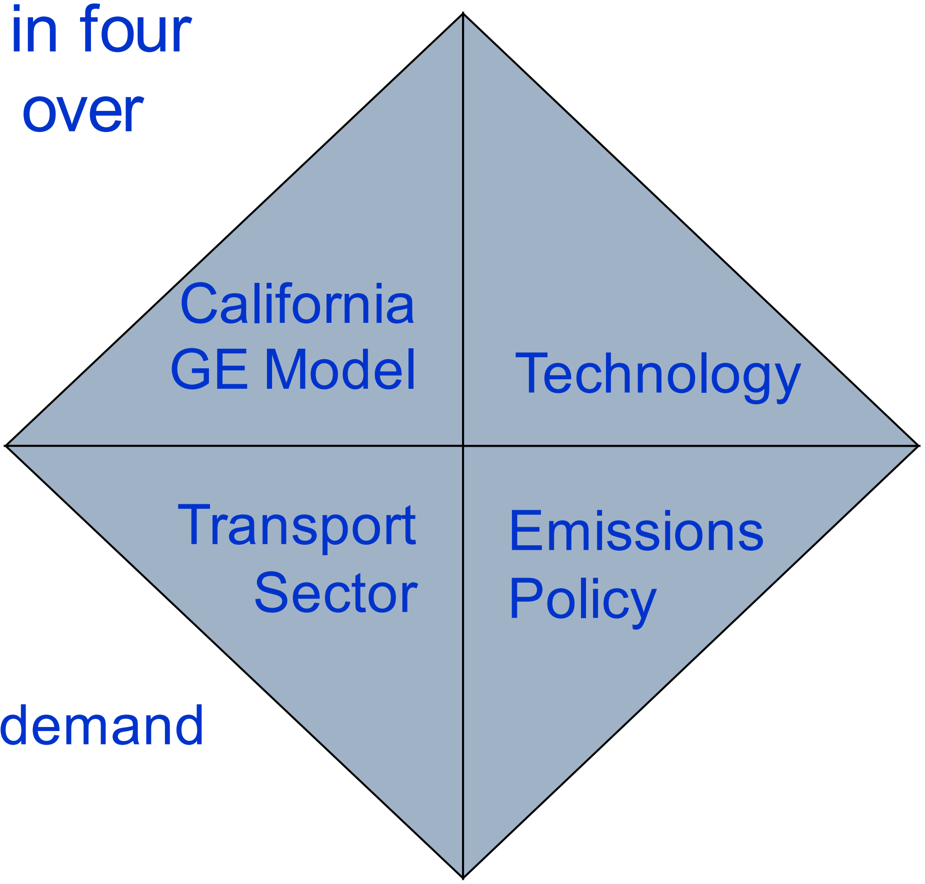
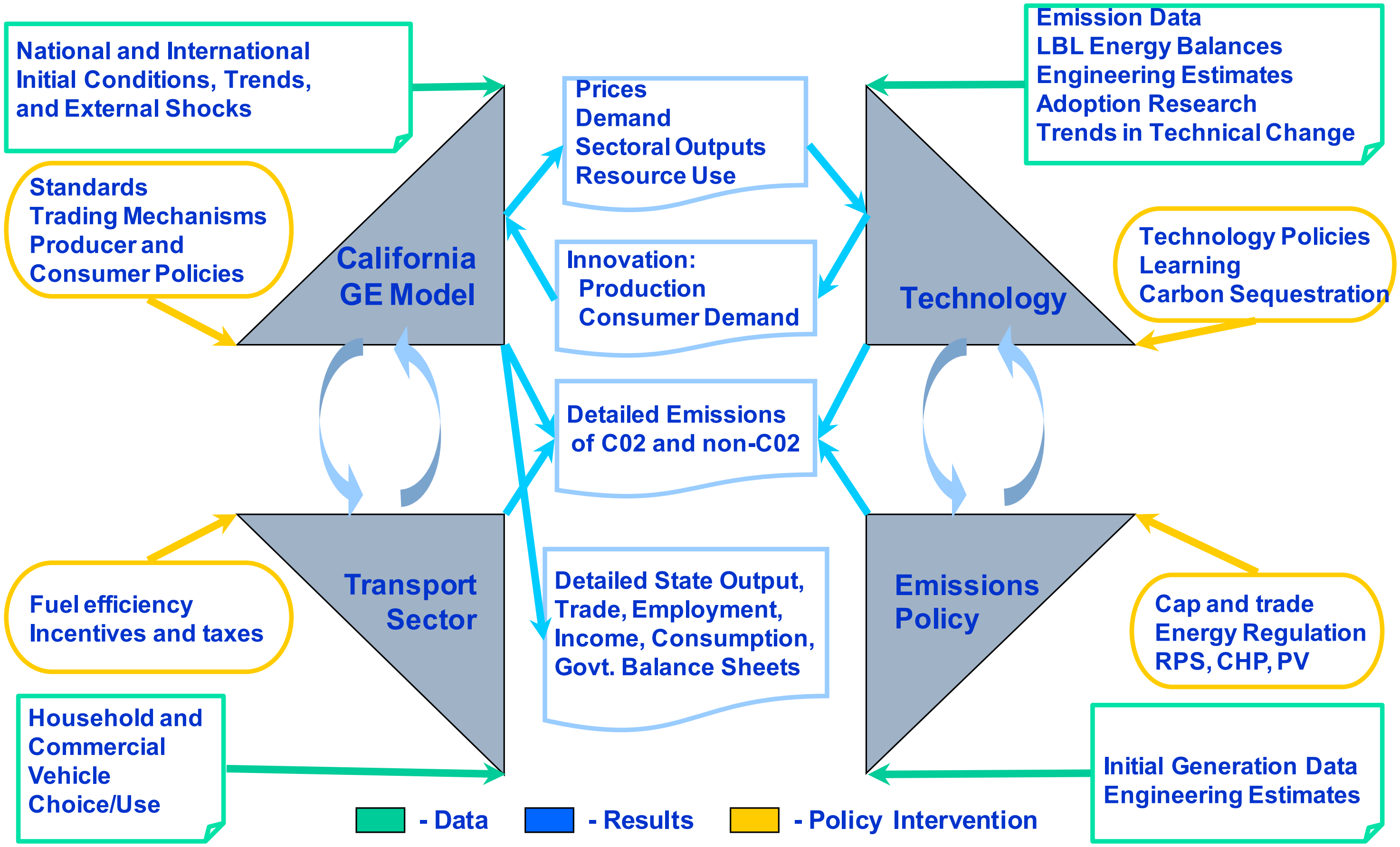


Figure A.2: Schematic Linkage between Model Components



Dynamic calibration

The model is calibrated on exogenous growth rates of population, labor for and GDP. In the so-called Baseline scenario, the dynamics are calibrated in ea region by imposing the assumption of a balanced growth path. This implies t the ratio between labor and capital (in efficiency units) is held constant o time.[14] When alternative scenarios around the baseline are simulated, technical efficiency parameter is held constant, and the growth of capita endogenously determined by the saving/investment relation.

Modeling Emissions

The BEAR model captures emissions from production activities in agricultu industry, and services, as well as in final demand and use of final goods (e appliances and autos). This is done by calibrating emission functions to each these activities that vary depending upon the emission intensity of the inp used for the activity in question. We model both CO2 and the other prim greenhouse gases, which are converted to CO2 equivalent. Following standa set in the research literature, emissions in production are modeled as fact inputs. The base version of the model does not have a full representation emission reduction or abatement. Emissions abatement occurs by substitut additional labor or capital for emissions when an emissions tax is applied. Thi an accepted modeling practice, although in specific instances it may eit understate or overstate actual emissions reduction potential.[15] In this framewo emission levels have an underlying monotone relationship with production lev but can be reduced by increasing use of other, productive factors such as cap and labor. The latter represent investments in lower intensity technologi process cleaning activities, etc. An overall calibration procedure fits obser intensity levels to baseline activity and other factor/resource use levels. In so of the policy simulations we evaluate sectoral emission reduction scenari

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[14] This involves computing in each period a measure of Harrod-neutral technical progress in capital-labor bundle as a residual. This is a standard calibration procedure in dynamic C modeling.

[15] See e.g. Babiker et al (2001) for details on a standard implementation of this approach.

using specific cost and emission reduction factors, based on our earlier analysis (Hanemann and Farrell: 2006).

Table A.2: Emission Categories

For the present research, we developed estimates of sector pollution intensities from official California data. The most detailed information from the Air Resources Board's emissions inventory(http://www.arb.ca.gov/cc/inventory/inventory.htm), was aggregated to conform to BEAR's 50 sector structure, with the resulting initial year sector inventory in Table 4.1 above. From this point, a dynamic baseline was created by stepping down some criteria intensities based on independent information regarding standards and other mitigation measures outside of AB32, such as NOx regulations for future truck and rail transport. More explicit definitions for the criteria categories are given below.

Criteria Pollutants

1. TOG : Total Organic Gases (TOG) means "compounds of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate."
    a. TOG includes all organic gas compounds emitted to the atmosphere, including the low reactivity, or "exempt VOC", compounds (e.g., methane, ethane, various chlorinated fluorocarbons, acetone, perchloroethylene, volatile methyl siloxanes, etc.).
    b. TOG also includes low volatility or "low vapor pressure" (LVP) organic compounds (e.g., some petroleum distillate mixtures). TOG includes all organic compounds that can become airborne (through evaporation, sublimation, as aerosols, etc.), excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate.

2. ROG: Total Organic Gas emissions are reported in the ARB's emission inventory and are the basis for deriving Reactive Organic Gas (ROG) emission estimates, which are also reported in the inventory.
    a. ROG means TOG minus ARB's "exempt" compounds (e.g., methane, ethane, CFCs, etc.).
    b. ROG is similar, but not identical, to U.S. EPA's term "VOC", which is based on EPA's exempt list. Also, various regulatory uses of the term "VOC", such as that for consumer products, exclude specific, additional compounds from particular control requirements.
3. CO: The concentration of Carbon Monoxide (CO) in the ambient air depends primarily on local weather conditions and the number of automobiles in the area. High levels of CO can have acute health effects on humans by reducing the supply of oxygen in the bloodstream. Normally, blood cells transport oxygen to, and remove carbon dioxide from, every cell in the body. The blood cells are more attracted to CO than to oxygen. Therefore, exposure to high levels of CO results in oxygen deprivation to various parts of the body. CO exposure can aggravate existing conditions such as heart and lung diseases. At high levels, CO exposure can be fatal. Nationally, a few hundred fatalities a year occur due to high concentrations of CO, usually in poorly ventilated buildings, idling parked cars with faulty exhaust systems and residential fires. The danger from CO is greatest in unborn and newborn infants, the elderly, and those suffering from chronic illnesses.
4. NOX: Nitrous Oxides (NOX) are chemicals formed in high-temperature combustion processes. The substances are themselves toxic and can react to form ozone or PM10 in the form of nitrates. Nitrogen dioxide (NO2) is brownish red gas with a biting odor. It is highly irritating in high concentrations. Nitrogen dioxide is always accompanied by nitric oxide (NO).
5. SOX: Sulfur Oxides are invisible gases with a pungent odor. At low concentrations, these gas can often be tasted before smelled. The major source of sulfur oxides is the combustion of sulfur-containing fuels, primarily coal and fuel oil. Sulfur dioxide is a toxic substance that can impair breathing.

6. PM: Particulate matter (PM), also known as particle pollution, is a complex mixture of dust and soot particles. PM is includes two small diameter categories of special public health interest, PM10 and PM2.5..
7. PM10: PM10 is matter 10 micrometers in diameter or less. That would be about one-seventh the width of a strand of human hair.
8. PM25: PM2.5 is even smaller - measuring 2.5 micrometers or less. These particles are so small that they can become imbedded in human lung tissue, causing or exacerbating respiratory diseases and cardiovascular problems. Other negative effects are reduced visibility and accelerated deterioration of buildings.

PM concentration is reported in micrograms per cubic meter or µg/m3. The particulate is collected on a filter and weighed. This weight is combined with the known amount of air that passed through the filter to determine the concentration in the air.

EPA revised the National Ambient Air Quality Standards(NAAQS) for PM pollution on September 21, 2006. The final standards address two categories of particle pollution: fine particles (PM2.5), which are 2.5 micrometers in diameter and smaller; and inhalable coarse particles (PM10), which are smaller than 10 micrometers. EPA strengthened the 24-hour PM2.5standard from the 1997 level of 65 µg/m3 to 35 µg/m3, and retained the current annual PM2.5 standard at 15 µg/m3. EPA also retained the existing national 24-hour PM10 standard of 150 µg/m3; however, it revoked the annual PM10 standard. These new standards went into effect on December 18, 2006.

9. VOC: Volatile Organic Compounds (VOC) are any compounds of carbon (other than carbon monoxide, carbon dioxide, carbonic acid, metallic carbonates, metallic carbides and ammonium carbonate) that participate in atmospheric photochemical reactions. A company must report all reactive VOC emissions (including fugitive emissions). VOC emissions which are non-reactive are not reported.

The model has the capacity to track several categories of individual pollutants and consolidated emission indexes, each of which is listed in Table A.2 above. Our focus in the current study is the effect of offsets policies on the emission of gases other than greenhouse gases.

An essential characteristic of the BEAR approach to emissions modeling is endogeneity. Contrary to assertions made elsewhere (Stavins et al:2007), the BEAR model permits emission rates by sector and input to be exogenous or endogenous, and in either case the level of emissions from the sector in question is endogenous unless a cap is imposed. This feature is essential to capture structural adjustments arising from market based climate policies, as well as the effects of technological change.

6 References

Abraham, S. (2004). "The Bush Administration's Approach to Climate Change." Science 305: 616-617.

Allergan, Inc. http://www.allergan.com/site/investors/home.asp?id=&largeText (2006)

Alza Corp. http://www.alza.com/alza/pr_1161880139 (Oct 2006)

Arc Advisory Group. http://www.arcweb.com/Events/forums/0206.htm (2006)

Babiker, M.H., J.M. Reilly, M. Mayer, R.S. Eckaus, I. Sue Wing, and R.C. Hyman (2001). “The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results,” MIT Global Change Joint Program, Report No. 1, February.

Bayer. http://www.bayerus.com/communities/berkeley/index.html (2006) California Energy Commission. 2004. Chemical Industry Profile. http://energy.ca.gov/pier/iaw/industry/chemical.html Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). 1993.

Burtraw, D., Alexander E. Farrell, Lawrence H. Goulder, and Carla Peterman (2006). “Lessons for a Cap and Trade Program,” in Hanemann and Farrell (eds.) *Managing Greenhouse Gas Emissions in California, op. cit.*

Burtraw, D. and K. Palmer (2004). The SO2 Cap-and-Trade Program in the United States: A "Living Legend" of Market Effectiveness. Choosing Environmental Policy. W. Harrington, R. D. Morgenstern and T. Sterner. Washington, DC, RFF Press.

California Environmental Protection Agency (2006). “Climate Action Team Report to Governor Schwarzenegger and the Legislature,” March, http://www.climatechange.ca.gov/climate_action_team/reports/2006-04-03_FINAL_CAT_REPORT.PDF

Center for Clean Air Policy (2005). Design of a Cap on Emissions from California Power Demand. Washington, DC: 27.

Center For Land Use Interpretation. Retrieved Nov Dec 2 from http://ludb.clui.org/tag/Mining/

Cheng, R., 1999. Low Emissions Burners. *EETD Newsletter*, Summer 1999, Lawrence Berkeley National Laboratory, Berkeley, CA.

Cost Effective GHG Mitigation Measures for California. (2006) Summary Report: An Independent Analysis of Measures to Reduce Greenhouse Gas Emissions in 2010 and 2020 to Meet Executive Order S-3-05. Retrieved Dec 3 from http://www.ccap.org/domestic/Summary%20Report-Final%20_1-19-06_.pdf

Ellerman, A. D., P. L. Joskow, et al. (2000). Markets for Clean Air: the U.S. Acid Rain Program. Cambridge, UK, Cambridge University Press.

Elliott, R.N., A.M. Shipley, E. Brown, R. Cleetus and S. Bernow. 2003. State-level Analysis of Industrial Energy Use. *Proc. 2003 ACEEE Summer Study on Energy Efficiency in Industry*, pp.6- 76-85, Washington, DC: ACEEE.

Energy Technology Support Unit (ETSU). 1999. “Design and operation of energy-efficient batch processes.” Report of the UK Best Practice Program, ETSU: Harwell, United Kingdom

Farrell, A. E. and L. B. Lave (2004). "Emission Trading and Human Health." Annual Review of Public Health 25: 119-138.

Fischer, C. and A. Fox (2004). Output-Based Allocations of Emissions Permits: Efficiency and Distributional Effects in a General Equilibrium Setting with Taxes and Trade. Washington, DC, Resources For the Future.

Fischer, C., I. W. H. Parry, et al. (2003). "Instrument choice for environmental protection when technological innovation is endogenous." Journal of Environmental Economics and Management 45(3): 523-545.

Hanemann, W. Michael, and A.E. Farrell (eds.) (2006) “Managing Greenhouse Gas Emissions in California,” California Climate Change Center, University of California, Berkeley, January, http://calclimate.berkeley.edu/managing_GHGs_in_CA.html

Hanson, D. and J.A. Laitner (2004). “An integrated analysis of policies that increase investments in advanced-energy efficient/low carbon policies.” Energy Economics 26: 739-755.

Harrison, K. and W. Antweiler (2003). "Incentives for pollution abatement: Regulation, regulatory threats, and non-governmental pressures." Journal of Policy Analysis and Management 22(3): 361-382.

Helme, Ned, Tom Peterson, and Eric Williams (2004). “Allowance Allocation: Who wins and loses under a carbon dioxide control program?” Center for Clean Air Policy, http://www.ccap.org/pdf/CRA_Background_Paper.pdf

Hoffert, M., K. Caldeira, et al. (1998). "Energy Implications of future stabilization of atmospheric CO2 content." Nature 395(6075): 881-884.

J.A. Laitner (2006). “An Annotated Review of 30 Studies Describing the Macroeconomic Impacts of State-Level Scenarios Which Promote Energy Efficiency and Renewable Energy Technology Investments.” American Council for an Energy Efficiency Economy: Comment Draft (July).

Kartha, S., M. Lazarus, et al. (2004). "Baseline recommendations for greenhouse gas mitigation projects in the electric power sector." Energy Policy 32(4): 545-566.

Kemp, I.C. and A.W. Deakin. 1989. “The Cascade Analysis for Energy and Process Integration of Batch Processes, Part 3: A Case Study.” *Chemical Engineering Research and Design*. pp.517-525.

Kerr, S. and R. G. Newell (2003). "Policy-induced technology adoption: Evidence from the US lead phase down." Journal of Industrial Economics 51(3): 317-343.

Linnhoff, B. 1993. Pinch Analysis: A State-of-the-Art Overview. *Chemical Engineering* (AS): pp.503-522.

Marsland. 1992. A User Guide on Process Integration for the Efficient Use of Energy (1992 edition), Institution of Chemical Engineers, Rugby, UK.

Milliman, S. R. and R. Prince (1989). "Firm Incentives to Promote Technological-Change in Pollution-Control." Journal of Environmental Economics and Management 17(3): 247-265.

Montero, J. P. (1999). "Voluntary compliance with market-based environmental policy: Evidence from the US Acid Rain Program." Journal of Political Economy 107(5): 998-1033.

Norberg-Bohm, V. (1999). "Stimulating 'green' technological innovation: An analysis of alternative policy mechanisms." Policy Sciences 32(1): 13-38.

Nordhaus, R. R. and K. W. Danish (2003). Designing a mandatory greenhouse gas reduction program for the U.S. Arlington, VA, Pew Center on Global Climate Change: 66.

Ono, T. (2002). "The effects of emission permits on growth and the environment." Environmental & Resource Economics 21(1): 75-87.

Palmer, K., D. Burtraw, et al. (2005). In Search of Simple Rules for Using CO2 Allowances to Compensate Firms. Washington, DC, Resources For the Future.

Pew Center on Global Climate Change(2006). “Designing a Mandatory Greenhouse Gas Reduction Program for the U.S.” http://www.pewclimate.org/global-warming-in-depth/all_reports/mandatory_ghg_reduction_prgm/usgas_conc.cfm

Pfizer. http://www.pfizer.com/pfizer/lajolla/index.jsp (2003)

Popp, D. (2003). "Pollution control innovations and the Clean Air Act of 1990." Journal of Policy Analysis and Management 22(4): 641-660.

Roland-Holst, D. (2006). Chapter 2: Economic Assessment of some California Greenhouse Gas Control Policies: Applications of the BEAR Model. Retrieved on Nov 29 from http://calclimate.berkeley.edu/2_Economic_Assessment.pdf

Roland-Holst, D. (2006). Chapter 2: Economic Assessment of some California Greenhouse Gas Control Policies: Applications of the BEAR Model. Retrieved on Nov 29 from http://calclimate.berkeley.edu/2_Economic_Assessment.pdf

Roland-Holst, David (2005). “Berkeley Energy and Resources Model: Technical Documentation,” Department of Agricultural and Resource Economics, University of California, Berkeley, processed.

Roland-Holst, David (2006). “Economic Assessment of some California Greenhouse Gas Control Policies: Applications of the Bear Model,” in Hanemann and Farrell (eds.) *Managing Greenhouse Gas Emissions in California , op. cit.*

Rubin, J. D. (1996). "A model of intertemporal emission trading, banking, and borrowing." Journal of Environmental Economics and Management 31(3): 269-286.

Schennach, S. M. (2000). "The economics of pollution permit banking in the context of Title IV of the 1990 Clean Air Act Amendments." Journal of Environmental Economics and Management 40(3): 189-210.

Stavins, R. (2003). Experience with Market-Based Environmental Policy Instruments. The Handbook of Environmental Economics. K. Goren-Maler and J. Vincent. Amsterdam, North-Holland/Elsevier Science. 1.

Taylor, M. R., E. S. Rubin, et al. (2003). "Effect of Government Actions on Technological Innovation for SO2 Control." Environmental Science & Technology 37(20): 4527-4534.

Tietenberg, T. (2003). "The tradable-permits approach to protecting the commons: Lessons for climate change." Oxford Review of Economic Policy 19(3): 400-419.

US DOE-OIT, 2002b. Industrial Combustion Technology Roadmap, A Technology Roadmap by and for the Industrial Combustion Community. Office of Industrial Technologies, US Department of Energy, Washington, DC.

US DOE-OIT, 2002c. Rotary Burner (Project Factsheet). Office of Industrial Technologies, US Department of Energy, Washington, DC.

Worrell, E. and C. Galitsky. 2004. Profile of the Chemicals Industry in California – California Industries of the Future Program. Berkeley, CA: Lawrence Berkeley National Laboratory (LBNL-55668) (June 2004).

Worrell, E. and Galitsky, C. (2004). Energy Efficiency Improvement Opportunities for Cement Making: An ENERGY STAR Guide for Energy and Plant Managers.

Worrell, E., J-W.Bode, and J. de Beer. 1997. Energy Efficient Technologies in Industry (ATLAS project for the European Commission). Utrecht University, Utrecht, The Netherlands.