Measuring Power Sector Emissions Leakage from California's Cap-and-Trade Program

James Bushnell, Professor, Department of Economics, University of California, Davis and NBER

Kevin Novan, Professor, Department of Agricultural and Resource Economics, University of California, Davis

October 2025

Extended Abstract

California has adopted a series of increasingly ambitious greenhouse gas (GHG) reduction goals over the last 20 years, starting with the passage of the Global Warming Solutions Act (AB 32) in 2006. California's Cap-and-Trade Program for GHG was developed by the California Air Resources Board (CARB) as part of a suite of climate policies developed for implementing AB 32. The program began selling allowances in 2012 and capping emissions of large sources in 2013. It was expanded to cover transportation fuels and the distribution of natural gas in 2015. The GHG emissions associated with the production of electricity serving California load have been covered under the Cap-and-Trade Program (and a set of other climate policies) since 2013.

The regulation of emissions from the electric sector posed a set of extremely difficult, if not unique, challenges to California regulators. In 2008, almost 1/3 of the electricity consumed in California was produced in other States, and imports accounted for almost half of California's electricity sector emissions (Bushnell, Chen and Zaragoza-Watkins, 2014). Given the ease with which California can substitute electricity produced out-of-state for in-state production, the setting makes the threat of leakage particularly acute. Intuitively, if an environmental regulation were to exclusively increase the private generation costs for California-based generators, output, and thus pollution, would be expected to immediately increase from the unregulated generators in the surrounding western region. Fowlie (2009) and Bushnell and Chen (2012) both utilize simplified models of the U.S. western electricity market to simulate the impact of a policy that regulates CO2 emissions exclusively from California electricity generators. The simulation results suggest that such a policy would result in substantial leakage, with emissions reductions from in-state generators being almost perfectly counteracted by increases in out-of-state emissions.

Largely due to the prominent role of electricity imports, CARB adopted an approach to regulating electricity sector emissions that is a hybrid of source-based and "downstream" on importers of electricity to California. Emissions from electricity produced inside California are reported at the facility level, similar to the reporting for emissions from all other sources inside the state. Under the Cap-and-Trade Program, the owner or operator of an in-state facility is also required to acquire and surrender compliance instruments (allowances and a limited number of offset credits) equal to its emissions. These California generation operators are considered the "first deliverers" of power into California's grid. The emissions associated with imported electricity is also the responsibility of the "first deliverers" of power into California. However, in the case of imports, the first deliverer may not be the power plant operator, but rather an entity that purchases power from the non-California plant and "first delivers" to the California grid. In this way, entities that purchase power outside of California and import it into the state, either for resale or to directly serve customers, are responsible for identifying the sources of that imported power, if possible, and reporting the emissions associated with that imported power. Under the Cap-and-Trade Program, such entities are also required to acquire and surrender compliance instruments equal to the emissions from those sources associated with the imports.

The adoption of this first deliverer approach to regulating electricity emissions at least partially address the most direct form of emissions leakage that can arise under purely source-based caps, where a plant simply closes in California and its output is replaced by imports from an unregulated plant in a neighboring state.

The first deliverer approach, however, introduces the possibility of other forms of emissions leakage. Many short-term electricity purchases are from exchanges or pools, such as from the market run by the California Independent System Operator or from "system" resources that are not traceable to any specific power plant. Imports from unspecified sources are given a default emissions rate. One concern is that importing firms will convert imports from sources known to be dirtier than these default emissions rates into unspecified resources.

The most prominent vulnerability to a "downstream" regulation such as California's first deliverer policy is the prospect of resource shuffling. Firms that had previously been importing from carbon intensive sources could switch their sources to pre-existing low-carbon sources. If the carbon intensive sources that had previously been selling into California divert their output to other parts of the western electric grid, the net transactions could result in little to no emissions reductions when the full western grid is considered. The reductions to emissions attributed to California imports would be counteracted by a corresponding increase in the emissions associated with consumption outside of California.

Using models that simulate market outcomes in the western electric grid, Bushnell et al. (2014), Xu and Hobbs (2021), and Fowlie et al. (2021) directly model policies that mimic the first deliverer approach. Each of the studies finds that, absent strict non-market barriers to prevent resource shuffling, electricity sector emissions throughout the western U.S. would be effectively unchanged by the adoption of a California Cap-and-Trade Program that applies facility-specific emission factors to quantify emissions attributed to imports (consistent with the first deliverer approach).

While there are numerous simulation-based studies of the potential for leakage and resource reshuffling in regional Cap-and-Trade Programs, there remains little in the way of ex-post empirical estimates of the degree to which leakage is occurring. Focusing on the Regional Greenhouse Gas Initiative (RGGI) cap-and-trade program adopted in the eastern U.S., Fell and Maniloff (2018) utilize a difference-in-difference estimation strategy to quantify the extent to which generation from unregulated electricity producers increased in response to the adoption of the Cap-and-Trade Program. Recent work by Lo Prete, Tyagi, and Xu (2021) employs a similar strategy to quantify how output from electricity generators inside and outside of California changed in response to the adoption of the Cap-and-Trade Program. Using generators from outside of the western U.S. (in the Texas and Eastern interconnections) as potential controls for generators in the western U.S., the authors find evidence, during some periods of the day and during some seasons, of a decline in natural gas generation within California and a corresponding increase in production from fossil units throughout the rest of the western U.S. during the first four years of the program. However, given the first deliverer approach utilized in California's Cap-and-Trade Program, observing a redistribution in fossil output from inside to outside of California does not by itself demonstrate that leakage is occurring.

As part of the Regulation for the Mandatory Reporting of Greenhouse Gas Emissions (MRR), firms generating electricity inside of California report their GHG emissions to CARB and entities importing electricity from out of state to serve California load must report electricity imports and associated emissions. **Error! Reference source not found.** displays the annual reported electricity imports coming into California, as well as the emissions attributed to these imports. Relative to 2011, the annual emissions attributed to California's electricity imports in 2021 fell by 29.6 million metric tons – a 58% decline.

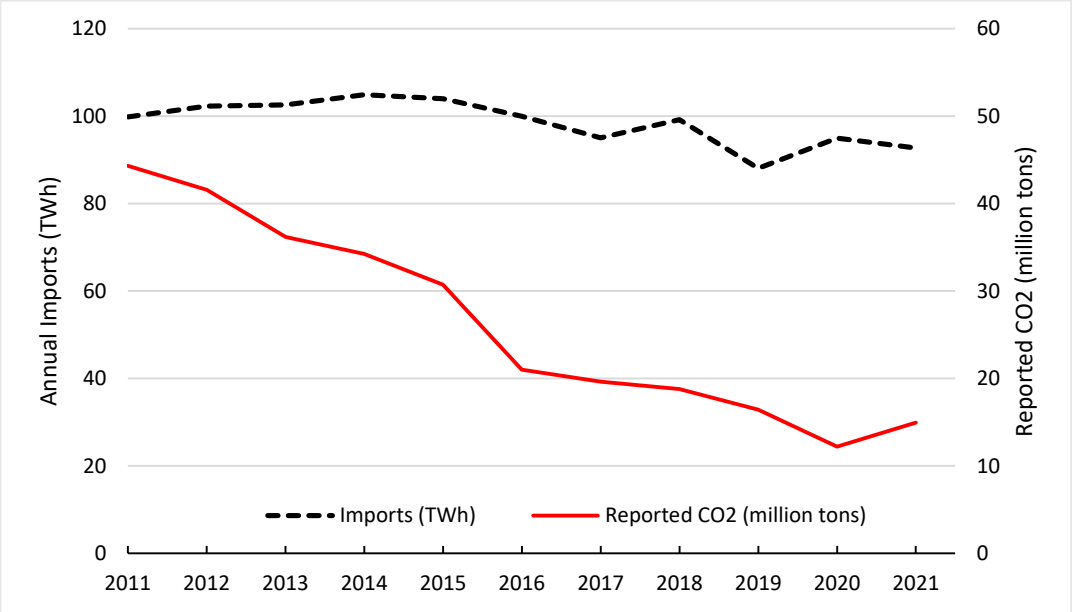


Figure E1: Annual Reported Electricity Imports and Emissions (Source: CARB MRR Data)

The objective of this study is to quantify the extent to which the reported reductions in emissions from California's electricity imports from 2011 through 2021 have been impacted by emissions leakage in the surrounding western electric grid.[1] This evaluation looks at aggregate outcomes and does not evaluate specific transactions, imports for individual load-serving entities or compliance with regulatory provisions to minimize emissions leakage.

Our empirical analysis presents two complementary estimation approaches. First, we apply marginal emissions estimation methods to quantify the amount of emissions caused by California imports each year and compare multi-year changes in our estimates of the import-driven emissions to the reduction in emissions from imports reported to CARB (displayed in **Error! Reference source not found.**).

This first estimation approach largely abstracts from potential longer-run changes in electricity generation capacity that may be caused by California's climate policies. To directly account for

[1] This report is not focused on evaluating emissions leakage from the operation of the western Energy Imbalance Market. CARB has an existing process to address emissions leakage occurring in the WEIM through the calculation of estimated emissions leakage (EIM Outstanding Emissions) and reductions of freely allocated allowances provided to electric utilities.

these longer-run capacity changes, we apply an attributional approach that examines long-run trends in the generation mix and emissions from both California electricity imports and the broader western electric grid. The purpose is to identify the extent to which the long-run decline in emissions associated with California imports reflect changes in overall western emissions or instead reflect emissions leakage.

To summarize how the resulting estimates of the annual emissions caused by imports have changed since the introduction of the Cap-and-Trade Program, we calculate the difference between the estimated annual emissions during each year relative to the estimated annual emissions attributed to imports in 2011. In addition, we calculate the *change* in the reported annual emissions relative to the reported imported emissions during 2011.

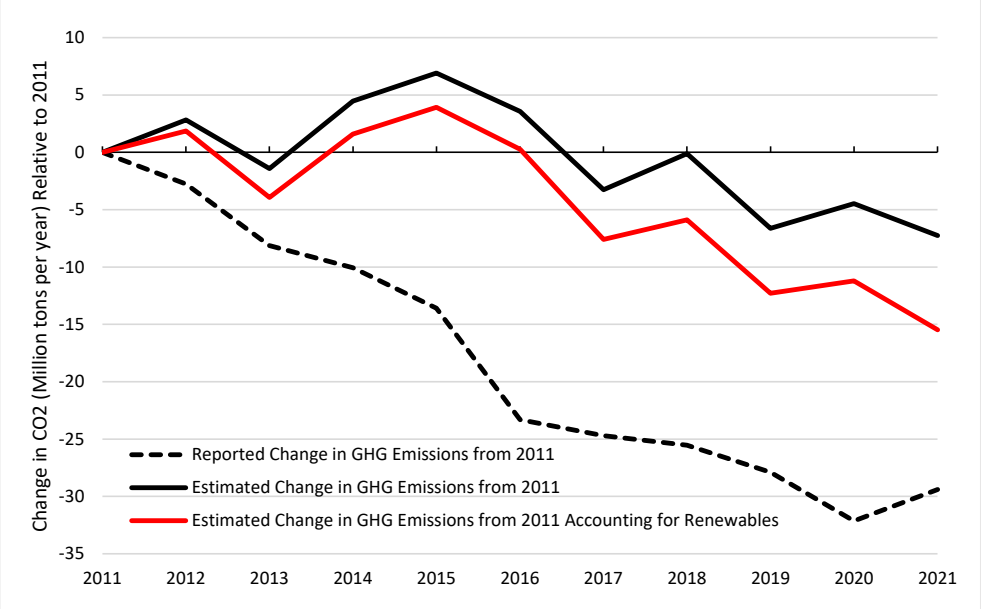


Figure E2: Reductions in Estimated Emissions Relative to Reported Emissions

Under the assumption that the new out-of-state renewable capacity in the reported imports was caused by the Cap-and-Trade Program (the red line in Figure E2), we estimate that the annual emissions attributed to California's imports in 2021 were 15.5 million tons lower than the 2011 emissions caused by California's imports. For comparison, the reported annual emissions attributed to California's imports were 29.6 million tons lower in 2021 relative to 2011 (the dashed line in Figure E2). That is, our estimates displayed by the red line above find that 57% of the reported emission reductions in 2021 relative to 2011 were reached through channels that would not be considered leakage, and that the remaining 43% could be construed as leakage.

Our second approach to estimating the extent of leakage contrasts trends in the energy sources being reported as sources of imports with those of power plants in the western grid overall. One finding is that since 2011, imports from existing zero or near-zero emissions sources such as nuclear and hydroelectric electricity have increased substantially, despite that overall production from those sources has remained flat or decreased during the same period. In other words, there

has been a substantial increase in the percentage of output from these sources reported as imported into California since 2011.

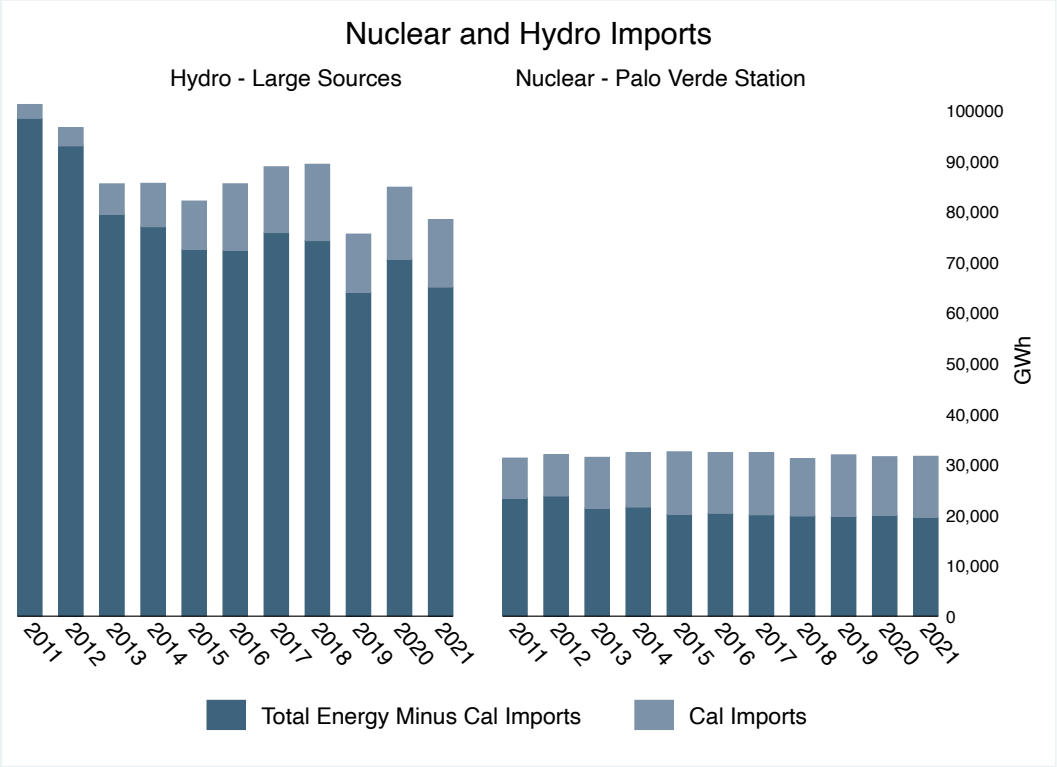


Figure E3: Total Output and Imports from Zero Carbon Sources

We combine several datasets from California and Federal agencies to decompose the sources of reductions in reported imported electricity emissions into 6 main categories, summarized below.

Category	**Description**	**Leakage Risk**
Imported TWh volume	*Changes in the quantity of imported energy*	None
New zero carbon	*Imports associated with new zero-carbon capacity*	Low
Retiring Fossil	*Reductions traced to no longer importing from plants with retiring units*	Low
Incumbent Zero Carbon	*Reductions traced to increasing imports from pre-existing nuclear and hydroelectric sources*	High
Incumbent Fossil	*Reductions traced to changes in the mix of fossil plants supporting imports*	High
Renewable Portfolio Standard (RPS) Adjustment	*Adjustments to Cap-and-Trade compliance for renewable energy supporting RPS compliance*	Unclear

Table E 1: Categories of Reductions in Emissions Associated with Electricity Imports

These categories include reductions traced to retirements in coal plants and newly added capacity in renewable energy. We consider these categories likely to represent actual reductions in GHG emissions across the western grid. We also assign a level of emissions reductions to two other categories: increased imports from existing hydroelectric and nuclear sources and reductions in the emission rates of reported imports from thermal sources. It is reasonable to assume that emissions reductions that could be traced to increased imports from existing sources and therefore constitute a form of leakage. While reductions in emissions rates of reported thermal emissions could be attributed to shifts in emissions rates overall, it could also represent leakage through a shift in import sources.

A sixth category assigns reductions associated with the RPS adjustment. This adjustment reduces Cap-and-Trade compliance costs for entities when renewable energy is used for compliance with California's RPS and is generated outside of, but not delivered to, California. The leakage implications of RPS adjustments are difficult to evaluate with the information available to us, but represents a relatively small share, about 6%, of overall reductions between 2011 and 2021for the electricity sector.

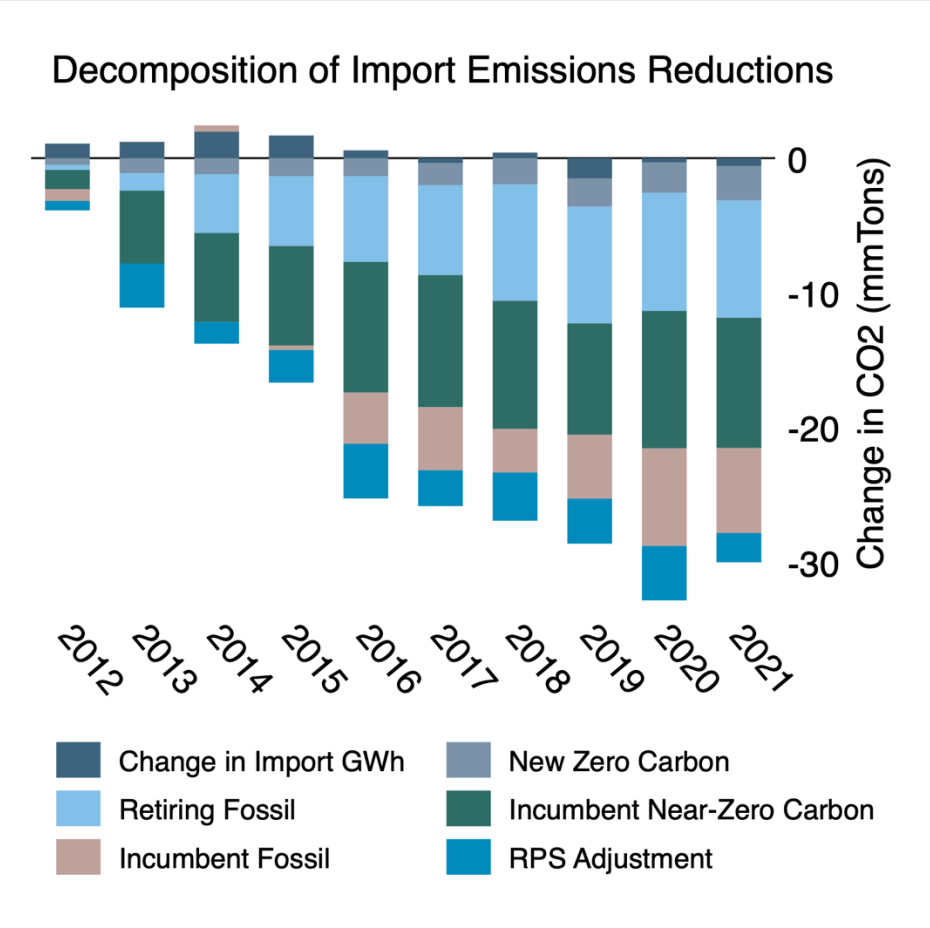


Figure E4: Sources of Import Emissions Reductions

If we consider the first three categories to *not* be leakage and the fourth and fifth categories to likely constitute leakage, we reach estimates similar to those calculated through our econometric approach. Roughly half of the 29.6 MMT reduction in emissions from electricity imports could be construed as leakage.

It is important to note that our analysis, and the summary above, address *aggregate* outcomes. There is an important distinction between aggregate outcomes and specific transactions that might constitute emissions leakage or violate the Cap-and-Trade Program's prohibition on resource shuffling. We are not aware of any evidence that any of these changes constituted activities that violate policies on reshuffling of sources.

These results do indicate that some degree of leakage is possible within the existing regulatory framework. The largest source of implied leakage can be traced to increased imports from existing hydroelectric and nuclear resources.

References

Bushnell, James, and Yihsu Chen. "Allocation and leakage in regional cap-and-trade markets for CO2." *Resource and Energy Economics* 34.4 (2012): 647-668.

Bushnell, James, Yihsu Chen, and Matthew Zaragoza-Watkins. "Downstream regulation of CO2 emissions in California's electricity sector." *Energy Policy* 64 (2014): 313-323.

Callaway, Duncan S., Meredith Fowlie, and Gavin McCormick. "Location, location, location: The variable value of renewable energy and demand-side efficiency resources." *Journal of the Association of Environmental and Resource Economists* 5.1 (2018): 39-75.

Cullenward, Danny, and David Weiskopf. *Resource shuffling and the California carbon market*. Environmental & Natural Resources Law & Policy Program, Stanford Law School, 2013.

Fell, Harrison, and Peter Maniloff. "Leakage in regional environmental policy: The case of the regional greenhouse gas initiative." *Journal of Environmental Economics and Management* 87 (2018): 1-23.

Fowlie, Meredith L. "Incomplete environmental regulation, imperfect competition, and emissions leakage." *American Economic Journal: Economic Policy* 1.2 (2009): 72-112.

Fowlie, Meredith, Claire Petersen, and Mar Reguant. "Border carbon adjustments when carbon intensity varies across producers: evidence from California." *AEA Papers and Proceedings*. Vol. 111 (2021).

Holland, Stephen P., et al. "Are there environmental benefits from driving electric vehicles? The importance of local factors." *American Economic Review* 106.12 (2016): 3700-3729.

Lo Prete, Chiara, Ashish Tyagi, and Qingyu Xu. "California's cap-and-trade program and emission leakage in the Western Interconnection: comparing econometric and partial equilibrium model estimates." *Journal of the Association of Environmental and Resource Economists* 11.2 (2024): 359-402.

Novan, Kevin, and Yingzi Wang. "Estimates of the marginal curtailment rates for solar and wind generation." *Journal of Environmental Economics and Management* 124 (2024): 102930.

Xu, Qingyu, and Benjamin F. Hobbs. "Economic efficiency of alternative border carbon adjustment schemes: A case study of California Carbon Pricing and the Western North American power market." *Energy Policy* 156 (2021): 112463.