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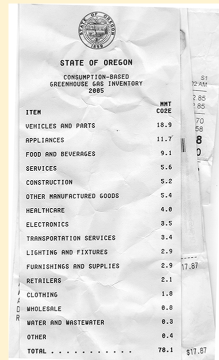
A Consumption-Based GHG Inventory for the U.S. State of Oregon

Peter Erickson,[*,†] David Allaway,[‡] Michael Lazarus,[†] and Elizabeth A. Stanton[†,§]

[†]Stockholm Environment Institute (U.S. Center), 11 Curtis Ave. Somerville, Massachusetts 02144-1224, United States
[‡]Oregon Department of Environmental Quality, 811 S.W. Sixth Avenue, Portland, Oregon 97204, United States

ABSTRACT: Many U.S. states conduct greenhouse gas (GHG) inventories to inform their climate change planning efforts. These inventories usually follow a production-based method adapted from the Intergovernmental Panel on Climate Change. States could also take a consumption-based perspective, however, and estimate all emissions released to support consumption in their state, regardless of where the emissions occur. In what may be the first such comprehensive inventory conducted for a U.S. state, we find that consumption-based emissions for Oregon are 47% higher than those released in-state. This finding implies that Oregon's contribution to global greenhouse gas emissions (carbon footprint) is considerably higher than traditional production-based methods would suggest. Furthermore, the consumption-based inventory helps highlight the role of goods and services (and associated purchasing behaviors) more so than do production-based methods. Accordingly, a consumption-based perspective opens new opportunities for many states and their local government partners to reduce GHG emissions, such as initiatives to advance lower-carbon public sector or household consumption, that are well within their sphere of influence. State and local governments should consider conducting consumption-based GHG inventories and adopting consumption-based emission reductions targets in order to broaden the reach and effectiveness of state and local actions in reducing global GHG emissions. Consumption-based frameworks should be viewed as a complement to, but not a substitute for, production-based (in-state) GHG emissions inventories and targets.



■ INTRODUCTION

Over the past two decades, a relatively standard method has evolved to account for greenhouse gas (GHG) emissions by geographic scale. Widely referred to as the production-based method, it involves quantifying emissions produced within a regional boundary, such as a nation,[1] subnational territory,[2] or community.[3] Emission sources within that boundary are identified, such as power plants, vehicles, or ruminant animals (e.g., cattle, sheep), and methods are applied to estimate their annual emissions of carbon dioxide and several trace gases.

Most production-based emission estimates draw from methods first set forth in 1994 by the Intergovernmental Panel on Climate Change for use by nations in compiling their official GHG inventories.[1] These methods serve as the official methods for nations to submit inventories and track progress toward emission-reduction goals, such as those established in the United Nations Framework Convention on Climate Change and the Kyoto Protocol.

Over time, analysts have pointed out limitations in production-based GHG accounting. One prominent critique is that the production-based method may give a misleading impression of national progress in curbing GHG emissions, as decreases (or increases) in national emissions may be due to the shift in emissions-generating activities (such as manufacturing) to (or from) another country, without decreasing (or increasing) total global emissions.[4−7] As an alternative, several authors have suggested consumption-based emissions accounting, which includes the emissions embodied in trade and would therefore, in principle, account for such carbon leakage effects, whether due to climate policy or broader economic trends.[8] Alongside discussions of emissions accounting, policy dialogues have focused on addressing leakage from differential carbon pricing, with a particular focus on mechanisms, such as border taxes or free allocation of allowances to industry, that would level the carbon costs associated with producing goods or services in different countries.[9−13] The European Union has recently finalized its rule for freely allocating emissions allowances to energy-intensive and trade-exposed industries in the EU,[13] but methods for addressing leakage from several other major industrialized countries (especially the U.S.) are, like national-scale climate policy itself, not as developed.

Concerned over the relatively slow pace of national-scale climate policy in the U.S., many subnational governments, such as states and cities, have stepped forward with more vigorous policy responses.[14] Accordingly, the methods that subnational territories use to account for emissions—and the policy tools they have at their disposal—may be critical in identifying new pathways for tracking and achieving emissions reductions.

Most state-level GHG inventories in the U.S. have used the IPCC's production-based method,[1] as adapted for U.S. states by the U.S. Environmental Protection Agency.[2] However, in recent years, some states have departed from the common practice in order to account for emissions associated with electricity used within the state, regardless of whether it is generated within or outside the state. Using this method helps to better align a state's inventory with actions it can take to reduce emissions, such as promoting efficiency in electricity use

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or sourcing electricity from renewable energy sources, and as such, provides important insights on how to design emission reduction strategies. This method, which is sometimes itself called a "consumption-based" approach for electricity, has also become common for community-scale GHG inventories in the U.S.[15] as well as for business GHG inventories.[16] Extending the consumption perspective to other products and services, as this paper will show, can extend such opportunities far more widely.

In this analysis, we conduct a full consumption-based GHG inventory for all products and services, not just electricity, for all consumption in the U.S. state of Oregon. While several studies have conducted consumption-based GHG inventories at national[6,17−21] and community[19,22−24] scales, and some have looked at GHGs associated with subsets of consumption at the state level,[25,26] our analysis here provides what we believe is the first such comprehensive assessment for all consumption within a U.S. state. Based on original input-output modeling analysis, we present estimates of the GHGs released to make, transport, use and dispose of all goods and services consumed in Oregon.

Oregon's official annual GHG inventory,[27] which has been prepared for over a decade, is largely production-based (except for electricity). It serves as the basis for tracking progress toward achievement of the state's emission reduction goals of 10% less than 1990 levels by 2020 and 75% less than 1990 levels by 2050. That inventory has also provided guidance in targeting major emissions sources and in designing actions called for in numerous state plans and legislative initiatives.[28−31] This new, companion, consumption-based GHG inventory can help clarify the role of Oregon's consumption in global GHG emissions, as well as to identify the specific contribution of different product types, ranging from food and beverages to clothing and appliances, to Oregon's overall emissions footprint. It can also open up new opportunities to reduce global GHG emissions, such as through efforts to advance sustainable consumption,[32,33] and, if applied over time, could also help quantify emissions leakage, just as other assessments have done at national scales.[4,6]

Oregon, other states, and other subnational governments may be an important venue for considering consumption-based GHG accounting. For one, these governments play leadership roles in advancing climate policy. In addition, the difference between consumption- and production-based perspectives may be more extreme at smaller scales. As described below, this is indeed the case in Oregon as compared with the U.S. as a whole.

■ MATERIALS AND METHODS

Organization of economic data into input-output tables allows for expenditures in one sector of the economy to be tracked to all other sectors.[34] For example, by using input-output analysis, it is possible to estimate what fraction of the cost of an average automobile is retained by the manufacturer, what fraction the manufacturer spends on steel, what fraction the steel mill spends on iron ore versus electricity and other inputs, and so forth. If the emissions intensity (per-dollar) of each of these industries is known, total greenhouse gas emissions released to produce the car can be estimated by totaling the emissions from each individual activity in the product chain. Since the U.S. government assembles detailed economic data for the entire country (and, to some degree, for U.S. states), similar assessments for entire economies (not just automobiles) can be feasibly conducted.

Our analysis for Oregon takes just such an approach.[35] First, we start with the widely used IMPLAN input-output model based on data from the U.S. Commerce Department's Bureau of Economic Analysis, the U.S. Bureau of Labor Statistics, the U.S. Census Bureau, and other sources.[36] From IMPLAN, we extract final demand for four types of institutions responsible for expenditures: personal or household consumption, which accounts for approximately two-thirds of final demand; Oregon-based federal government; state and local government entities; and investment expenditures in capital formation and net inventory replacement. Because our model considers all types of final demand, it is more comprehensive than methods that look only at the carbon footprint of household consumption[25] and those that exclude government spending.[17,19] IMPLAN also produces data series at the level of U.S. counties and zip codes, suggesting it could be used to conduct similar analyses at the local level.[37]

IMPLAN organizes final demand data into about 500 sectors. We multiply this vector of final demand by IMPLAN's input-output matrices to calculate gross (or direct plus indirect) demand. Gross demand is calculated for Oregon (including Oregon's final and intermediate purchases of commodities produced in Oregon), the other 49 states (including Oregon's final and intermediate purchase of commodities produced in the other 49 states, where intermediate purchases are used to produce final products consumed in Oregon), and foreign (including Oregon's final and intermediate purchase of commodities produced in foreign countries). For a description of the method used to estimate final and gross demand by region (Oregon, U.S., foreign) of production, please see the additional methodology material available online.[38] Gross demand for each location of production is then multiplied by the appropriate emissions intensity (Oregon, U.S., or foreign), derived as follows.

To develop emissions intensities for each region and sector of the economy, we use existing GHG inventories that address carbon dioxide and other gases (e.g., methane, nitrous oxide). For U.S.-produced goods (outside Oregon), we rely largely on the U.S. Energy Information Administration (EIA)'s national GHG inventories,[39−41] which provide significant sectoral detail, divided by total industry output (in dollars) by sector from IMPLAN.[36] Similarly, for Oregon-produced goods and services, we take emissions from the state's official GHG inventory[27] divided by industry output in the respective sectors of the economy.[36] Where the EIA and Oregon inventories are not disaggregated by sector (e.g., fuel use by industry or commercial services), we allocate emissions to sectors in proportion to their economic output. For international emissions intensities, we map results from a 57-sector global multiregional input-output model[5] to IMPLAN categories. This approach for addressing emissions from foreign production represents an improvement over existing community and national-scale input-output models that assume foreign production has the same emissions intensity as domestic production.[19,42] Further details on the development of emissions intensities by region and sector are available online.[38]

For emissions associated with direct use of fuels by households or government, we use Oregon's existing GHG inventory together with EIA analysis and data[43] and an assessment of energy end-use conducted by the Northwest Power and Conservation Council.[44] For emissions associated with postconsumer disposal of waste, we use waste disposal data from Oregon DEQ[45] and emission factors from the U.S.

EPA[46] adjusted for DEQ's current and projected future rates of landfill methane recovery.

The end result of this process is an integrated model of the GHG impacts of Oregon's consumption: the consumption-based emissions inventory (CBEI) model,[35] which relates consumption (in dollar terms of final demand) to GHGs (in terms of tons of carbon dioxide equivalent, CO_2e) for each of the approximately 500 categories in IMPLAN. As described above, unlike other input-output life-cycle models commonly applied to the U.S.,[19,42] CBEI models foreign production explicitly, instead of assuming that foreign production has the same emissions intensity as domestic production. CBEI also expands upon existing approaches to model and report results by institution (households, government, or investment demand), life-cycle phase (production, transportation, wholesale/retail, use, and disposal), and geography (where the emissions were released: Oregon, rest-of-U.S. or international).

All estimates of emissions associated with consumption in Oregon exclude any emissions associated with land-use change (e.g., clearing of forest to allow for planting of crops) due to data and modeling limitations. As a result, emissions associated with some products (e.g., those grown in the tropics on recently cleared forestland) may be underestimated. For example, one study found that accounting for land-use change could add 57% to the emissions associated with Brazilian beef.[47] However, since Brazilian beef (and, more broadly, tropical beef) represents only a small portion of the beef consumed in the U.S., this would have a much smaller impact on emissions associated with the average beef consumed in Oregon. This example shows that significant differences may exist between particular products or producers—differences that our model cannot distinguish.

Of course, economic input-output analysis is not the only method of conducting a carbon footprint or life-cycle inventory, as process-based and hybrid methods also exist.[48] For the purpose of conducting a consumption-based GHG emissions inventory for all consumption in a given region, however, input-output analysis has the clear advantage in that it can use existing government economic data and input-output tables to manage what could otherwise be an unmanageable task of conducting or compiling hundreds of process-based life-cycle studies for all types of goods and services consumed in a community. Input-output analysis also helps avoid truncation errors associated with leaving out far-upstream stages of production processes.[49] However, economic input-output methods assume that emissions scale directly with expenditures (for example, that a piece of clothing that costs twice as much as another has twice the emissions) and obscure the fact that higher levels of expenditures could instead be directed to increased quality with few if any increases in emissions.[50] How input−output models, or hybrid alternatives, can address how emissions scale with expenditures in particular categories (or income, which is closely related) remains an important area for further research, as it has important implications for the creation of consumption-based inventories, and identification of emission reduction measures, in communities with differing socio-economic composition.[19,51]

■ RESULTS

Our principal finding is that the emissions "footprint" of Oregon's consumption is significantly greater than the emissions released within state boundaries. We estimate that 78 million metric tons carbon dioxide equivalent (MMT CO_2e) were associated with the consumption of goods and services in Oregon in 2005, compared to the 53.2 MMT CO_2e released within the state in the same year.[27] Emissions associated with Oregon's consumption are roughly 47% greater than the emissions released within state boundaries. This difference is greater than for the nation as a whole, for which a consumption-based GHG inventory[52] is about 17% greater than a production-based inventory.[53]

In short, because Oregon imports more goods and services (particularly emissions-intensive products, such as electricity and vehicles) than it exports, its share of global GHGs exceeds the emissions released within the state.

Of Oregon's 78 MMT CO_2e, a little more than half (42 million, or 54%) were released outside of Oregon, largely in other U.S. states (24 million, or 32%) and to a lesser extent (18 million, or 22%) in other countries.

The distribution of emissions far beyond Oregon's boundaries reflects the complex international supply chains for many products. For example, an Oregonian's purchase of a car assembled in Tennessee would be associated with some emissions in the U.S. at the assembly plant. In addition, emissions might occur at factories in other countries where component parts are fabricated, materials such as steel are produced, or raw materials such as iron are extracted.

Provision of Goods and Materials. In addition to assessing overall levels of emissions associated with consumption, our model also allows for calculation of emissions associated with the production, transportation, sale, use and disposal of goods and services consumed in Oregon. Our consumption-based GHG inventory for Oregon finds emissions associated with each of these phases to be (1) *Producer*, 39.0 MMT CO_2e: manufacturing, growing, raising, or otherwise producing a good, material or service, including any supplies or materials needed; (2) *Prepurchase transportation*, 3.4 MMT CO_2e: transporting supplies or materials to a manufacturer or other producer, transporting a good from producer through wholesaler to retailer (to the extent producers undertake their own transportation instead of purchasing transportation services, these emissions are included in the *producer* phase, due to the nature of input-output analysis; the *prepurchase transportation* phase includes only purchased/contracted transportation); (3) *Retail/Wholesale,* 2.9 MMT CO_2e: operating wholesale and retail establishments; (4) *Use,* 32.0 MMT CO_2e: using a good, such as a personal vehicle or home heating system; and (5) *Postconsumer disposal,* 0.8 MMT CO_2e: disposing of postconsumer wastes in landfills or incinerators. Producing all goods and services consumed in Oregon (i.e., the *producer* phase) releases slightly more greenhouse gases than using them (i.e., the *use* phase). By contrast, purchased transportation involved in goods and services represents a relatively minor share, as do emissions at retail/wholesale establishments and disposing postconsumer goods.

Consumption-based emissions can also be categorized by type of consumption, whether by the approximately 500 categories in our model or by broader, aggregated categories. For example, emissions can be divided into four broad categories, related to consumption (final demand) of electricity, fuels, materials and services. Table 1 shows the results of this approach.[54]

Emissions associated with materials and services in Table 1 include emissions resulting from electricity and fuel required to produce those materials and services and transport them to consumers, while the "electricity" and "fuels" categories include

Table 1. Oregon's Consumption-based GHG Emissions by Category

category	2005 emissions (MMT CO_2e)
electricity	12.0
fuels	20.1
materials[a]	27.5−37.1
services[a]	8.8−18.5
total	**78.1**

[a]Some commodities can be classified as either "materials" or "services", such as restaurants (technically a service, but largely associated with the provision of materials) or home construction. Here we treat these types of commodities as either "materials" or "services", and so display the results for these categories as ranges.

only emissions resulting from direct use of electricity and fuels by consumers. Thus, efforts to reduce both the use and carbon intensity of fuel and electricity across the full economy (consumers and producers) are more important than Table 1 might suggest. But from the Oregon consumer's perspective, Table 1 shows that the quantity and types of materials purchased can have significant bearing on GHG emissions—even more so than direct purchases of fuel or electricity. Compared to electricity and fuels, strategies for reducing emissions associated with the consumption of materials have not been as well evaluated, and the relative importance of materials is not commonly accounted for in public information on climate mitigation. Further development of that field may be an important element of future emissions reduction work.

The broad conclusion that producing and using goods is a significant contributor to GHG emissions in Oregon underscores the importance of consumption on emissions. Simply by buying products, Oregonians contribute to climate change through emissions released to make these products. Using the products (especially vehicles and home heating equipment) also releases significant emissions. Efforts to practice or promote "sustainable consumption"[55] would therefore need to look at which products and services are particularly emissions-intensive to produce in addition to which are particularly intensive to use, so that consumers can focus on decisions that are likely to have the greatest benefit.

Unsurprisingly, different types of products and services require varying quantities of energy and GHGs to produce. Some products, such as vehicles, which have both complex supply chains and use large quantities of metal, require large amounts of energy, which, when based on fossil fuels, releases correspondingly high quantities of GHGs. Other products, such as food, require both significant amounts of energy and also release emissions when fertilizers are applied to soil or when animals (particularly cows) digest their feed. Table 2 presents emissions by product category and consolidated life-cycle phase. Emissions in this table are allocated to each category based on the life cycle of activities and emissions associated with each product or service, including component parts, electricity use and other inputs. In this table, emissions associated with transporting and selling products through wholesale and retail channels are counted under the *transportation services, retailers* or *wholesale* categories and not within the respective "pre-purchase" figure for each individual product or service category. For example, emissions associated with *transportation services* are those resulting from actual final demand for transportation as a service (e.g., passenger air travel) as well as the transportation needed to move final products to warehouses and stores.

Table 2. Oregon's Consumption-based GHG Emissions by Life-cycle Phase and Product Category (MMT CO_2e in 2005)

	total	prepurchase	use	postconsumer disposal
vehicles and parts	**18.9**	2.6	16.3	<0.1
appliances	**11.7**	0.3	11.4	<0.1
food and beverages	**9.1**	8.9	[a]	0.3
services	**5.6**	5.5	[a]	0.1
construction	**5.2**	5.1	[a]	0.1
other manufactured goods	**5.4**	5.4	[a]	<0.1
healthcare	**4.0**	4.0	[a]	<0.1
electronics	**3.5**	2.1	1.4	<0.1
transportation services	**3.4**	3.4	[a]	<0.1
lighting and fixtures	**2.9**	<0.1	2.9	<0.1
furnishings and supplies	**2.9**	2.6	[a]	0.3
retailers	**2.1**	2.1	[a]	0.0
clothing	**1.8**	1.8	[a]	<0.1
wholesale	**0.8**	0.8	[a]	0.0
water and wastewater	**0.3**	0.3	[a]	<0.1
other	**0.4**	0.4	[a]	<0.1
total	**78.1**	**45.3**	**32.0**	**0.8**

[a]*Use* phase emissions for these product categories are zero, though in some cases emissions may be associated with the use of products in these categories but are assigned to another category. For example, emissions associated with washing clothing (e.g., use of a washing machine) are included under the *use* phase of appliances, as are emissions associated with home heating (e.g., the furnace, a type of appliance) and food preparation (e.g., a refrigerator, range oven, microwave, or blender). Emissions associated with the "use" of an airplane are included under *transportation services* ("pre-purchase" phase) since the consumer is purchasing the service of the airplane, not the airplane itself or the jet fuel.

Immediately apparent from these results are significant emissions from use of personal vehicles (16.3 MMT CO_2e) and appliances (11.4 MMT CO_2e), a category that includes home heating and cooling equipment. These emissions include direct emissions from burning fossil fuels, indirect emission associated with extracting, refining and delivering those fuels, and emissions released to produce electricity used to power electric appliances. After vehicles and appliances, the biggest category of emissions is food, where total life-cycle emissions are 9.1 MMT CO_2e and prepurchase emissions are estimated at 8.9 MMT CO_2e. Overall, most of Oregon's 78 MMT CO_2e are attributed to household demand (63 million, or 81%), with relatively smaller shares attributed to government spending (7 million, or 9%) and business investment (8 million, or 11%).

Another way to look at emissions by product category is to look at emissions intensity, as normalized to expenditures. When Oregonians make choices about how to spend their limited discretionary income, the results in Table 3 could help support decisions that minimize climate impact.

DISCUSSION

Compared to a production-based approach, a consumption-based method provides a more complete picture of how consumption in Oregon contributes to global GHGs, as well as increased detail on emissions (particularly the presale emissions) associated with specific categories of consumption.

Table 3. Pre-Sale Emissions Intensity by Product Category

product category	2005 prepurchase emissions per \$ of final demand (kg $CO_2e/\$$)
transportation services	1.6
clothing	1.1
food and beverages	0.9
lighting and fixtures	0.7
water and wastewater	0.7
appliances	0.7
other manufactured goods	0.6
electronics	0.6
vehicles and parts	0.5
furnishings and supplies	0.5
construction	0.4
healthcare	0.2
services	0.2
retailers	0.2
wholesale	0.1
other	<0.1
total (all presale consumption) emissions intensity	**0.36**

Looking at GHGs from a consumption-based approach offers some new insights. For example, consumption-based accounting makes clear how food contributes more substantially to Oregon's carbon "footprint" (in which food represents about 2.5 MT CO_2e per capita) than Oregon's production-based inventory might suggest (in which *agriculture*, a sector that produces more than just food, represents about 1.5 MT per capita).

In other cases, a consumption-based approach reinforces lessons from production-based inventories. Both approaches, for example, strongly suggest that the use of vehicles, home heating and appliances, and manufacturing of goods contribute to the bulk of GHGs.

The primary difference between the two approaches – and the key to gathering and applying potential lessons—lies in the basic definition of the consumption inventory. It represents emissions associated with products and services Oregonians buy, use and dispose, not emissions that arise within the state as a production-based method would do.

Several analyses have demonstrated the relevance of consumption-based accounting at the international level, as nations debate the relative responsibility for global GHGs.[6−8] Our analysis suggests that the debate is also relevant at the level of subnational jurisdictions. For example, most of Oregon's planned actions, as contained in the Oregon Global Warming Commission's *Report to the Legislature*, are designed to reduce emissions as measured by its existing (largely production-based) inventory. While these actions, such as improving energy efficiency, expanding urban transit, and developing compact communities, could do much to lower GHG emissions within the state, effects on the emissions intensity of goods consumed within the state would be limited. Why? Because about two-thirds of emissions released to produce goods and services consumed in Oregon are released outside Oregon. Addressing global climate change will require that Oregon reduce its own emissions, but every world region that makes goods will also need to reduce emissions. A consumption-based accounting framework for Oregon helps provide an indication of how Oregon consumers—and policymakers—might spur emission reductions outside of Oregon.

As context, consider that worldwide emissions in 2005 were 44 000 MMT CO_2e, or 6.8 MT CO_2e per person,[56] and that consumption-based emissions for the U.S. are about 28.6 MT CO2e per person.[21] This study suggests that Oregon, at 21.5 MT CO_2e per person, is responsible, on a per-person basis, for a much higher share of global GHGs than the world average, though somewhat lower than the average U.S. resident.

We find that two factors contribute most to the difference between Oregon and U.S. emission footprints: the serendipity of Oregon's location in a region that relies more heavily on low-emission hydroelectricity, and Oregon's lower overall levels of per-capita consumption. As indicated in Table 4, the emissions

Table 4. Comparison of Key Underlying Factors for Oregon and United States (All Statistics for 2005 unless Otherwise Noted)

	Oregon	U.S.	ratio of Oregon to U.S.	data sources
General				
population (millions)	3.55	290.33	0.01	57
per-capita income, \$/resident	\$23,785	\$25,035	0.95	58
electricity emissions intensity, kg CO_2e/kwh sales	0.49	0.64	0.77	27,53,59
Vehicle Travel				
vehicle miles traveled per resident	9,588	10,167	0.94	60
motor gasoline, MBTU/resident	52.6	57.6	0.91	59
Home Energy Use				
residential energy, MBTU/resident	33.6	39.0	0.86	59
fraction of residential energy as electricity	52%	40%	1.28	59
residential GHG intensity of energy (kg CO2e/MBTU)	97	110	0.88	27,53,59
heating degree days	4,837	4,229	1.14	61
cooling degree days	386	227	1.70	61
Consumption of Goods and Services (2006)				
final demand, \$/resident (total)	\$45,441	\$49,966	0.91	36
Production of Goods and Services (2007)				
industry, value added, \$/resident	\$14,771	\$12,785	1.16	62
industry, energy use per value added (MBTU/thousand \$)	3.6	6.7	0.54	59,62,63
industry, GHG intensity of energy (kg CO2e/MBTU)	61.0	82.4	0.74	27,53,59
services, employees/resident	0.31	0.32	0.96	62
services, energy, MBTU/employee	79.8	89.6	0.89	59,62,63
services, GHG intensity of energy (kg CO2e/MBTU)	107.1	123.4	0.87	27,53,59

intensity of Oregon's electricity supply (considering only combustion emissions) is 77% of the national average, which contributes to Oregon's residential and commercial (services) sector energy being 88% and 87% of the national average emissions intensity, respectively. If Oregonians used energy at the national average GHG intensity, then (despite greater heating and cooling demands in Oregon), emissions associated with the *use* of appliances, lighting and fixtures, and electronics (as in Table 2) would be 2 MT CO_2e/resident higher. Table 4 also indicates that total final demand for goods and services in Oregon is 91% of the national average, due in part to slightly lower average incomes. If Oregon expenditures instead occurred at the national average, the embodied emissions in these goods and services (the "pre-purchase" emissions in Table 2) could be 4 MT CO_2e/resident higher. Other factors can also help explain why Oregon's consumption-based emissions are lower than the national average, including 6% lower vehicle miles traveled per resident and the lower energy intensity of Oregon services and industry (even as these local products fulfill only a fraction of final demand in Oregon).

Of the data presented in Table 4, the starkest difference is in industrial energy use, where the energy intensity of Oregon industry (in MBTU per thousand dollars of value added) is just 54% of the national average. This is due both to the particular mix of industry in Oregon (fewer energy-intensive heavy industries such as petroleum refining or chemical manufacturing, and more less-intensive industry, such as computer and electronic product manufacturing) and due to the higher share of electricity as a fuel in industry.

■ CONCLUSIONS

Our analysis can help address the possible impacts of alternative modes of consumption on Oregon's contribution to global GHG emissions. For example, our results can help assess opportunities to switch from high-carbon to low-carbon goods and services.

Our model cannot distinguish between individual products within a given commodity (e.g., organic vs conventionally grown produce), but it can help identify opportunities to shift from one type of good to another and put them in context relative to other more commonly cited strategies for reducing emissions. For example, each of the following would result in a reduction of about 2 MMT CO_2e in Oregon's consumption-based GHG emissions:

- **Increasing the efficiency of personal vehicles by 15%,** comparable to a shift from a standard sedan car (such as a Toyota Camry) to a highly efficient hybrid (such as the Toyota Prius) for about a quarter of the cars on the road in Oregon. Such a shift would reduce the *use* phase emissions of vehicles.
- **Increasing the efficiency of home appliances (including heating) by 25% in almost all Oregon's households**. Such a reduction, averaged over 90% of Oregon households, would reduce the *use* phase emissions of "heating and cooling appliances."
- **Doubling the useful life of home furnishings (and supplies) and clothing.** Extending the useful life of just these two product categories could lead, through reduced need for new products, to an avoidance of emissions associated with manufacturing of at least 2 MMT CO_2e.

The results suggest a number of opportunities to address climate change through policies and programs that engage public education, government purchasing, and business action. In particular, we suggest that this study's results may be particularly relevant for government efforts on sustainable consumption,[32,33] including government procurement, where this study could help public agencies develop priorities for product or service categories for further research. Results may also be helpful to businesses wanting to estimate the carbon footprint of the types of products studied here, either to engage suppliers or to prioritize internal actions.

For example, our analysis can help assess what *categories of decisions* matter most in terms of reducing GHG emissions and addressing climate change. In particular, as was indicated in Table 2, the categories of consumption associated with the greatest GHG emissions are

1. Personal vehicles, 18.9 MMT CO_2e;
2. Appliances, 11.7 MMT CO_2e; and
3. Food and beverages, 9.1 MMT CO_2e.

Together, these three categories account for half of all the GHG impacts of Oregon's consumption. All three are categories where clear opportunities exist for reducing GHG emissions. Pursuing other changes in consumption can also yield significant benefits, and the results can help support consumer choices about how to spend discretionary income. For example, spending in the *services* category (e.g., haircuts, concerts, or massages) is much less emissions-intensive than in the *transportation services* category (e.g., air travel).

Calculating consumption-based GHG inventories is highly complex, however, and presents some disadvantages for integration into state (or national) climate policy. For one, the calculations depend on less-certain national and international data sources, making them inherently less reliable than relatively straightforward production-based inventories based largely on direct fuel-use data within each state. Even more critical, however, are the political implications of taking responsibility for GHG emissions outside the jurisdictional boundary of a state or nation.[8]

Consumption-based emissions accounting also suffers from some critical flaws that limit its ability to track progress against the very types of goals it might inspire. For example, at the subnational level, few consistent, regular data sources are available that would enable monitoring of changes in consumption behaviors (e.g., resident diets) over time. The development of robust local survey data on consumption behaviors remains an important area for further research, both to assess impacts of individual decisions as well as any broader assessments of emissions leakage due to changing patterns of consumption and production in a region. New data collection efforts should focus particularly on methods that might be able to identify and accurately assess changes over time in *functional units*—such as calories of food—that may more closely correlate with emissions than do dollars of expenditure.[51]

Nevertheless, states and local governments have the opportunity to adopt methods of counting GHG emissions that allow them to assess the emissions implications of consumption-related decisions over which they and their residents have influence. By including imported electricity emissions in its official inventory, for example, Oregon has recognized that it has large influence over emissions through activities that affect electricity consumption, such as energy efficiency programs. We suggest that Oregon and other states also have influence over product, material and service choices of government practices as well as opportunities to create policy and outreach programs that support climate-friendly decisions by residents and businesses. Our analysis helps quantify these potential benefits and makes the case for why looking at GHGs from a consumption-based perspective can open up new opportunities for engaging both consumers and producers in reducing global GHGs. State and local governments could conduct regular consumption-based GHG inventories and adopt emission reductions targets, just as many currently do for production-based (in-state) GHG emissions. Inventorying consumption-based emissions alongside the more traditional in-boundary emissions offers a more comprehensive and, by extension, more accurate picture of how the community contributes to emissions as well as opportunities to reduce them.

■ AUTHOR INFORMATION

Corresponding Author

*Phone: +1 (206) 547-4000; fax: +1 (206) 312-4720; e-mail: pete.erickson@sei-us.org.

Author Contributions

§Lead model developer

Notes

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■ REFERENCES

(1) IPCC. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (3 volumes)*; Intergovernmental Panel on Climate Change, 1996.

(2) U.S. EPA. *State Inventory Tool (SIT)*; ICF International for the U.S. Environmental Protection Agency: Washington D.C., 2008.

(3) ICLEI International Local Government Greenhouse Gas (GHG) Emissions Analysis Protocol (IEAP) - Version 1.0 2009.

(4) Wiedmann, T. *Development of an Embedded Carbon Emissions Indicator: Producing a Time Series of Input-Output Tables and Embedded Carbon Dioxide Emissions for the UK by Using a MRIO Data Optimisation System*; Defra (Department for Environment, Food and Rural Affairs): London, UK, 2008.

(5) Peters, G. P.; Hertwich, E. G. CO_2 embodied in international trade with implications for global climate policy. *Environ. Sci. Technol.* **2008**, *42*, 1401−1407.

(6) Peters, G. P.; Minx, J. C.; Weber, C. L.; Edenhofer, O. Growth in emission transfers via international trade from 1990 to 2008. *Proc. Natl. Acad. Sci. U.S.A.* **2011**, *108*, 8903−8908.

(7) Carbon Trust. *International Carbon Flows*, CTC793; The Carbon Trust: London, 2011.

(8) Peters, G. P. From production-based to consumption-based national emissions inventories. *Ecol. Econ.* **2008**, *65*, 13−23.

(9) Dröge, S.; Harro van A.; Thomas B.; Michael G.; Roland I.; Yasuko K.; Michael M.; Stephanie M.; Karsten N.; Philippe Q.; Katja S.; Lennart M.; Wojciech S.; Yukari T.; Tancrede V.; Xin W. *Tackling Leakage in a World of Unequal Carbon Prices*, 2009.

(10) Reinaud, J. *Issues Behind Competitiveness and Carbon Leakage. Focus on Heavy Industry*, IEA Information Paper; International Energy Agency: Paris, 2008.

(11) Houser, T.; Bradley, R.; Childs, B.; Werksman, J.; Heilmayr, R. *Leveling the Carbon Playing Field: International Competition and U.S. Climate Policy Design*; Peterson Institute for International Economics and the World Resources Institute: Washington DC, 2008.

(12) US EPA; US EIA; US Treasury *The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive Trade-Exposed Industries*; An Interagency Report Responding to a Request from Senators Bayh, Specter, Stabenow, McCaskill, and Brown; Washington, DC, 2009.

(13) European Commission 2011/278/EU. Commission Decision of 27 April 2011 determining transitional Union-wide rules for harmonised free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council. Off. J. Eur. Union 2011.

(14) Litz, F. *Towards a Constructive Dialogue on Federal and State Roles in U.S. Climate Change Policy*; Solutions White Paper Series; Pew Center on Global Climate Change: Washington D.C., 2008.

(15) ICLEI - USA Clean Air and Climate Protection Software User's Guide 2003.

(16) WBCSD. *WRI The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*, 2004.

(17) Weber, C. L.; Matthews, H. S. Quantifying the global and distributional aspects of American household carbon footprint. *Ecol. Econ.* **2008**, *66*, 379−391.

(18) Davis, S. J.; Caldeira, K. Consumption-based accounting of CO2 emissions. *Proc. Natl. Acad. Sci.* **2010**, *107*, 5687−5692.

(19) Jones, C. M.; Kammen, D. M. Quantifying carbon footprint reduction opportunities for U.S. households and communities. *Environ. Sci. Technol.* **2011**, *45*, 4088−4095.

(20) Brower, M.; Leon, W. *The Consumer's Guide to Effective Environmental Choices: Practical Advice from the Union of Concerned Scientists*; Three Rivers Press: New York, NY, 1999.

(21) Weber, C. L.; Matthews, H. S. Embodied environmental emissions in U.S. international trade. *Environ. Sci. Technol.* **2007**, *41*, 4875−4881.

(22) Dawkins, E.; Roelich, K.; Owen, A. *A Consumption Approach for Emissions Accounting - the REAP Tool and REAP Data for 2006*; Stockholm Environment Institute: Stockholm, 2010.

(23) Ramaswami, A.; Hillman, T.; Janson, B.; Reiner, M.; Thomas, G. A demand-centered, hybrid life-cycle methodology for city-scale greenhouse gas inventories. *Environ. Sci. Technol.* **2008**, *42*, 6455−6461.

(24) Hillman, T.; Ramaswami, A. Greenhouse gas emission footprints and energy use benchmarks for eight U.S. cities. *Environ. Sci. Technol.* **2010**, *44*, 1902−1910.

(25) Morris, J.; Matthews, H. S. Development of a consumer environmental index and results for Washington State consumers. *J. Ind. Ecol.* **2010**, *14*, 399−421.

(26) Masanet, E.; Matthews, H. S.; Carlson, D.; Horvath, A. *Retail Climate Change Mitigation: Life-Cycle Emission and Energy Efficiency Labels and Standards*, 2011.

(27) Oregon Global Warming Commission. *Report to the Legislature 2011*; Oregon Department of Energy on behalf of the Oregon Global Warming Commission, 2011.

(28) Kulongoski, G. T. R. *Answering the Oregon Challenge: Climate Change*; 2008.

(29) Governor's Advisory Group on Global Warming Oregon. *Strategy for Greenhouse Gas Reductions*; State of Oregon, 2004.

(30) *Interim Roadmap to 2020: Roadmap Elements as Adopted by the Oregon Global Warming Commission on October 28, 2010*; Oregon Global Warming Commission, 2010.

(31) Governor's Climate Change Integration Group *A Framework for Addressing Rapid Climate Change; State of Oregon*, 2008.

(32) Oregon DEQ *Oregon DEQ Waste Prevention Strategy: Ten-year Framework and Short-term Plan; Oregon Department of Environmental Quality*, 2007.

(33) Allaway, D.; Kochan, L.; Grabham, C. *Literature Review: Alternatives for Advancing Sustainable Production and Consumption through Government Programs and Policies*; Oregon Department of Environmental Quality: Portland, OR, 2012.

(34) Miller, R. E.; Blair, P. D. *Input-output analysis: foundations and extensions*, 2nd ed.; Cambridge University Press: Cambridge UK, 2009.

(35) Stanton, E. A.; Bueno, R.; Ackerman, F. *Consumption-Based Emissions Inventory (CBEI)*, Version 1.2; Stockholm Environment Institute−U.S. Centre: Somerville, MA, 2011.

(36) MIG Inc. *IMPLAN® Economic Impact Modeling System: U.S. and Oregon Datasets*; Minnesota IMPLAN Group: Hudson, WI, 2006.
(37) Chavez, A.; Ramaswami, A. Progress toward low carbon cities: approaches for transboundary GHG emissions' footprinting. *Carbon Manage.* **2011**, *2*, 471−482.
(38) Stanton, E. A.; Bueno, R.; Ackerman, F.; Erickson, P.; Hammerschlag, R.; Cegan, J. *Greenhouse Gas Impacts of Oregon's Consumption: Technical Report*; Stockholm Environment Institute (U.S.) for the Oregon Department of Environmental Quality, 2011; http://www.deq.state.or.us/lq/pubs/docs/ConsumptionBasedGHGEmissionsInventoryORTechnicalReport.pdf.
(39) Schipper, M. *Energy-Related Carbon Dioxide Emissions in U.S. Manufacturing*, DOE/EIA-0573; Energy Information Administration, 2005.
(40) U.S. EIA. *Emissions of Greenhouse Gases in the United States 2006*; U.S. Energy Information Administration Office of Integrated Analysis and Forecasting: Washington DC, 2007.
(41) U.S. EIA *Emissions of Greenhouse Gases in the United States 2005*; U.S. Energy Information Administration Office of Integrated Analysis and Forecasting: Washington DC, 2006.
(42) Weber, C. A.; Matthews, D.; Venkatesh, A.; Costello, C.; Matthews, H. S. *The 2002 Benchmark Version of the Economic Input-output Life Cycle Assessment (EIO-LCA) Model*; 2010.
(43) U.S. EIA. *Commercial Buildings Energy Consumption Survey*; U.S. Department of Energy, Energy Information Administration: Washington DC, 2008.
(44) *Draft 6th Northwest Power Plan*; Northwest Power and Conservation Council: Portland, OR, 2009.
(45) *Oregon DEQ Oregon DEQ 2006 Report to the Legislature: 2005/2006 Disposal Status*; Oregon Department of Environmental Quality: Portland, OR, 2007.
(46) *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 3rd ed.; U.S. Environmental Protection Agency, 2006.
(47) Cederberg, C.; Persson, U. M.; Neovius, K.; Molander, S.; Clift, R. Including carbon emissions from deforestation in the carbon footprint of Brazilian beef. *Environ. Sci. Technol.* **2011**, *45*, 1773−1779.
(48) Suh, S.; Lenzen, M.; Treloar, G. J.; Hondo, H.; Horvath, A.; Huppes, G.; Jolliet, O.; Klann, U.; Krewitt, W.; Moriguchi, Y.; Munksgaard, J.; Norris, G. System boundary selection in life-cycle inventories using hybrid approaches. *Environ. Sci. Technol.* **2004**, *38*, 657−664.
(49) Lenzen, M. Errors in conventional and input-output—based life—cycle inventories. *J. Ind. Ecol.* **2000**, *4*, 127−148.
(50) Girod, B.; de Haan, P. GHG reduction potential of changes in consumption patterns and higher quality levels: Evidence from Swiss household consumption survey. *Energy Policy* **2009**, *37*, 5650−5661.
(51) Girod, B.; de Haan, P. More or better? A model for changes in household greenhouse gas emissions due to higher income. *J. Ind. Ecol.* **2010**, 14.
(52) Hertwich, E. G.; Peters, G. P. Carbon footprint of nations: A global, trade-linked analysis. *Environ. Sci. Technol.* **2009**, *43*, 6414−6420.
(53) *Greenhouse Gas Emissions and Emissions Intensities for Consumption of Materials, Services, Materials and Electricity*; U.S. Environmental Protection Agency, 2011.
(54) Oregon DEQ. *Oregon Consumption-based Emissions Inventory - Supplemental Calculations Prepared by DEQ*; Oregon Department of Environmental Quality: Portland, OR, 2011.
(55) Hertwich, E. G. Life cycle approaches to sustainable consumption: A critical review. *Environ. Sci. Technol.* **2005**, *39*, 4673−4684.
(56) *Climate Analysis Indicators Tool*; World Resources Institute: Washington DC, 2011.
(57) U.S. Census Bureau Population Estimates. http://www.census.gov/popest/estimates.html (accessed September 6, 2011).
(58) U.S. Census Bureau American Community Survey 2005. http://factfinder.census.gov/ (accessed September 6, 2011).
(59) *U.S. EIA State Energy Consumption Estimates*, DOE/EIA-0214(2009); U.S. Energy Information Administration: Washington DC, 2011.
(60) U.S. DOT *Highway Statistics 2006; Office of Highway Policy Information, Federal Highway Administration*, U.S. Department of Transportation: Washington DC, 2006.
(61) NOAA Heating and Cooling Degree Day Data Archives. ftp://ftp.cpc.ncep.noaa.gov/htdocs/products/analysis_monitoring/cdus/ (accessed September 7, 2011).
(62) *Economic Census*; U.S. Census Bureau: Washington DC, 2007
(63) USDA. *Farm Income: Summary Totals for 50 States*; U.S. Department of Agriculture Economic Research Service: Washington DC, 2011.