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ORIGINAL ARTICLE

The uneven weight of carbon on policy: towards a framework for understanding how greenhouse gas inventories can inform equitable climate policy design

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Abstract

In this analysis, we systematically review and synthesize the results of two local-level studies linking various types of carbon emissions data with nationwide measures of affluence. We focus on the socio-economic dimensions of climate policy, differentiating between different sources of greenhouse gas emissions, and between different methods of collecting greenhouse gas emissions data. We demonstrate that high levels of affluence spatially displace carbon-intensive production-based emissions. We then synthesize a framework for future research on environmental policy design to explicitly consider the method of collecting data on carbon emissions by sector and activity. We offer strategies for policymakers regarding the conditions under which specific carbon emissions data collection methods may be more relevant or appropriate than other methods. We emphasize that more equitable environmental policy objectives can be achieved by recognizing the socio-economic dimensions of carbon emissions data, thus the importance of critically examining the way those data inform policy.

Keywords Carbon emissions and affluence · Direct indirect measures of carbon emissions · Policy

Introduction

For several decades now, there has been continuous improvement in the development and accessibility of environmental data. While these data tended to be inventoried first at the macro-level (e.g., states and countries), there are now abundant resources available for environmental scholars researching local-level dynamics. Relatively speaking, while many local-level data sets still lack a longitudinal component (e.g., Leon-Corwin et al. 2020), there is widespread cross-sectional coverage, not just subnationally within the USA but in several other countries around the world (e.g., Li et al. 2019). Since the start of the twenty-first century, the analysis of local-level environmental data has become a core and indispensable feature of high-quality environmental scholarship (Dietz et al. 2007). Indeed, the progression of local-level data on carbon emissions within the USA (e.g., Gurney et al. 2009; Ummel 2014) has generated a wide array of scholarship on the demographic, economic, and political dimensions of climate change. In the following discussion, we track the progression of local-level carbon data, emphasizing what this means for the design of environmental policy, specifically subnational climate policy.

In the past 15 years, climate action plans and policies in the US have improved in terms of explicit goals, policy details, and evaluation measures (Krause 2011; Rabe 2004), but gaps remain. In meta-analyses of local government climate plans in the USA, Woodruff and Stults (2016) found that most plans lacked a prioritization of strategies based on impacts as well as comprehensive implementation guidelines, and Galucci (2013) found plans often do not explicitly document how new initiatives will be funded. In similar meta-analyses of US subnational climate action plans and sustainability policy tools, Hess & McKane (2021) Russo and Pattison (2016; 2017) and Finn and McCormick (2011) found that policies addressing social equity concerns were scant or absent from many of these plans, which instead emphasized environmental and economic concerns. Using local government survey

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data, Wang (2013) shows that community characteristics play a role in the prioritization and adoption of climate mitigation versus adaptation goals and in the follow-through implementation into policy as well. Interestingly, Habans et al. (2019) demonstrated that a local government's carbon emissions profile as well as social, political, and economic characteristics can shape local climate policy adoption. Furthermore, different carbon emission profiles, i.e., profiles with more production-based versus consumption-based emissions, can have distinct relationships with climate policy adoption. We attempt to bridge some of these gaps in the literature and inform policymakers how to better utilize carbon emission data in the creation of local climate policy.

We systematically review the results of two studies that utilized different forms of local-level carbon emissions data, with a general distinction between production-based and consumption-based emissions and a distinction between studies that use directly measured emissions as opposed to indirectly measured. This latter distinction is discussed in the context of the carbon footprint, which addresses the transboundary problem by combining the direct and indirect emissions embedded in the production of the goods and services humans consume. To narrow our focus, we emphasize the role that affluence plays in the analysis of different forms of carbon data, which then reiterates the importance of making a distinction between production and consumption emissions. After reviewing these projects, we synthesize a framework for future research on environmental policy design to explicitly consider the method of collecting data on carbon emissions by sector and activity. We emphasize that more equitable environmental policy objectives can be achieved by recognizing that carbon emissions data come in different forms.

How these different kinds of carbon data may inform policy differently was a concern of our colleague Dr. Lamont Hempel, who we aim to honor here. Dr. Hempel, Monty, was both passionate and rigorous in the way he explored the socio-economic dimensions of data and technical information and how that information informed policy. He acknowledged the importance of local-level metrics of sustainability. Specifically, our synthesis focuses on two strategies for data and analysis highlighted in Hempel (2009): (i) the importance of utilizing local-level direct and indirect measures of environmental impact as can be done with the carbon footprint and (ii) how geographic information system (GIS) analysis can illuminate the socio-ecological dynamics of communities across vast scales. Accordingly, we frame our synthesis in consideration of Hempel's (2009) discussion of the evolution of local-level sustainability data, and we also recognize, as Hempel did, the need to continue improving data quality to inform policy design.

Theoretical and analytical background

Before moving on, as background context for the following review, we highlight and describe several important analytical concepts and theories that are utilized in these studies. The studies address central questions in the environmental inequality literature (Mohai et al. 2009), with a focus on the distinction between environmental harm and privilege (Pellow and Brehm 2013). The studies draw on theories and concepts in political economy (Logan and Molotch 2007; York et al. 2003) to assess whether and how affluence influences the spatial distribution of carbon emissions associated with different types of activities at the local level. In the international environmental inequality literature, the traditional notion of the environmental Kuznets curve (Dinda 2004) suggests that wealthy, developed nations produce less environmental pollution than poor, underdeveloped nations. However, cross-national scholars have clarified that wealthy, developed nations are able to displace environmentally harmful practices to poor, underdeveloped nations, revealing a phenomenon called the "Netherlands Fallacy" (York et al. 2003).

Do these international dynamics also transpire at a subnational, local level? That is the general research question guiding the analyses reviewed below. The studies assess whether the spatially uneven distribution of environmental harm and privilege are observed at the local level across the USA utilizing two complimentary county-level data sets on carbon emissions (Gurney et al. 2009; Ummel 2014, 2016). The first data set provides information on the direct combustion of fossil fuel by the commercial, residential, transportation, electrical, and industrial sectors, which allows us to distinguish direct carbon emissions in terms of consumption-based versus production-based activities. The second county-level data set provides information on the carbon footprint, which assigns indirect carbon emissions to the point of consumption. Synthesizing results from studies using these two data sets, we are able to evaluate systematically whether more affluent counties are able to spatially displace carbon emissions associated with dirty, industrial practices. At the local level, an environmental Kuznets curve (EKC) with production-based emissions would suggest an experience of "aristocratic conservation," whereby more affluent counties are able to engage in consumption while preserving their localities "as a setting for life and work, rather than as an exploitable resource" (Molotch 1976: 328). Empirically, we describe this association as an environmental inequality Kuznets curve (rather than simply an EKC) to highlight how affluent counties have low levels of production-based carbon emissions while maintaining high levels of consumption-based emissions.

Table 1 (Adapted From Pattison et al. 2014): Summary of hypothesized relationships between measures of affluence and production and consumption emissions

Measure of affluence	Ecological modernization		Aristocratic conservation	
	Production-based emissions	Consumption-based emissions	Production-based emissions	Consumption-based emissions
Economic output per capita	∩	∩	+	+
Median household income	∩	∩ or -	∩	+

According to ecological modernization theory, the inverted-U shape represents the environmental Kuznets curve

Directly measured carbon emissions, at the county scale

Our initial 2014 analysis of county-level carbon emissions examined potential relationships between the variation in the amount of emissions and economic output per capita, as well as median household income. Employing the concept of aristocratic conservation, we hypothesized that affluence is positively related to carbon emissions from consumption activities but negatively related to emissions from production activities. We tested these hypotheses using county-level data in the USA for the year 2002. See Table 1 for a summary of the hypotheses and Fig. 1 for a graphical summary of the results (Pattison et al. 2014).

Spatial regression analysis demonstrated that median household income is positively associated with consumption-based emissions (per capita emissions from the residential, commercial, and transportation sectors), but we found evidence of an environmental inequality Kuznets curve in the relationship between median household income and production-based emissions (per capita emissions from both the electrical and industrial sectors). This finding suggests that the wealthiest counties can displace certain types of emissions, specifically those related to energy and industrial production. To contextualize the main finding above, we highlight four main points:

1) Economic output and household income are distinct forms of affluence at the county level.
2) These distinct measures of affluence are differentially related to production- and consumption-based emissions.
3) Our results suggest that household income plays a significant role in the spatial distribution of production-based emissions.
4) There is a significant degree of spatial dependence between neighboring counties in terms of carbon emissions; the causal mechanism for this final point and its significance for local climate policy needs to be further explored.

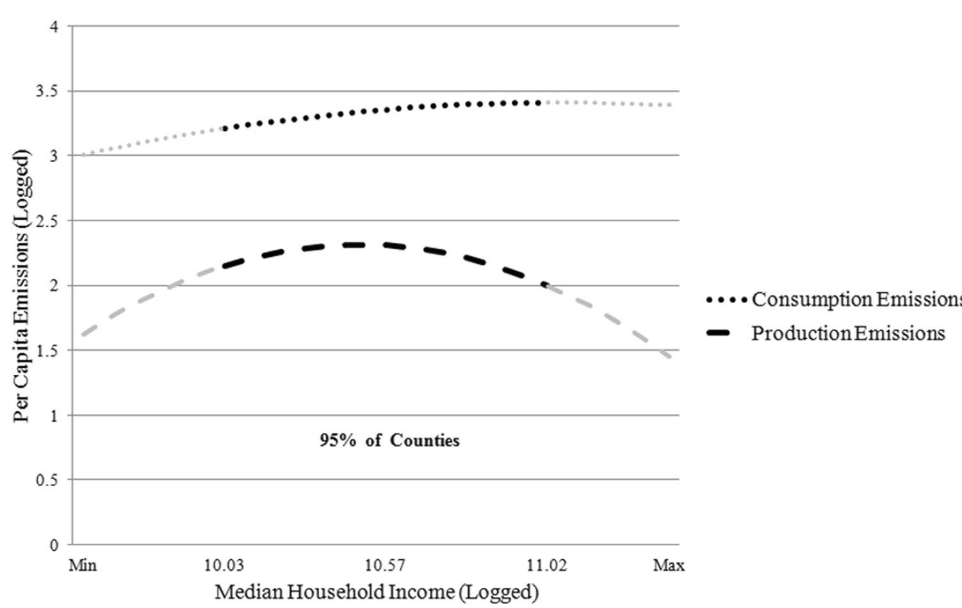

Fig. 1 (From Pattison et al. 2014): Summary of findings of an Environmental Kuznets curve

Direct measures of carbon emissions

This study employed the Vulcan Project database,[1] a US carbon emissions database representing the first comprehensive, reliable nationwide inventory of local carbon emissions in the USA that is not based on proxy measures. These data track the direct combustion of fossil fuel by various activities at the county-level of carbon dioxide (CO_2) emissions for the year 2002, with coverage for the entire USA. Taken from emissions-monitoring and fuel-consumption inventories conducted regularly by government agencies, such as the Environmental Protection Agency and the Energy Information Administration, these data were categorized by sector, including, for instance, the commercial, electrical, industrial, residential, and (on-road) transportation sectors. For each county, the reported values are derived from the amount of fossil fuel directly consumed by that specific sector within that specific county; there is no estimate of indirect or embodied carbon generated either further upstream or outside the county's boundaries.

It is worth noting that the Vulcan Project data set is only cross-section data, and transboundary (i.e., trans-county jurisdiction in this case) patterns of consumption are not accounted for. We attempted to address this with our theory and analysis, and while our methods do not fully bridge the gap between large nationwide emission inventories, which are capable of a litany of comparative analysis, and locally based carbon inventories of individual cities, which are better able to examine a finer grain of consumption patterns, we believe it is a step forward. Still, the distinction of direct CO_2 emissions by sector allows for the opportunity to conduct an exploratory analysis that can help lay the foundation for a more rigorous study when better carbon footprint data become available.

Spatial effects and other considerations

Our analysis suggests the presence of a spatial effect for production-based emissions, whereby the factors that result in production emissions diffuse across county borders. But for consumption-based emissions, the test suggests spatial dependence is limited to spatial "disturbance" and not necessarily to spatial "effects," meaning the error term of the model rather than the dependent variable is significantly clustered. In other words, these results indicate a possible clustering of industrial processes and facilities, but no corresponding clustering of the consumption behaviors. We provide some theories in the 2014 piece related to regionals differences in urban form that may explain the nature of a spatial ''effect'' that would apply to production emissions but not to consumption emissions. But the geography of clustered production emissions may result from certain production complexes agglomerating in specific regions as similar and related industries cluster together—leading to different carbon signatures across space. Examples are the Midwest's industrial belt and the oil and gas infrastructure on the Louisiana and Texas Gulf Coast, both of which are discernible concentrations of production emissions. These regions span dozens of counties and multiple states but are distinguished less by urban form than by industry-specific forms of agglomeration. Again, we would highlight that the difference in model specifications tentatively supports our initial argument for unpacking anthropogenic emissions sources.

The spatial models used in this analysis may yield lessons for similarly minded studies of climate change at the scale of local political jurisdictions. Our findings provide relatively strong evidence for the presence of spatial dependence. This possibility has far-reaching implications, from spatial variation in the validity of emissions inventories on the local level to the potential existence of a causal spatial ''effect'' that ties emissions produced in one jurisdiction to its neighbors' characteristics. We believe future research concerned with the subnational scale might do well to broaden its focus beyond merely considering the local political unit as a unique site of inquiry and policy activism to also look toward inter-local and cross-political jurisdictional relationships.

Directly and indirectly measured carbon emissions, at the zip code scale

Building on the previous work, in a later study we employed the Citizens' Climate Lobby US Household Greenhouse Gas Footprint database.[2] This local-level carbon footprint dataset with coverage for 28,321 zip codes are across the USA. In an attempt to improve our understanding of transboundary consumption patterns and resulting carbon emissions, we again focus on the effect of local affluence, measured in terms of median household income on the carbon footprint, i.e., an environmental outcome that includes both direct and indirect carbon emissions. See Table 2 for a summary of the results and Fig. 2 for a graphical summary of the results. While our previous study found a positive correlation between affluence and a direct measure of consumption-based emissions, we examined if a similarly positive correlation exists

[1] Available here: http://vulcan.rc.nau.edu/index.html Last accessed November 9, 2020.

[2] Available here: https://citizensclimatelobby.org/wp-content/uploads/2016/02/Household-Impact-Study-Ummel.pdf Last Accessed November 9, 2020.

Table 2 (Adapted From Clement et al. 2017): Summary of hypothesized relationships between measures of affluence and production and consumption emissions

	Ecological modernization			Political economy		
	Production-based emissions	Consumption-based Emissions	Carbon footprint	Production-based emissions	Consumption-based emissions	Carbon footprint
Affluence (median household income)	∩	∩ or –	∩ or –	∩	+	+ or "J"

According to ecological modernization theory, the inverted-U shape represents the environmental Kuznets curve; according to political economy, it represents the environmental *inequality* Kuznets curve (see Pattison et al. 2014). For carbon footprint, according to political economy theory, the "J" shape represents a superlinear (or exponential) relationship between affluence and the carbon footprint

between affluence and the per capita carbon footprint. In other words, is the effect of affluence changed when we consider both the direct and indirect consumption of fossil fuel, operationalized in the per capita carbon footprint?

Numerous studies have observed that without considering the embodied carbon in cross-boundary goods and services consumed, the true carbon impact of urban systems is artificially discounted (see Hillman and Ramaswami 2010; Kennedy et al. 2009). This is sometimes referred to as the "long tailpipe" problem or as "the Netherlands Fallacy" (Ehrlich and Holdren 1971; York et al. 2003). According to the Netherlands Fallacy, a wealthy, developed nation like the Netherlands may appear to have minimal environmental impacts because many of the products consumed within its borders are produced elsewhere. Ramaswami et al. (2012: 802) offered a way to conceptualize these transboundary issues as nested within a social-ecological-infrastructural systems framework, including "…associated cross-scale social actors and institutions that govern these infrastructures."

As with the previous study, we distinguish consumption-based emissions and production-based emissions. Consumption-based emissions include fossil fuel combustion by the commercial, residential, and transportation sectors, and production-based emissions include the industrial and electrical sectors. While consumption-based emissions are assumed to be the direct result of the end-user, production-based emissions represent fossil fuel combustion not directly attributed to the end-user. The distinction between consumption-based and production-based emissions becomes a proxy for the direct versus indirect components of a footprint measure of environmental impact. Production emissions are assumed to happen upstream and separate from consumption emissions. With the best available data at the time, our 2014 study skirted the issue of the cross-boundary flow of resources;

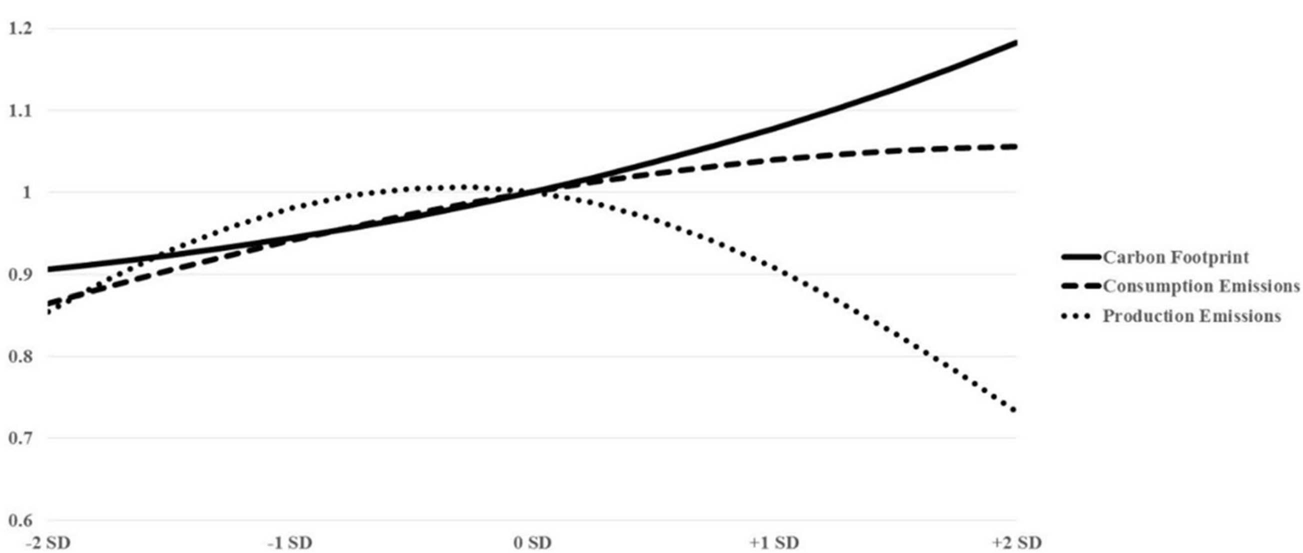

Fig. 2 (From Clement et al. 2017): Summary of observed relationship between affluence, carbon emissions, and carbon footprint. *Median household income* on *X*-axis measured in terms of standard deviations (SD) from the mean. Values on the *Y*-axis are standardized values of the dependent variable, representing a proportional difference relative to the value of the dependent variable at 0 SD for *median household income*. For example, the *carbon footprint* at + 2 SD of *median household income* is almost 20% *greater* than the *carbon footprint per capita* at 0 SD; likewise, the value of the *carbon footprint* at -2 SD is nearly 10% *smaller* than it is at 0 SD

and while we did not address the Netherlands Fallacy explicitly, this initial analysis laid the groundwork for a subsequent local-level evaluation of the fallacy.

While presenting a challenge to ecological modernization theory, our 2014 study's findings do not precisely test that theory. For instance, the inverted-*U* seen in the relationship between median household income and production-based emissions may be the result of affluent communities demanding that their electrical and industrial sectors invest in more energy-efficient technologies. However, because rising affluence continuously increases consumption-based emissions, the more logical hypothesis would emphasize that the inverted-*U* seen in production-based emissions results from spatial displacement, in the manner of the Netherlands Fallacy. If it is the result of spatial displacement, when both the direct and indirect sources of fossil fuel are combined, the relationship between affluence and the carbon footprint should be positive.

In looking at the results of the 2014 study (Fig. 1) to represent the effect of affluence on the carbon footprint, one could invert the downward slope of the line for production-based emissions (as the indirect component of fossil fuel use) and add it to the upward slope of the line for consumption-based emissions (the direct component). Doing so would make the relationship look *J*-shaped, i.e., "superlinear" (Bettencourt et al. 2007), in which the carbon footprint increases exponentially at higher levels of affluence. The visual experiment discussed above in the literature review corroborates our primary finding, and we can now see how the effect of affluence changes when we include the per capita carbon footprint measure, i.e., including both direct and indirectly measured emissions (see Fig. 2):

1) Again, we see the environmental inequality Kuznets curve: as affluence rises, consumption-based emissions increase, but production-based emissions take on an inverted-*U* shape.
2) Meanwhile, the slight but noticeable "J" shape seen in the solid line suggests that the relationship between affluence and the carbon footprint is moderately superlinear (or exponential), i.e., the positive association between median household income and the carbon footprint per capita becomes even greater at the highest levels of affluence.

This finding brings new light to our previous analysis results because when including the emissions that have been spatially displaced (i.e., the embodied carbon), the effect of affluence becomes even more dramatic. Comparable to wealthy nations, the most affluent zip codes in the USA *have the biggest carbon footprints per capita and* can separate geo-graphically sites of consumption and production, in the manner of the Netherlands Fallacy.

Indirect and direct measures of carbon emissions (carbon footprints)

This second study's dataset is based on household-level expenditure data obtained from the Bureau of Labor Statistics' Consumer Expenditure Survey (CEX). Household-level expenditures were averaged over the years 2008–2012 for 52 spending categories, including specific items such as air travel, beef, electricity, major and small appliances, public transportation, and telecommunications. Specific emissions intensity factors for each of the 52 categories are derived from different academic and governmental sources; for instance, fuel price and life-cycle data from the Energy Information Administration is used to generate intensity factors for energy consumption; the Environmental Protection Agency's eGRID program provides intensity factors for electricity generation, and the MIT Airline Data Project was used to help estimate an intensity factor for airline travel. With these emission intensity factors, the expenditure data from the CEX can be used to calculate the amount of carbon associated with the amount spent on that particular category.

We note that Citizens' Climate Lobby first converted these into a per capita carbon burden dollar amount based on a price of $15 per metric ton of CO_2 equivalent. *In other words, like the direct measures of carbon emissions in the Vulcan Project data employed in the 2014 piece, these carbon footprint data also include indirectly calculated values by multiplying the emission factor (i.e., carbon intensity per unit) of various measures of individual behaviors and purchases, and hyper-localized economic activities.* For our study, we take these data at the zip code level and divide the per capita dollar burden by $15, yielding an estimate for the carbon footprint per capita. See Clement et al. (2017) for a detailed account of our independent variables and controls, but our two primary predictors were median household income and its quadratic term (i.e., the squared values of median household income).

The effect of density and other considerations

While the carbon footprint allows for additional and more refined analysis when combined with the Vulcan data, there are two limitations to consider. First, these data are not longitudinal. Second, while an advance in data quality, the dependent variable used in this study is still an estimate of the carbon footprint based on the dollar amount of the carbon burden, and, as explained by Ummel (2014, 2016), this measure does not represent an exhaustive list of all the different spending categories. All the same, the study results certainly provide momentum for subsequent research at the local level examining connections between carbon emissions, carbon footprint, and affluence.

There were two notable findings from the control variables. First, whereas both population density and median household size have highly significant, negative effects on the dependent variable, the magnitude of the latter is much greater: for every 1% increase in the median size of households in a zip code, its per capita carbon footprint decreases by 0.439% compared to 0.011% for density. While population density clearly has the effect of efficiency that many urban scholars have discussed, the long-term trend of decreasing household size must also be emphasized as an important factor behind environmental change (Elliott and Clement 2015). Second, while cross-national scholars have examined the relationship between environmental change and human well-being, the results of our model suggest that the different dimensions of well-being should also be considered at the local level.

Implications for climate policymaking—include analysis of affluence, economic advantage, and power at multiple scales

Our 2014 findings show that the counties with the highest median household incomes have the lowest production-based emissions and the highest consumption-based emissions. We describe the inverted-*U* shape relationship between affluence and production-based emissions as an environmental inequality Kuznets curve, to be contrasted with a traditional environmental Kuznets curve. Rising affluence increases consumption-based emissions, but it does not reduce carbon emissions in the way that the traditional environmental Kuznets curve would predict, through increasing access to more efficient technologies and processes. What is observed in more affluent counties is a reduction in CO_2 from production-based activities; citing our 2014 study, other authors (e.g., Adua et al. 2016; Jorgenson et al. 2017) have pointed out how this finding suggests that the wealthiest counties can displace carbon-intensive activities (the industrial and electrical sectors) onto less affluent communities, hence the environmental inequality Kuznets curve.

This finding has implications for policymaking as local government carbon footprint methodology and policy process models seek to educate policy actors but do not include explicit examinations of different measures of local affluence (e.g., Pichler et al. 2017; Ramaswami et al. 2012; Davis and Weible 2011). We have shown that affluence and per capita carbon emissions are related at the county level and that patterns of production- and consumption-related emissions are not the same. Given the unequal and nonlinear relationship between the different measures of affluence and different types of emissions, policymakers must strongly consider the potential disproportional impacts that may be imposed on different communities when climate policies are implemented.

The relationship between household income and per capita production emission may exist at scales smaller than the county level. Thus, as standardized carbon footprint methodologies for cities, towns, and counties develop, national carbon emissions inventories with greater granularity are created (see Ramaswami et al. 2012; Ramaswami et al. 2008; Hillman and Ramaswami 2010), and models are used by scholars and policymakers to develop and implement subnational and national climate mitigation policy, the effects of local measures of affluence on different types of carbon emissions cannot be ignored. Just as critics of public choice theory have pointed out that environmental inequalities across local governments are not the result of different tastes but rather differing advantages related to being able to ‘‘vote with your feet,’’ we claim that theories that examine the relationship between carbon emissions and local communities must explicitly examine the role of economic advantage and power.

Theory is needed to describe and examine the behavior of different categories of social actors across localities and thus better understand greenhouse gas mitigation policies. For instance, based on the typology proposed by Ramaswami et al. (2012) and Davis and Weible (2011), the production emissions in our model may be more determined by the activities of ‘‘policy actors’’ and ‘‘infrastructure designers and operators,’’ while the consumption emissions in our models are more determined by ‘‘individual infrastructure users’’ (Davis and Weible 2011:485). On that note, our findings could aid in the development of interdisciplinary metatheories needed to help explain and understand the complex socio-ecological systems of local populations and carbon emissions (Ramaswami et al. 2012). We look forward to future work on these essential topics. Towards that work, our 2014 and 2017 results show value in using both the *direct* measures of carbon emissions tied to specific geographical spaces, such as the Vulcan Project dataset and carbon emissions dataset calculated *indirectly* through consumer expenditure surveys and carbon footprint techniques. Our framework for understanding how different greenhouse gas inventories can inform different specific climate policies is summarized in Table 3.

Implications for climate policymaking using directly measured carbon emission data

Direct emissions inventory data allows for spatial analysis of emissions, which (if of sufficient resolution) may enable policymakers to tie specific mitigation efforts to regions. An example might be *using directly measured consumption-based emissions data* to assess regional transportation

Table 3 Framework matrix for understanding how greenhouse gas inventories can inform equitable climate policy design

	Consumption-based emissions	Production-based emissions
Direct measures of emissions	Regional transportation planning policies • CA SB 375 • “smart growth initiatives”	Regional- and industry-specific policies • e.g., Clean Power Plan • Fracking methane rule • State CAPs, RGGI, etc
Indirect measures of emissions	Pigouvian carbon signaling policies • Carbon tax on products, purchases, or “behaviors”	Building codes and zoning • Waste reduction policies • Multi-modal transit • “shop local” initiatives • LEED, etc

planning efforts designed to reduce carbon emissions from the aggregation of individual driving behaviors, such as California’s SB 375 or any of the various national “smart growth” initiatives. Or using *directly measured production-based emissions data* to determine if industry-specific policies such as the now-repealed Clean Power Plan or fracking-related methane rules are working to reduce specific sector-based emissions. That is, we can see if policy efforts to reduce carbon emissions are working.

In this same way, direct emissions data could be used to measure regionally-based policies such as the electricity sector components of statewide Climate Action Plans or regional carbon emissions reduction programs. This kind of systematic analysis across the nation might represent a powerful tool in our capability to compare various policies made to address carbon emissions across specific sectors or regions and assess how well regional sustainable transportation planning policy tools, or industry-targeted policies, are performing in terms of reducing emissions. Measuring the emissions directly at multiple scales in these cases would allow policymakers at the national, state, or local scale to target not only specific sectors or regions but also potentially target emitters by, for example, firm size or prior performance. This in turn could allow for policy details to be included to address equity issues.

Implications for climate policymaking using indirectly measured carbon emission data

But carbon inventories built “indirectly” by surveying home consumption of various goods (e.g., beef, fruits, and appliances) and applying up-to-date GHG footprint techniques for those goods can tie to the point of consumption more directly. This would allow for carbon taxes to be imposed on specific goods or services. In a study emblematic of many similar studies, Shewmake et al. (2015) model consumer responses to “carbon labels” on goods providing information on the carbon footprint of household items at purchase. Their model indicates shifts in consumer demand for dozens of food and non-food goods and that carbon labels can reduce emissions, but warn that “…labeling only some items could lead to perverse impacts where consumers substitute away from labeled goods to unlabeled goods with a higher carbon footprint…”. In this way, *indirectly measured consumption-based emissions data* can be used to create Pigouvian carbon signaling policies and incentivize behaviors in ways that reduce consumption-based emissions at the local and regional scale.

We recommend that carbon footprint data inventories we have employed here be used comprehensively across household goods, and especially target goods fitting a description of “carbon-intense and expensive.” Of course, doing this while also attaching a price to embodied carbon would have the effect, the desired effect we might argue, of targeting communities with the largest footprints—i.e., the wealthiest communities. Likewise, we could use *indirectly measured production-based emissions data* such as the embodied energy in buildings to better understand the effectiveness of building codes, such as LEED, and zoning changes, such as transit-oriented development initiatives designed to reduce carbon emissions. Or to measure the reduction in waste stream–related emissions from recycling and compost programs. Lastly, this type of data could inform the evaluation of policies and programs designed to reduce emissions through the promotion of shopping or eating “locally.”

Returning to the example of assessing whether regional transportation policy is successfully reducing emission, we might observe carbon emission reductions if we only use directly measured carbon emission data but miss that community carbon footprints are growing based on home expenditures. In a study, we find very instructive, but overlooked in the literature, Jones & Kammen (2014), using household surveys similar to those employed here, found “…consistently lower HCF [household carbon footprints] in urban core cities…and higher carbon footprints in outlying suburbs…in the 50 largest metropolitan areas. *Population density exhibits a weak but positive correlation with HCF until a density threshold is met*, after which range, mean, and standard deviation of HCF decline” (emphasis added). In other words, suburban sprawl negated the carbon emission reduction benefits of increased density in urban areas. Policy tools, therefore, must have a two-fold approach of addressing carbon impacts at larger metropolitan areas, as well as more localized scales (such as at the zip code scale), and pair regional transportation planning with hyper-localized policy internalizing the cost of carbon using indirectly measured footprints of goods and services. One way to do this might be the "trans-boundary infrastructure supply chain footprint (TBIF) GHG emissions accounting method" assessed by Chavez et al. (2012).

Closing discussion and the legacy of Monty Hempel

We hope to build on the work of others attempting to solve the transboundary problem of assessing environmental impact at subnational scales (Chavez and Ramaswami 2011; Hillman and Ramaswami 2010). We hope to inform innovative climate policy that includes consideration of cross-scale carbon embodied in goods and services consumed in one location while the emissions are displaced in another locality. By linking directly sourced and indirectly sourced carbon emissions inventories, we can internalize the displaced carbon emissions and more authentically assess a locality's environmental impact in comparison to other localities. Our research here shows this most conspicuously will allow us to add the displaced production-based carbon emissions embodied in goods consumed in affluent counties back into their total carbon footprint. In doing so, the direct link between affluence and the carbon footprint is clear, and this is crucial. If we are to address the coming climate crisis we need to adapt our communities to be more resilient to climate destabilization, but we must also have policies and measures that allow us to (perhaps dramatically) reduce carbon emissions. It is worth mentioning here that Jorgenson et al. (2017:1167), conducting research similar to what has been outlined here, found that carbon intensity and income concentration were positively associated in U.S. subnational analysis and concluded that "…reducing forms of inequality, especially poverty and the concentration of income among the most affluent, are potential pathways to sustainability."… and decarbonization, we might add.

Carbon inventories built on direct measures, with a large geographic scope and fine resolution would presumably allow policies to be designed to target carbon emission reductions from specific carbon-intense industries and sector-based activity, as well as perhaps tailor policies to specific geographic regions or localities. Meanwhile, carbon inventories built on indirect measures of embodied carbon would allow policies and programs to target specific goods and services. In any case, carbon mitigation policies must be designed in ways that ensure that communities with larger footprints bear the larger burdens on any increased prices. Indeed, linking the success of local climate and carbon mitigation policies to direct and indirect measures of carbon emissions is a gap to be addressed in future scholarship. Following the lead of Ramaswami et al. (2012), we attempt to help build towards a conceptual framework that links theories and models explaining governance of transboundary environmental challenges, such as the Institutional Collective Action Framework (Feiock 2013), with transboundary environmental impact data.

We opened with how our project honors the work of Monty Hempel. Following his example, we ask critical questions regarding the socio-economic dimensions of data and technical information and how that information might inform climate policy. Specifically, Hempel (2009) signaled not only the advantage of the ecological footprint as a local-level sustainability metric but also the utility of GIS analysis to explore local-level variation in this metric across vast scales. Honoring his call, our project synthesizes these data and tools to begin making connections between local-level accounting of carbon footprints and climate policy. Any climate policy hoping to be both effective and equitable would need to employ the contextually appropriate kind of carbon data (i.e., the way it is collected, the scale) and, more importantly, the policymakers and managers involved would need to communicate the data informing the policy in clear and transparent ways, e.g., to the public, to government leaders and managers across jurisdictional boundaries. This would be an essential aspect of any discussion attempting to build coalition support around specific proposed climate policies that are explicitly tied to carbon emissions data. Simply put, we must be as clear and transparent about the socio-economic factors related to the generation of carbon data informing policy as we are about the policy design itself.

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