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The role of CO_2 emissions from large point sources in emissions totals, responsibility, and policy

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Abstract

A large fraction of anthropogenic CO_2 emissions comes from large point sources such as power plants, petroleum refineries, and large industrial facilities. The existence and locations of these facilities depend on a variety of factors that include the distribution of natural resources and the economy of scale of operating large facilities. These large facilities provide goods and/or services well beyond the political jurisdiction in which they reside and their emissions to the global atmosphere are not a simple reflection of the consumption of goods and services within the geographic region in which they reside. And yet many accounting schemes do not distinguish between emissions for local consumption and emissions for export. Looking at the geographic distribution of large point sources of CO_2 emissions in the U.S. suggests that per capita emissions from a geographic area are not necessarily a good indication of the mitigation responsibility of the residents. The design of effective and fair mitigation strategies needs to consider that emissions embodied in the products of large facilities, such as electric power and refined petroleum products, are often transferred across accounting boundaries; e.g. the CO_2 emissions occur in one jurisdiction even though the electricity is used in another. We close with a short discussion of how two sub-national emissions trading schemes in the U.S. have confronted the issue of embodied emissions crossing their jurisdictional boundaries.

1. Introduction

With the Earth's climate changing because of anthropogenic emissions of greenhouse gases, there is widespread interest in characterizing who is responsible for these emissions and who should take action for mitigation and adaptation efforts. It is a significant challenge to determine an accounting framework that effectively allocates responsibility and that motivates decision making. In this paper we examine data on emissions from large point sources and argue that: (1) emissions from a geographic space (a city or a country, for example) reflect – among other factors – the spatial distribution of Earth's resources, (2) emissions from a geographic space are not necessarily a good indication of consumption and thus of mitigation responsibility, (3) the role of large point sources needs to be considered in mitigation strategies, and (4) allocation of emissions on the basis of equal per capita shares is not an obvious indication of fairness. Annual inventories of emissions from large point sources identify obvious targets for greenhouse gas emissions reductions, but it is not a simple story.

How one envisions the distribution of responsibility for greenhouse gas emissions among different parties is influenced by what gases, sources, spatial and sectoral boundaries, and time intervals are represented in the accounting process (den Elzen et al., 2013). Such accounting choices are critical as they are likely to shape future climate policies and actions to curb anthropogenic greenhouse gases. Responsibility for GHG emissions and mitigation efforts are particularly dependent on the spatial and sectoral boundaries of accounting. Studies have shown, for example, the implications of distinguishing between emissions that occur within a country (emissions from production) and emissions driven by a country's consumption (emissions from consumption) (Peters et al., 2012; Davis et al., 2010). Who should be held responsible for reducing emissions – the country (party) that produces the goods and services, or the country (party) that consumes the goods and services? Also, greenhouse gases are stock pollutants where the climatic effects depend not only on current emissions, but on the cumulative effect of emissions over time on atmospheric concentrations. This suggests that a party's responsibility for anthropogenic climate change may be viewed not only as a function of current emissions but also of past emissions, and perhaps of future emissions committed due to current actions and decisions.

2. Materials and methods

In this paper we look at the distribution of CO_2 emissions as a function of a set of factors that is not generally considered in discussions of emissions responsibility, namely: access to resources, efficiency of scale, and the consequent leakage of emissions across spatial accounting boundaries. (The term ''leakage'' refers to emissions changes that occur outside of an accounting boundary as the result of decisions or actions that occur within the accounting boundary. ''Embodied'' emissions, on the other hand, are emissions that occur in the production of a particular good or service.) We do this by focusing on large point sources of CO_2 emissions in the U.S. – i.e. power plants, petroleum refineries, and other large industrial facilities. In the United States, over 53% of fossil fuel-derived CO_2 emissions are attributable to electricity generation and other large industrial facilities (U.S. EPA, 2013a, 2013b), and the most recent U.S. initiative to reduce national emissions will likely have an important focus on large point sources (White House, 2013). We suggest that the observations below have broad implications for international accounting but we focus on state-level accounting within the U.S. because of the high quality of available data.

We explore the impact of large point sources on the spatial distribution of CO_2 emissions within the United States. Power plants and other large point sources are frequently located in response to the natural distribution of resources and, while they impose costs and benefits on local communities, they also provide benefits for populations that extend beyond local political or jurisdictional boundaries. Our basic contention is that the distribution of emissions from large point sources is conceptually different than the distribution of emissions from homes, transportation systems, and small enterprises because the large point sources supply goods and services beyond local consumers. The distribution of emissions from power plants with different fuel sources (e.g. coal, wind, hydro-power) varies greatly and represents differences in access to resources as well as differences in consumption patterns.

Because of the availability of data we examine the distribution of emissions across states in the U.S. to illustrate how the apparent distribution of emissions across jurisdictional boundaries (potential accounting boundaries) can be impacted by the heterogeneous distribution of resources and facilities that serve regional or national demands. At all levels, of course, the distribution of large facilities is also influenced by a variety of economic, political, historical, infrastructure, cultural, and climatic factors. In this analysis we examine the distribution of emissions from large point sources but we cannot fully disentangle the various incentives that motivate the existence and distribution of large point sources. It is nonetheless clear that some approaches to accounting could result in mitigation strategies that are potentially misleading, ineffective, and/or lead to significant inequities. We also discuss briefl two sub-national emissions mitigation programs in the U.S. – California's cap-and-trade system and the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade partnership among nine northeastern and Mid-Atlantic States. In the two regions where these programs operate the magnitude of emissions from large point sources is at least partially related to the distribution of resources, and the design of the programs has had to consider the potential for emissions leakage that can undermine mitigation benefits.

There is recognition in the literature that the intensity of emissions in a given area is very much influenced by local circumstances. den Elzen et al. (2009), for example, write that comparing per capita emissions ''does ignore limiting factors, such as the availability of renewable energy resources, climatic differences, and historically grown sectoral spreads, among others.'' Even within a country Feng et al. (2013) note that the level of development across China is very different and that this results in large discrepancies in CO_2 emissions and the trade of embodied emissions among regions within the country. Feng et al. show that 57% of China's CO_2 emissions in 2007 were related to goods that were consumed outside of the province where the emissions actually occurred. They further observe that two provinces, ''Inner Mongolia and Shanxi, which together produce more than 80% of coal burned in China. . . export 23% and 36% of the electricity they generate to other provinces.'' In this paper, we use U.S. state-level data to illustrate a similar dynamic in CO_2 emissions distribution among different localities of production and consumption.

2.1. Carbon accounting

We make a distinction between inventorying and accounting of CO_2 emissions. Inventorying is counting, making a complete list: in this case a count of where CO_2 is coming from and where it is going. An emissions inventory may keep track of the fuel sources of the emissions or of the processes that produce the emissions and can even keep track of the products produced to help determine the upstream and downstream emissions of those products. In the U.S, power plants and other large point emissions sources are currently required to count their emissions and report them. All of these emissions and flows of carbon can be tracked as inventories. Accounting, on the other hand, is concerned with information determined relevant for decision making and planning. Accounting implies a measure of attribution or responsibility, and uses inventories of emissions as a starting point. Accounting takes the numbers from an inventory and uses them to make decisions by: attributing emissions to various parties, discounting factors such as time, incorporating economic value to different components of the inventory, and developing rules to drive mitigation and adaptation efforts. Accounting may ignore portions of an inventory if, for example, uncertainties are deemed too large, or for political reasons. We note that a complete inventory is essential since any changes in the assumptions in a particular accounting approach rely on being able to restart with original source data.

Carbon accounting incorporates spatial and sectoral boundaries, time horizons, and both production and consumption flows. Political decisions based on CO_2 accounting are challenging because of geographic and historical heterogeneities and differential benefits from the choice of accounting approach, as reflected in the rich literature of climate change discussions and negotiations (see, for examples, Bernstein et al., 2010; Betsill, 2010; Dimitrov, 2010).

The Kyoto Protocol is based on greenhouse gas inventories– emissions are measured at the point of CO_2 production and individual, national emissions targets are based on those production points that lie within the spatial boundaries of each country. However, traditional production-based inventory policies have often been discussed alongside different possible rules for emissions accounting. Developing countries have long argued that they should not face the same stringency of emission reduction goals as developed countries because it is the developed countries that are responsible for the majority of historical emissions. Leaders of these developing countries further argue that to limit their countries' emissions means to inhibit their capacity for economic development and growth. During the Kyoto negotiations the Brazilian delegation offered an alternative accounting method, arguing for distributing the responsibility for emissions reductions based on cumulative, historical emissions from 1840 onwards (UNFCC, 1997). This would have drastically reduced the responsibility of developing nations like Brazil and China, which had low historic emissions but had rapidly increasing emissions in recent years. The Brazilian proposal is one among a growing number of alternative accounting approaches (den Elzen et al., 2013).

The consequence of these different approaches to accounting is that the burden of emissions can be shifted to or from different parties depending on the accounting approach chosen. Each party generally recognizes which approaches favor their circumstances and tends to advocate accordingly.

A global accounting of consumption-based emissions presents a very different picture of the world than does one based on production alone. In their analysis of global CO_2 emissions from 2004, Davis et al. (2010) found that 23% of global emissions were embodied in international trade, primarily from China and other emerging markets to developed European countries and the United States. Wealthy nations such as Germany, the United Kingdom, and France imported more than 30% of their consumption-based emissions embodied in the production of the goods and services that they imported. The United States imported approximately 11% of its consumption-based emissions, and China exported 22.5% of its emissions embodied in goods and services. Peters et al. (2012) estimated that 37% of global emissions are from burning fossil fuels that have been traded internationally. Emissions embodied in goods and services produced in one country but consumed in another are estimated to represent 22% of global emissions. In addition, harvested wood products, livestock, and food crops are traded across borders and contribute to global emissions but are not always accounted for in the country of consumption. Such distancing between the points of production and consumption has relevance for climate accounting mechanisms and is likely to shape the effectiveness of future climate mitigation initiatives.

Emissions accounting can use indices such as emissions per capita or per unit of GDP. For example, while China has now exceeded the United States in terms of overall emissions, China's per capita emissions of CO_2 are still significantly lower than those of the U.S. and of many other developed nations. While per capita calculations take into account population, they cannot recognize aggregate emissions (Mu¨ ller et al., 2009). Indeed, China's per capita emissions are on par with those of Malta (Boden et al., 2013), but comparing those two nations in terms of total emissions tells a dramatically different story. den Elzen et al. (2013) propose an alternative method to incorporate per capita emissions by deducting allowances for ''basic needs'' – that is, emissions necessary for cooking and heating and the other basic necessities of life. By adopting a basic needs level equal to the ocean's CO_2 sink, they essentially claim to remove the climate change effects of those basic needs emissions. This calculation generates larger contributions to climate change for countries with higher per capita emissions and lower contributions for undeveloped and developing countries. It is clear then, that different approaches to carbon accounting lead to different levels of perceived responsibility across countries, and therefore have important political ramifications. Additionally, despite the fact that climate change is global in scope and has a long history of attempts at international regulation, it has increasingly been addressed at local and regional levels (Rabe, 2011). The general lack of agreement in pushing past the Kyoto Protocol in recent international meetings on climate change has led to little international action on greenhouse gas emissions reductions. This lack of agreement at the international scale has contributed to minimal cohesive activity at the national scale in many countries. In the U.S. it has left individual states, cities, and regions to implement their own climate change mitigation agreements. These smaller scale programs range from U.S. mayors' climate protection agreements (U.S. Mayors, 2005), to states' renewable portfolio standards (RPS), to regional cap-and-trade systems. We argue here that because of variable accounting approaches, resource heterogeneity, and inconsistent spatial and sectoral boundaries, U.S. climate policy is building on a patchwork playing field, potentially leading to ineffective or misleading policies. An analysis of the emissions from large point sources illustrates some of the issues within the U.S. and provides implications for the international context.

3. Per capita emissions and large point sources

The use of per capita emissions has been used frequently as a starting point for conversations about emissions reductions because it effectively accounts for the vast differences in population and population density throughout the world. These discussions imply an individual emissions allocation and generally translate the need for reductions to reductions per individual. Differences in per capita emissions are typically correlated with differences in development; with wealthier, more-developed nations having higher per capita emissions than their less-developed neighbors. Estimates of 2010 national average per capita CO_2 emissions range from 40.1 metric tons per year to less than 0.04, with a global average of 4.9 metric tons of CO_2 per person (Boden et al., 2013). Eighty countries show average per capita emissions over 4.9 metric tons, while 135 countries are below the global average level. These values are based on emissions that occur within the country. While these differences in emissions may reflect differences in development and wealth, they also reflect differences in climate, geography, political stability, and access to resources. Countries with similar levels of development and wealth may have very different emissions per capita because they have very different resource endowments (for example, consider Australia at 16.8 metric tons CO_2 per capita and Sweden at 5.6 metric tons CO_2 per person in 2010) (Boden et al., 2013).

We show that emissions from large point sources have a major impact on national or state levels of emissions and that these emissions reflect a variety of factors, including the heterogeneous distribution of natural resources such as coal, natural gas, and hydropower potential, as well as the delivery of goods and services beyond local demand. Opportunities and commitments in electric power generation will result in the use of coal, natural gas, petroleum, nuclear power, hydropower, or the various renewables, and this preference will very strongly affect local total and per capita CO_2 emissions. The opportunities and economics for large power generation plants can result in large transmissions of power across accounting boundaries, and this also strongly affects local total and per capita emissions. As an illustration beyond electric power generation, 44% of petroleum refining capacity (and the associated CO_2 emissions) in the U.S. exists in a small number of states along the Gulf of Mexico (U.S. DOE/EIA, 2012a), while the refined products are distributed broadly across the nation. With this perspective, we examine the effect of electric power generation and other large point sources on the distribution of CO_2 emissions in the U.S.

A quick look first at the global scale (Fig. 1) reveals that there is a large range in the contribution of electric power generation to national emissions. Values range from less than 1% (e.g. Nepal) to over 70% (e.g. Malta) with an unweighted global average of 27%. Low values represent, for example, both countries with low levels of electrification and those with large contributions from hydropower or nuclear power plants. Including other large-point sources such as natural gas system facilities, petroleum refineries, and large scale industrial production facilities would increase the percentage of emissions from large point sources. Although we focus here on sources in the U.S. and on differences in emissions among states, there is a similar contrast in the proportion of emissions from large point sources in different countries around the world. We see that the variation among countries can be just as great as among adjacent U.S. states. Hence the conclusions we draw from our study are broadly relevant and can offer insights about emissions comparisons at the global scale.

We distinguish here between: (1) emissions from electric power generation, for which U.S. data are available from the U.S. EPA Clean Air Markets Division (U.S. EPA, 2013c) and global data are available from CARMA (2013); and (2) emissions from large point sources broadly (including power generation, petroleum refining, and other large industrial facilities), for which U.S. data are available from the U.S. EPA Greenhouse Gas Reporting Program (U.S. EPA, 2013a), but there is no comparable global data base.

Not only are U.S. CO_2 emissions concentrated at large point sources, but they are heavily concentrated in a small number of very large point sources. The U.S. EPA data set on large point sources (U.S. EPA, 2013a) provides data on nearly 7,000 point sources, with the size distribution shown in Fig. 2A. Fig. 2B shows the proportion of emissions that comes from various size classes. Together, the figures reveal that a small fraction of very large sources produces a large fraction of the total emissions. In short, the largest facilities contribute the bulk of the CO_2 emissions. The largest two size classes (greater than 2.5 million tons of CO_2 per facility) contribute 61% of the total emissions from large point sources. In the U.S. 73% of CO_2 emissions from large point sources are from electric power plants and 33% of total U.S. CO_2 emissions are released at the 311 largest facilities, i.e. those with emissions greater than 2.5 million metric tons of CO_2 per year.

Within the U.S., production-based CO_2 emissions average 18.3 metric tons of CO_2 per capita with a high average of 115.1 in Wyoming and a low average of 8.9 in New York (Fig. 3). Note that all 5 of the states with more than twice the national average value are states with large fossil fuel resources while the 9 lowest values include several states with large hydropower resources (i.e. Oregon, Idaho, and Washington) or large nuclear plants (i.e. Vermont and Connecticut) (see, U.S. DOE/EIA, 2012b). Using state-level data, the unweighted mean of state values is 23.1 metric tons of CO_2 per capita per year with a standard deviation of 18.8 metric tons.

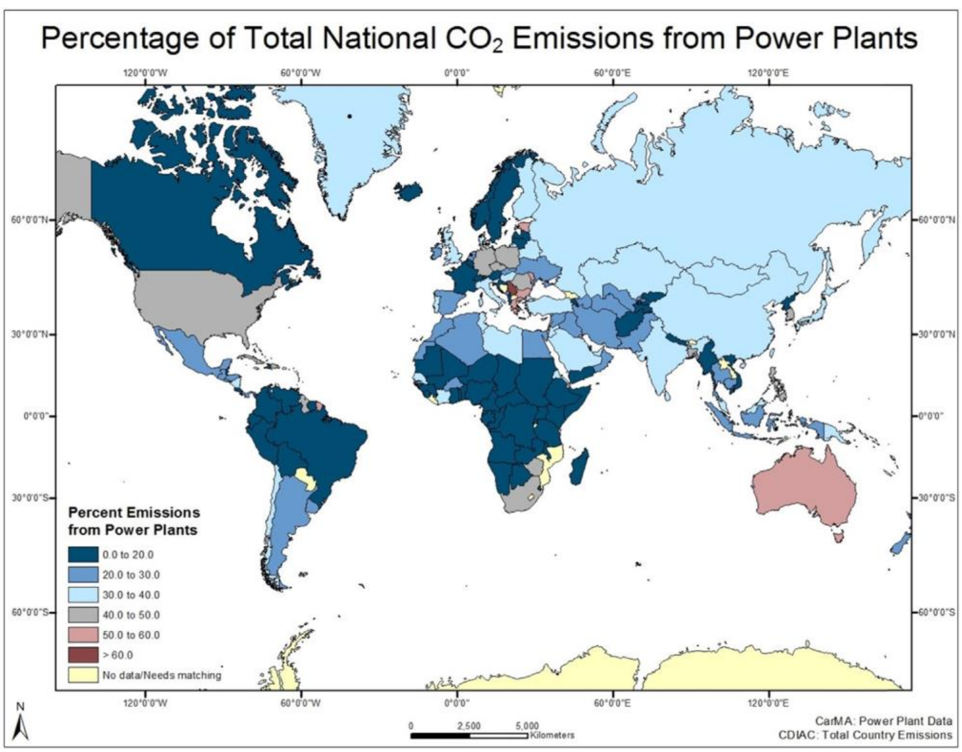

Fig. 1 – The percentage of national total anthropogenic CO_2 emissions (production based) that were from electric power generation in 2009.
National total emissions are from Boden et al. (2012) and power plant emissions are from CARMA (2013).

This wide range of per capita emissions across the U.S. states is not simply a measure of differences in wealth and development. Fossil fuels are unevenly distributed and unevenly used across the United States, as are, for examples, hydropower resources, biological productivity, and solar insolation (see, for example, U.S. DOE/EIA, 2011). Although the distribution of resources is not the only factor affecting per capita emissions by state, isolation of the data on large point sources shows that the distribution of these large point sources has a major impact on per capita emissions across states.

With data on large point sources of emissions we can subtract emissions from large point sources and recalculate average per capita emissions by state for the remaining emissions (Fig. 4). The data on

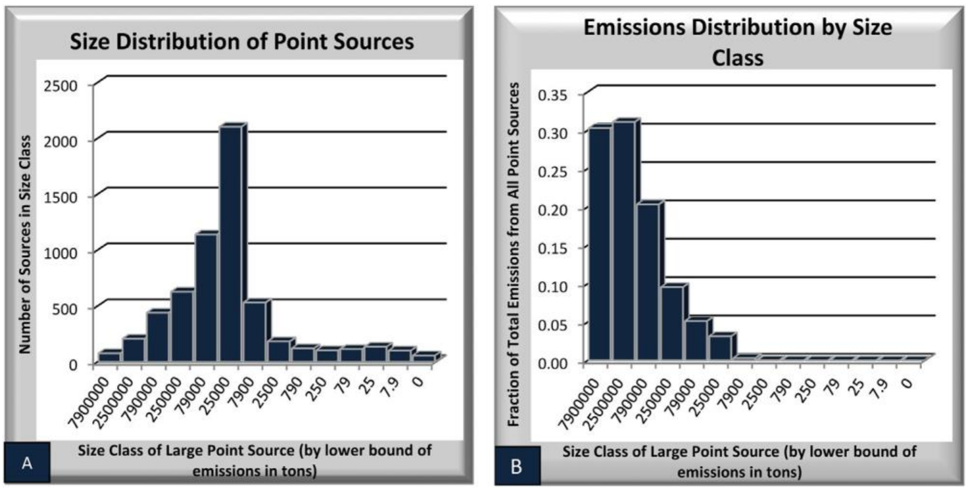

Fig. 2 – (A) The number of facilities per size class for large point sources of CO_2 emissions in the U.S. in 2011. (B) The mass of CO_2 emissions per facility size class from large point sources of CO_2 emissions in the U.S. in 2011. Note that the x-axis scale in both drawings is logarithmic. Values shown are the lower bound of the size class in metric tons of CO_2 per year per facility.
Data are from U.S. EPA (2013a).

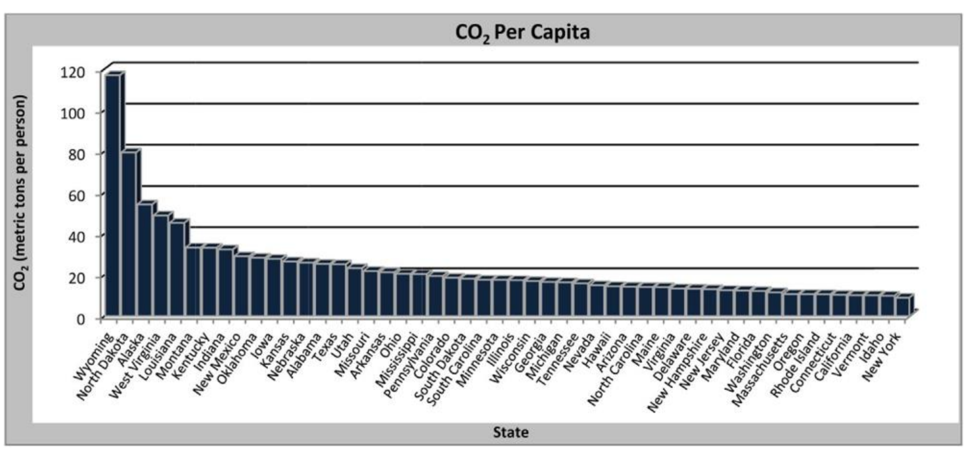

Fig. 3 – Per capita emissions of CO_2 from fossil fuels by state in the U.S. in 2010 when all fossil-fuel emissions are counted and all are attributed to the state in which they physically occur. The national average is 18.3 metric tons of CO_2 per capita. Data are from U.S. DOE/EIA (2013) and U.S. Census Bureau (2011).

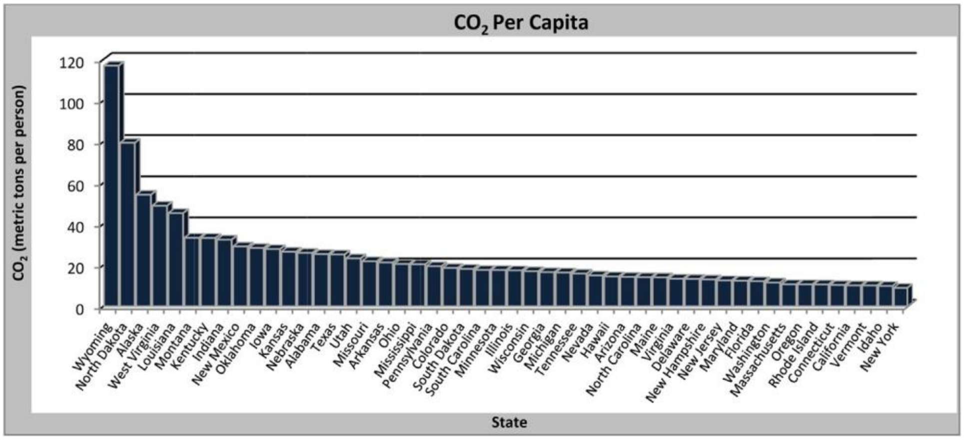

Fig. 4 – Per capita emissions of CO_2 from fossil fuels by state in the U.S. when all emissions are attributed to the state in which they physically occur; showing both total per capita emissions black(dark) and per capita emissions when emissions from large point sources (as defined in the text) are not counted red(light).
Data are from U.S. DOE/EIA (2013), U.S. Census Bureau (2011) and U.S. EPA (2013a).

large point sources for the U.S. include nearly 7,000 sites that either have electric power generation, greenhouse gas emissions in excess of 25,000 metric tons CO_2 equivalent, or otherwise reported emissions to the EPA reporting program. The list is dominated by power generation but includes refineries, oil and gas facilities such as pumping stations, cement plants, steel mills, and other large industrial facilities that are typically CO_2 intensive and serve greater than local demand.

Removing emissions from large point sources, of course, lowers the per capita emissions of all states, but more interestingly it drastically narrows the range of per capita emissions across states. Alaska now has the highest per capita emissions with 30.95 metric tons of CO_2 emitted per person, and Arizona has the lowest at 5.8 metric tons per capita. The unweighted mean value across states is reduced to 9.6 tons CO_2 per capita with the standard deviation reduced to 4.4. Only 3 states (Alaska, North Dakota, and Louisiana) fall outside of the range of 5.8 (Arizona) to 11.4 (West Virginia) tons CO_2 per capita (Fig. 4). These three anomalously high states are places where we will have to look elsewhere to explain the remaining high per capita emissions values, but we note that all are major producers of petroleum and/or natural gas and both Alaska and Louisiana are hosts to large off-shore production. In sum, per capita emissions of CO_2 across the U.S. are quite uniform when emissions from large point sources are not included.

It is important to recognize the role of large point sources when creating public policies on emissions. We have seen that differences in natural resource endowments and large point source locations

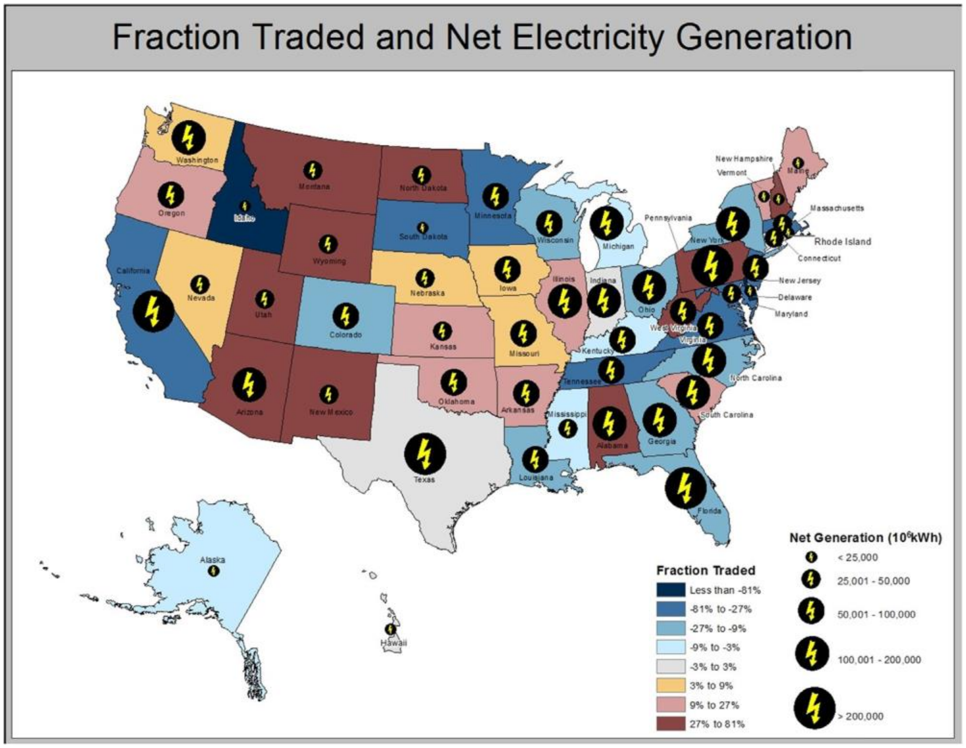

Fig. 5 – The net generation of electricity for U.S. states in 2009 and the fraction that is traded either internationally or interstate. Positive values represent net electricity exports, while negative values are net imports.
Based on data from U.S. DOE/EIA (2012b).

contribute to individual states producing vastly different amounts of CO_2 and CO_2 per capita. These large point source emitters support the states in which they reside, but they also export electricity to neighboring states and provide goods and services to fulfill demand throughout the country and beyond. Data on trade in electric power are available and Fig. 5 shows for each state the fraction of electricity generation that is traded across state or national borders. The calculation represented in Fig. 5 is:

Fraction of electricity traded = Net exports/Generation – system losses

where all numbers are in kwh and positive values represent net exports and negative values represent net imports.

It is clear in Fig. 5 that electrical imports and exports vary greatly among states. It comes as no surprise that states with the highest percent of emissions from large point sources are all states rich in fossil fuels (West Virginia, Wyoming, North Dakota, Kentucky, and Arizona round out the top five, and all but Kentucky are net electricity exporters). The states with the lowest percent emissions from large point sources tend to be lacking in fossil fuel resources (Vermont, Idaho, California, New Jersey and with the exception of oil-producing Alaska) and all but Vermont are electricity importers. The variation in electrical imports and exports, and per capita emissions, has the potential to influence state and regional climate change policies. As an example, states with large net generation and a high rate of electricity imports, such as New York and California, might find it politically easier to implement a cap-and-trade program. Large net generation helps because it gives a state somewhere to cut emissions. For example, since most of Idaho primarily uses hydroelectric power, few of their CO_2 reductions could come from the electricity sector, which would restrict their ability to spread out emission reductions. Large imports help because any reductions a state makes internally could be buffered by imports. California, for example, produces a large amount of CO_2 and imports a large amount of its electricity from neighboring states like Arizona and Oregon. New York also has high generation and high import rates, and is a neighbor of Pennsylvania, one of the nation's largest generators and exporters of electricity. Both California and New York show very low per capita CO_2 emissions (Fig. 3). In the next section we review two specific climate policy schemes: California's cap-and-trade system and the Regional Greenhouse Gas Initiative (RGGI), a cap-and- trade partnership between nine northeastern and Mid - Atlantic States, including New York.

4. State-level climate policy in the United States

Within the U.S. there are currently two state-level programs to limit CO_2 emissions. The Regional Greenhouse Gas Initiative (RGGI), based in the northeast, was conceived as a regional emissions trading scheme in 2003 and the first auctions of emissions allowances were sold in 2008. Compliance began on January 1, 2009 (see EDF, 2013a, for a short summary of the RGGI program). The program only impacts emissions in the utility sector. California initiated the Global Warming Solutions Act, California Assembly Bill 32 (AB 32) (California, 2006), in 2006 in an attempt to lower emissions to 1990 levels by the year 2020 (Hogan, 2008). The cap-and-trade system went into effect on January 1, 2013 (see EDF, 2013b, for a short summary of the California program).

Of the 50 U.S. states only these 10 currently have specific CO_2/greenhouse gas emissions policies. Although it is not clear what drives the legislation to create these mitigation programs, the ultimate question is whether state-level emissions limits are able to have a significant impact on total, national-level emissions. This will be influenced by whether states are cognizant of state-level resource distributions, and whether they are likely to avoid additional emissions leakage and the trans-boundary trade of embodied emissions. Here we use the term emissions leakage to refer to a source of emissions caused by one party that is either misattributed to another party or not attributed at all within the accounting framework. In particular, leakage might result from a shift in electricity production from regulated jurisdictions to unregulated jurisdictions in the case of incomplete regulation (Chen, 2009; Fowlie, 2009; Price et al., 2009). Trans-boundary trade of embodied emissions refers to products that are consumed in one location but cause emissions in another (e.g. gasoline refining, forest products, etc.). Some climate change policies might result in uncontrolled emissions leakage and ultimately fail to reduce total emissions in any meaningful amounts. Mitigation policies might also create regional inefficiencies and/or inequities that derive from the unequal distribution of natural resources or the efficiencies of scale of large facilities. To understand the impact of a policy, it is important to understand to what extent the policies are crafted to acknowledge current trans-boundary trade in embodied emissions and the potential for emissions leakage.

The percent of emissions from large point sources appears to correlate with state-level CO_2/greenhouse gas policy emergence. All ten states that have implemented an emissions trading policy are ranked below 36th in a ranking of states in terms of percent emissions from large point sources. That means that ten out of the fifteen states with the lowest fraction of emissions from large point sources have been the first to have instituted policies to limit CO_2 emissions (if we count New Jersey's initial participation in the RGGI it would be 11). It is important to keep in mind that the data presented here are for 2009, the first year of RGGI's program, and before California's law went into effect.

Conversely, several of the states that border currently regulated states and supply them with electricity emit significantly greater amounts of CO_2 from large point sources. West Virginia, for example, which is part of an electricity network that includes some RGGI states, has the highest percentage of emissions from large point sources in the country and Arizona, which exports a significant amount of electricity to California, has the fifth highest. Pennsylvania and Nevada, both of which also supply electricity to regulated states, are among the twenty highest in percentage of large- point-source emissions. New Mexico, though it does not border California, does account for some of California's imports, and also has a very high percentage of large point source emissions due to its easy access to large amounts of coal. Only 4 states export electricity to regulated states but have relatively low percentages of emissions from large point sources: Virginia (an observer state and possible future member of the RGGI), New Jersey (a participant in the RGGI until 2012), and Oregon and Washington (both of which have large amounts of hydropower generation).

Though California and the RGGI partner states are regulating their own electricity generation, imported electricity could, if not regulated, increase or otherwise change and reduce the effects of the regulation. Contract or resource shuffling, in which an unregulated plant that previously delivered to the newly-regulated location shifts its delivery outside the realm of regulation, could avoid any actual emissions reductions (Price et al., 2009). In the face of multiple jurisdictions and regulations for greenhouse gas mitigation, emissions leakage needs to be addressed in any regulatory measure to curb greenhouse gases. Policies can be constructed in ways that minimize leakage, but this would require alternate, consumption-based methods of carbon accounting as opposed to more traditional production-based methods.

A cap-and-trade system, for example, can function in a variety of ways, which primarily depend on who is capped and who is trading. One possibility is a source-based cap-and-trade system under which a prescribed quantity of emissions allowances is provided (either directly distributed or sold at auction, or a combination) to generators that then trade amongst themselves. Total emissions cannot exceed the number of allowances provided (Chen et al., 2011). Under this system only the generating units within the regulated area participate in the trading scheme, and therefore imported electricity, for example, is not accounted for. Alternatively, a first-seller approach incorporates both in-jurisdiction generation and imports. A first seller is defined as ''the entity that first contracts to sell electricity'' (Chen et al., 2011) in the regulated region, and therefore may exist outside the political boundaries of legislation. Under this type of a program the first seller is responsible for emissions associated with the electricity it sells within the regulated area and all of these participate in the allowance trading (Chen et al., 2011). We explore the emergence and policy options of cap-and-trade systems using California's AB 32 and the RGGI as useful case studies.

4.1. California AB 32

The first CO_2 emissions reduction bill in the United States mandated enforceable regulations and the California Air Resources Board set emissions targets out to 2020 that represent substantial reductions below business-as-usual (Hogan, 2008; EDF, 2013b). California implemented a cap- and-trade system that would be phased in over a period of years, and whose inherent flexibility would allow individual emitters to choose a cost-effective way to lower their emissions or to buy permits from other parties if they were unable to cheaply reduce their own emissions.

California ultimately settled on a first-seller approach and added restrictions to try to limit leakage. Regulated under the program are electric utilities, electricity importers, and industrial sources that produce more than 25,000 metric tons of CO_2 equivalent annually. Industrial sources include cement plants, petroleum refineries, and steel, iron, pulp, paper, glass, and lime manufacturing (Caron et al., 2012). The Air Resources Board will monitor the system for gaming or fraudulent activity. California held its first emissions allowance auction in November of 2012, and January 1, 2013 saw the official start to the cap-and-trade program. A second phase begins in 2015, and expands the list of regulated entities to include transportation fuels, natural gas, and other fuels (Caron et al., 2012).

In addition to addressing imported electricity, California attempts to limit leakage through addressing contract shuffling, which it defines as ''any plan, scheme, or artifice to receive credit based on emissions reductions that have not occurred, involving the delivery of electricity to the California grid'' (quoted in Caron et al., 2012, 5). If a seller simply sells California cleaner energy and sends its dirtier energy elsewhere, no emissions reductions have actually occurred so this behavior is discouraged. However, as Caron et al. (2012) point out, enforcing the contract shuffling regulation may require sanctions against importers and therefore raises questions, subjecting it to legal challenges. Indeed, enforcement of the policy was suspended for 18 months beginning on January 1, 2013, due to concerns over the vagueness of the definition of contract shuffling (Gibbs and Kline, 2013).

4.2. RGGI

The RGGI was formalized on December 20, 2005, when seven states signed a Memorandum of Understanding to implement a regional cap-and-trade program. Connecticut, Delaware, Maine, New Hampshire, Vermont, New York, and New Jersey were the original participating states, and they were followed by Massachusetts, Rhode Island, and Maryland in 2007. The program sets individual state caps which are aggregated into a multi-state CO_2 cap. Starting in 2015 the cap will decrease by 2.5% each year until 2018. All fossil-fuel-fired electric power generators with a capacity above 25 MW must have allowances equal to their annual CO_2 emissions, and allowances can be freely traded among states. CO_2 allowances are allocated through quarterly auctions, with the proceeds going to programs to improve energy efficiency and renewable energy technologies (RGGI, 2013).

When developing the specifics of its cap-and-trade program, the RGGI considered a variety of ways to address emissions leakage, including policies that reduce the demand for electricity, policies that seek to reduce emissions of individual load serving entities (LSE) without specifically capping them, and policies that include LSE emissions in the overall cap, similar to California's first-seller approach. The working group ultimately recommended that trying to reduce the total demand for electricity was the most viable option, and that ''because of their administrative complexities and challenges, as well as untested effectiveness as leakage mitigation strategies,'' the other two policy options should not be implemented at the time (RGGI, 2008). The RGGI is thus a source-based trading program, and, unlike California, regulates only electrical generating units and does not address large manufacturing plants or stationary combustion sources. In a summary of the RGGI program the Environmental Defense Fund (EDF) noted that ‘‘RGGI state[d] commitment to identify a workable policy to address emissions associated with imported electricity’’ (EDF, 2013a), though such a policy has not been enacted.

4.3. Preliminary perspective on emissions leakage

Because both the RGGI and California policies were implemented so recently, it is still not possible to determine their efficacy and their impact on large point sources of emissions. However, predictive models and emissions data have been used to try to look at the leakage that might be produced with each policy. Because California has extensive natural gas resources, 92% of the electricity generated within the state is through combustion of natural gas. Arizona, Nevada, and Utah, all states that export electricity to California, use more carbon-intensive, coal-fired generation units. Washington and Oregon, on the other hand, which also export electricity to California, are actually less carbon-intensive because of a preponderance of hydropower opportunities (Caron et al., 2012).

A number of studies performed predictive modeling to evaluate the different policy options once California announced its intention to develop a cap-and-trade system. Depending on the model used, emissions leakage ranged from 1.5% (Caron et al., 2012) to 85% (Chen et al., 2011). Chen et al.’s (2011) model showed that California itself could reduce its emission to fall under the cap, but the carbon-intensive Southwest region could shift its exporting from California to the Pacific Northwest, which would then be able to export more of its clean electricity to California. As a result of contract shuffling then, the neighboring regions would show no decreases in emissions. Caron et al.’s (2012) low leakage model stipulated that contract shuffling was illegal, and therefore the current exporters to California must abate their emissions in order for California to meet its reduction target. While this model most closely imitates the initial legislation, as discussed above the contract shuffling law faces legal pressure as well as difficulties in enforcement and is not currently enforced. It remains to be seen how much emissions leakage actually results from AB 32.

The RGGI system, unlike California, currently makes no attempt to deal with electricity imports, and therefore numbers for predicted leakage are either unavailable or highly speculative. Maryland and Delaware, both RGGI states, are part of the PJM Interconnection electricity market, which also includes Pennsylvania, West Virginia, Virginia, New Jersey, and Washington, DC, none of which are currently regulated under the RGGI. In the full PJM network, only 23.7% of installed capacity is at coal plants (Chen, 2009), whereas 45% of installed capacity is from coal in the non-RGGI states that are part of PJM, and much of this electricity is exported to RGGI states. Using models that imitate the RGGI regulations, Chen (2009) found that emissions leakage would be expected to be between 70% and 90%, depending on the elasticity of supply and demand. The RGGI working group (RGGI, 2007) estimated leakage at a significantly lower level of 27% but the 2012 RGGI program review called for a policy to address emissions from imported electricity. Some of the difference in expectations may be accounted for by Chen’s (2009) focus only on the PJM network, and neglect of the rest of the RGGI partner states.

Time will be required to determine the extent to which the California and RGGI systems affect the distribution of large point sources and the national total of CO_2 emissions, but both systems started with recognition of the problem and envisioned systems that would internalize emission reductions and minimize leakage.

5. Conclusions

A large fraction of CO_2 emissions from fossil fuel combustion comes from large point sources. Focusing on these large point sources for mitigation of emissions is a common and logical approach, but including these emissions in emissions accounting for specific geographical areas needs to be done with care. Because large point sources typically respond to the distribution of resources and the benefit of economies of scale, and because these facilities typically produce power or other goods that are consumed at regional or larger scales, the emissions are not necessarily representative of local-scale consumption. Measures of emissions per capita can lead to misrepresentation of responsibility for emissions. Allocation of emissions responsibility or mitigation effort needs to be cognizant of the different role of large point sources as compared with local-scale consumption. We note that this analysis is particularly relevant to a pollutant like CO_2 where the impact is global and the location of the source of emissions does not materially affect the environmental consequences of the emissions.

The uneven distribution of fossil fuels and alternative energy resources contributes to a region's energy portfolio and economic decision-making. It can indirectly influence policy attempts to mitigate anthropogenic greenhouse gas emissions. California and the RGGI states in the U.S., largely states with low values for per capita CO_2 emissions, have taken the lead in climate change actions within the U.S., implementing cap-and-trade systems that could serve as models for a national program in the future. However, the two programs offer quite different policies, and their ability to affect national level CO_2 emissions is yet to be understood. When regulatory measures are incomplete or differ between regions or countries, carbon leakage may occur and undermine the intent of the policy. Under the Clean Air Act, for example, industrial emissions in nonattainment areas with stringent standards have been to some extent displaced by industrial growth in attainment areas with less stringent and cheaper standards (Bushnell et al., 2008). This may be a desirable outcome for a pollutant with primarily local impacts, but it is less desirable for a stock pollutant with global impacts such as CO_2.

The data on emissions from large point sources in the U.S. show that they have a major impact on the distribution of CO_2 emissions. As emission mitigation policies spread and connect, issues of leakage and trans-boundary trade will be important. Local or regional-level policies should be designed with an eye to the spatial and temporal accounting boundaries and the role of large point sources. Using a simple per capita measure does not adequately reflect a party's opportunity for emissions reduction or its emissions mitigation responsibility. Policies to reduce CO_2 emissions must be aware of issues of scale, trans boundary transfers, and equity. Continuing international and national negotiations need to be aware of geographical, historical, and resource heterogeneities.

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