

Dane County Emissions Accounting

By

Erin Bulson, Rishika Tumula, Richard Imagwe, Samuel Garcia

Submitted to Kathy Kuntz

University of Wisconsin-Madison

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1 Executive Summary

1.1 Recommendation

It is our recommendation that Dane County track both consumption-based and production-based carbon emissions inventories. Consumption-based emissions inventories (CBEI's) account for the full lifecycle of a product or service, which is notably absent from geographically constrained production-based inventories. Consumption-based emissions inventories reveal critical information to help guide policies, programs, and incentives for emissions reductions that may otherwise be unaccounted for with sole reliance on production-based emissions inventories. Furthermore, implementation of consumption-based emissions inventories along with production-based emissions inventories will improve Dane County's ability to meet its commitments to the six additional priorities identified by the Dane County Climate Action Plan: equity, economic benefits, health benefits, resilience, rural-urban cooperation, and ecosystem benefits.

1.2 Background & Literature Review

Our recommendation is based on an extensive literature review consisting of peer-reviewed journal articles, white papers, conference proceedings, government documents, non-governmental organization documents, and newspaper articles—of which spanned all levels of government both domestic and abroad. Furthermore, review on literature published by EcoDataLab, the most prolific CBEI emission accounting firm for many municipalities in the United States, along with interviews conducted with leadership informed depth and difficulty of CBEI analysis.

1.3 Key Findings

It was found that municipalities that include CBEI's as part of their reporting requirements often found CBEI's were between 20-400% larger than traditional inventories, depending on socioeconomic features. Additionally, consumer behavior that would otherwise not be observable had potential pathways for mitigations, such as emissions hotspots in supply chains which would then be regulated through changes in procurement methods. However, direct emissions through firm operations becomes more unclear through CBEI methods. To address data gaps, it was found that many municipalities utilize both traditional and CBEI methods to holistically assess and map emissions to different sectors and entities.

1.4 Conclusion

Overall, with looming emissions goals on the horizon and with increasingly marginal gains to be made in emissions reductions, it is important to identify sources of emissions accurately and fairly. Often, traditional inventories in absence of CBEI lead to incomplete conclusions such as identifying lower-income regions are the largest source of emissions, without understanding the source of that demand. To this end, we believe that Dane County should incorporate consumption-based accounting into its carbon accounting strategy. Incorporation of a CBEI, in addition to production-based emissions accounting, will better position the county to advance public initiatives that support emissions reductions and the six additional priorities identified by the Dane County Climate Action Plan. Outsourcing expertise for CBEI reports via firms or research groups is advised, as the work entailed may exceed the county's current capacity.

2 Introduction & Background

The onset of human-induced climate change has had increasingly impactful and detrimental effects to society such as accelerating global temperatures, severe weather patterns, growing health risks through disease, and decreasing biodiversity via extinction. As a result, there is a growing effort to limit and halt climate change through legislative and technological means, primarily by way of emissions reduction. Currently, the Paris Climate Agreement seeks to reduce global greenhouse gas (GHG) emissions by 43% in 2030 to limit global warming to 1.5°C above pre-industrial levels [1]. In this way, there is a need for accurate GHG auditing methods to 1) provide comprehensive visibility over a region's activities and supply chain 2) understand incentives that drive firms to emit GHG's and 3) discern and implement climate legislation equitably and efficiently.

Traditionally, GHG inventories are done through the production-based emissions inventory (PBEI) approach. This approach accounts only for GHG's that are directly emitted by consumers or firms within a defined geographic area [2]. This would include emissions from travel, residential use, and industrial use among others. Though this provides a clear image of some consumer habits, this inventory method historically portrays a positive image for developed regions while placing a disproportionate number of emissions on developing regions [3]. Thus, developed nations posture climate agreement adherence through offsetting emissions via production in emerging nations [3], [4]. Furthermore, future global agreements are postulated to harshly impact economic growth for developing nations while largely maintaining the status quo for those with affluence—an inequitable and inaccurate implementation of legislation [4]. For these reasons, there is growing interest in alternative inventory methods that include direct and indirect emissions.

Consumption-based accounting of CO₂ emissions differs from traditional, production-based inventories because of imports and exports of goods and services that, either directly or indirectly, involve CO₂ emissions. In the 1990s, consumption and production levels of CO₂ were similar—a reflection of the US oil industry and relatively smaller share of trade. However, since 2000, consumption levels of CO₂ have been higher than production levels even when utilizing simple models, as depicted below in Figure 1 [5]. This reflects trends observed on national scale emissions inventories [6].

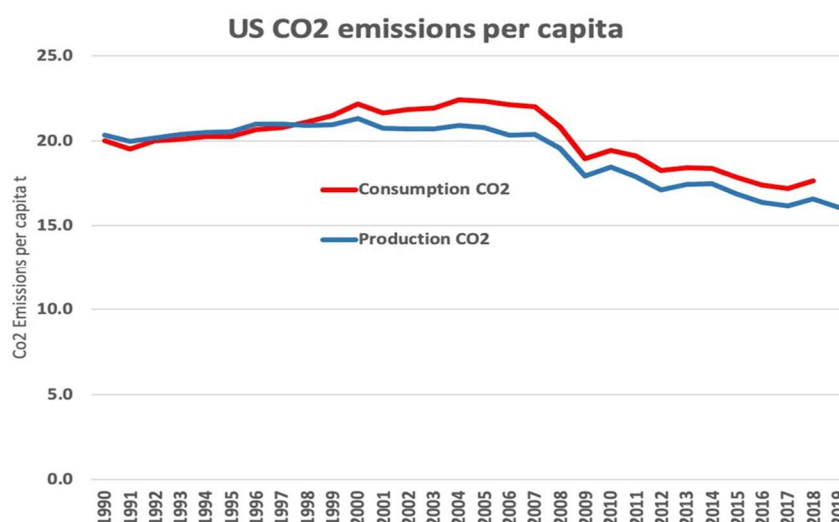


Figure 1: Rudimentary emissions and consumption inventory differences for the United States

The difference between production emissions (F_{Pr}) and consumption emissions (F_{Cr}) represents the net effect of emissions embodied in trade (EET) and therefore equals emissions embodied in exports (EEE) minus emissions embodied in imports (EEI). A positive difference reflects the net export of emissions, and

a negative value indicates the net import of emissions. Results are typically discussed as factors of the Kaya identity.

$$F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E} = P \times g \times e \times f = P \times g \times h \quad (2)$$

where F represents global emissions, P is population, G is world GDP or gross world product, E is global energy consumption, $g = G/P$ is per-capita GDP, $e = E/G$ is energy intensity of world GDP, $f = F/E$ is carbon intensity of energy consumption, and $h = F/G$ is carbon intensity of world GDP. We apply the intensity relationships in assessing traded goods and their embodied emissions or energy and denote these instances with subscript t .

For the purposes of this report, the consumption-based emissions inventory (CBEI) method is the primary method of interest as it accounts for indirect emissions not currently inventoried in Dane County, such as those associated with the production of goods imported to and consumed in a specific area [7]. This would include food products, motor vehicles, clothing, shipped goods, and services. The consumption-based approach accounts for emissions both up and downstream of a specific product to holistically assess its GHG impact, which better captures consumer and firm behavior. Furthermore, it looks to clarify the supply and demand for products and services (and by extension the supply and demand for GHG's) which more clearly depicts the influence of affluent entities [3].

While CBEIs have predominately been performed at a national scale, there is increased interest for local-level government adoption of CBEIs. For example, CBEI reports for San Francisco (California) and King County (Washington) have recently been completed [7], [8]. Interest in CBEI has extended into Dane County, Wisconsin, which has historically completed PBEI. In this report, CBEIs are evaluated for their advantages and disadvantages in tracking emissions in addition to and in lieu of production emissions for Dane County. This evaluation is done based on the feasibility for a CBEI to be done inhouse, the actionability of the additional data, and if tracking both sets of emissions increases adherence to six priorities: equity, economic benefits, health benefits, resilience, rural-urban cooperation, and ecosystem benefits. This work will serve as a recommendation for Dane County to either pursue CBEIs or to seek alternative methods.

3 Literature Review

The literature review for this project consisted of peer-reviewed papers, white papers, conference proceedings, government documents, and non-governmental organization (NGO) documents, and newspaper articles, relevant to the adoption of consumption-based carbon emissions accounting. Upon review, the most pertinent papers and documents were selected to provide background information from an unbiased perspective (both in support of consumption-based carbon accounting as well as not in favor of consumption-based carbon accounting). The scope of the literature reviewed is international.

The literature reviewed provided perspective on the merits of national versus more local carbon accounting, the merits of CBEI versus PBEI, and how this information can inform policy at all levels of government. Due to Dane County's current consideration for consumption-based carbon accounting at the county-level, literature review specifically included:

- Background information obtained through Local Governments for Sustainability (ICLEI), a non-governmental organization.
- Consumption-based greenhouse gas emissions reports for other localities (city-level and county-level reports conducted by CoolClimate Network or EcoDataLab); Note: CoolClimate Network and EcoDataLab are linked.
- Newspaper articles about a university research group that conducts consumption-based greenhouse gas emissions on the local level (CoolClimate Network).

Peer-reviewed literature, EcoDataLab reports, and newspaper articles about CoolClimate Network data are considered separately.

3.1 Peer-reviewed literature

Consumption-based emissions accounting literature is dominated by studies that focus on a national scale. The national-scale focus is understandable, in that it addresses international trade and emissions responsibility issues. For example, Móznér discussed concerns about emissions with respect to global trade imbalances and explored the relationships between international trade and embodied emissions [9]. The embodied CO₂ emissions associated with both imports and exports were compared for four European countries. The results of the study showed that “a consumption-based principle and allocation approach would help to increase the efficiency of emission reductions and would force countries to rethink their trading activities in order to decrease the environmental load of production activities,” [9].

The evolving shift in attention to “subnational climate governances” versus a national focus was summarized by Larsen et al. [10]. The growing interest in more localized emissions accounting is attributed to a combination of climate-oriented initiatives, including the “Cities for Climate Protection” campaigns [11]–[13] along with the Greenhouse Gas (GHG) protocol [14] followed by the Local Government Operational Protocol [15].

City-level consumption-based emissions studies in academic literature appear to have focused on European cities; Millward-Hopkins et al. [16] assessed and compared production- and consumption-based emissions for Bristol, England, from 2003 – 2005. Among the results, it was found that Bristol's production-based emissions were only one third of its consumption-based emissions [16]. Furthermore, this disparity was attributed mostly to the impacts associated with a particular sector—imported food and drink. It was suggested that the incorporation of “consumption-based emission statistics into cities' accounting and decision-making processes could uncover largely unrecognized opportunities for mitigation that are likely to be essential for achieving deep decarbonization.” In this instance, the suggested local mitigation policy

would address minimizing food waste. Of note, the authors clearly advocate for the continued use of production-based emissions accounting as well.

Harris et al. [17] evaluated and compared consumption-based versus production-based emissions for ten European cities. Three scenarios were considered: 1) base year 2007; 2) business-as-usual (BAU) projected for 2050; and 3) post carbon scenario (PC 2050) projected for 2050. The PC 2050 scenario was created by a city stakeholder workgroup, which used a framework provided by a European research project [17]. Multiregional input-output models were used to quantify emissions. The study results are shown in Figure 2 below. Overall, consumption-based emissions increased and were linked to an increase in GDP (Gross Domestic Product) and likewise increase in spending and consumption. Importantly, the increase in consumption was projected to override the local and global efficiency improvements, thus highlighting the importance of accounting for consumption.

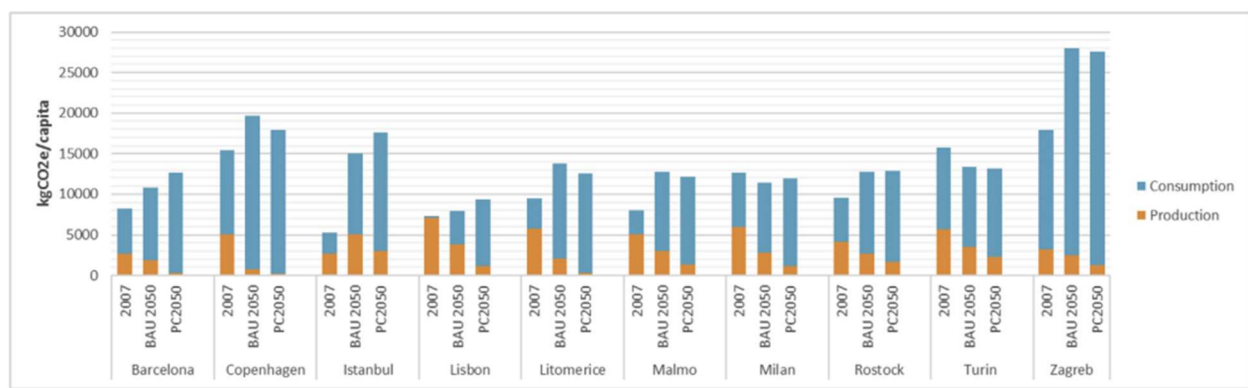


Figure 2: Comparison of production- and consumption-based GHG emissions per capita for 2007, BAU and PC2050 [17].

Combined carbon accounting approaches have been suggested as a best path forward, with the rationale that the different approaches have their respective complimentary merits. Tukker et al., [18] advocated that production-, consumption and income-based approaches provide unique pathways for different, complimentary mitigation strategies. For instance, a consumption-based approach highlights emissions hotspots in supply chains, which can be addressed through changes in procurement. Production-based accounting, in theory, should lead to reduction measures for direction emissions. Finally, the income-based approach focuses more on the end-of-life materials phase, which encourages producer responsibility for “green” design (in line with circular economy and low-carbon design). These accounting perspectives and suggested related mitigation measures are depicted by Ref. [18] in Figure 3. Consumption-based accounting is framed in red for the benefit of Dane County’s interest in this emissions approach.

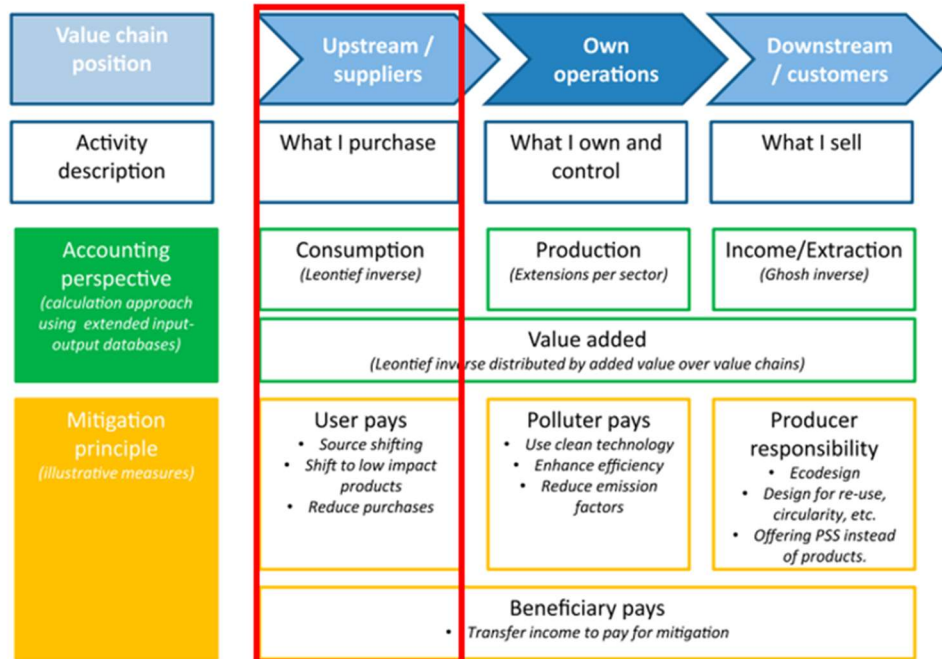


Figure 3: Different accounting perspectives and related mitigation measures as suggested by Ref. [16], modified to draw attention to consumption accounting.

Currently there is not ubiquitous acceptance of consumption-based emissions accounting. Challenges with the adoption of emissions-based accounting at the local level have been described previously [6]. Consumption-based accounting (CBA) and Production-based accounting (PBA) ratios were computed for 110 countries for the time span of 1997 to 2011 and concluded that PBA alone was sufficient. They examined if Organization for Economic Co-Operation and Development (OECD) membership or GDP per capita correlated with carbon leakage (indicated by a CBA:PBA ratio > 1). Based on their analysis, they found that OECD membership or GDP per capita were not good indicators of carbon leakage, and suggested energy efficiency and high import rates were more indicative of carbon leakage. Furthermore, they argued that PBA and CBA differences were negligible and did not warrant CBA in addition to PBA. Results of their CBA to PBA ratios analysis are shown in Figure 4.

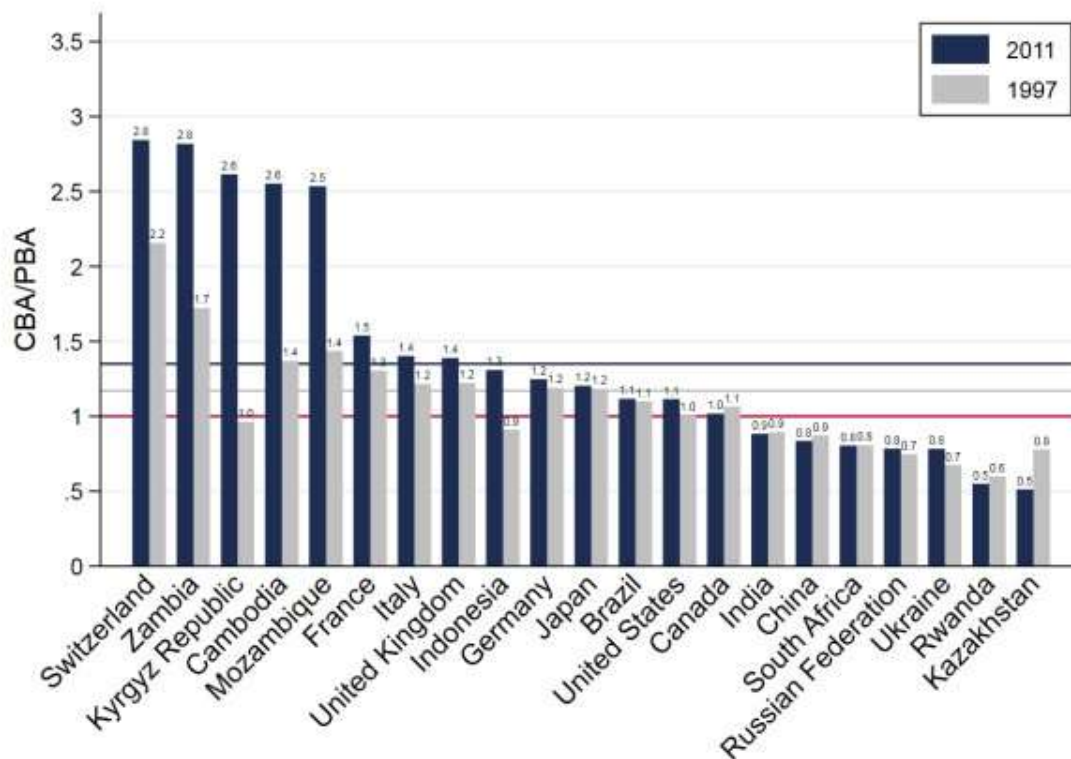


Figure 4: CBA:PBA ratios for several OECD and non-OECD nations

It is worth noting this work [6] was conducted at the national level, which is unable to capture important carbon leakage at the local level. This is discussed in more depth in Section 5.

3.2 Local Governments for Sustainability (ICLEI)

Local Governments for Sustainability (ICLEI) is a global organization that focuses on advancing sustainable urban development, particularly through influencing policies that work towards low emissions [19]. ICLEI is comprised of 2500+ local and regional governments—including Dane County, and spans 125+ countries. The ICLEI community collaborates via peer exchange, partnerships, and capacity building.

ICLEI has made its position clear that lifestyle-driven consumption-based emissions must be evaluated to fully address the climate crisis. ICLEI has noted that 45% of global emissions relate to consumption habits, with a focus on land management, production of buildings, vehicles, food, and consumer goods and services.

A Consumption-Based Emissions Inventory Cohort was launched through ICLEI to provide technical assistance to up to 15 ICLEI-member cities or counties to create a “consumption-based greenhouse gas inventory as a baseline to support local policies and programs to operationalize the transition to a circular economy from infrastructure, business and community perspectives.” Interestingly, participants were given the option to conduct a consumption survey of their community, or alternatively downscale national or state data. The consumption-based emissions reporting is intended to align with the U.S. Community Protocol (USCP) or the Global Covenant of Mayors for Climate & Energy’s Common Reporting Framework (CRF). This cohort ran through April 2021 to October 2021. A schedule of the cohort sessions was provided through the ICLEI website and is outlined below [19]. This workflow may be helpful to Dane County, particularly as it relates to policy which is the focus of Session 6. Moreover, this workflow may help Dane County work

together with counties and cities across the state of Wisconsin to collaborate on policy initiatives as they relate to consumption-based accounting.

Session 1: Intro to consumption-based inventories

Session 2: Survey design and dissemination

Session 3: Downscaling and adjusting data

Session 4: Understanding life cycle emissions factors

Session 5: Round robin comparison of results

Session 6: Policies, communicating results

Session 7: Takeaways and next steps

3.3 New York Times article: The Climate Impact of Your Neighborhood, Mapped (December 13, 2022)

A recent New York Times (NYT) article featured information about the growing recognition of the critical role that consumption-based emissions accounting has in guiding policy development to address climate change [20]. The article primarily focused on the work of Dr. Chris Jones and his team at University of California-Berkeley, called the CoolClimate Network. Dr. Jones was interviewed for this EAP Capstone project as well, so more details about how CoolClimate Network functions are included below. The NYT article included an interactive map produced by CoolClimate Network that shows the varying household contributions to climate change. Figure 5 provides a snapshot of the CoolClimate Network modeled household emissions for areas within Dane County for the year 2014 [20].

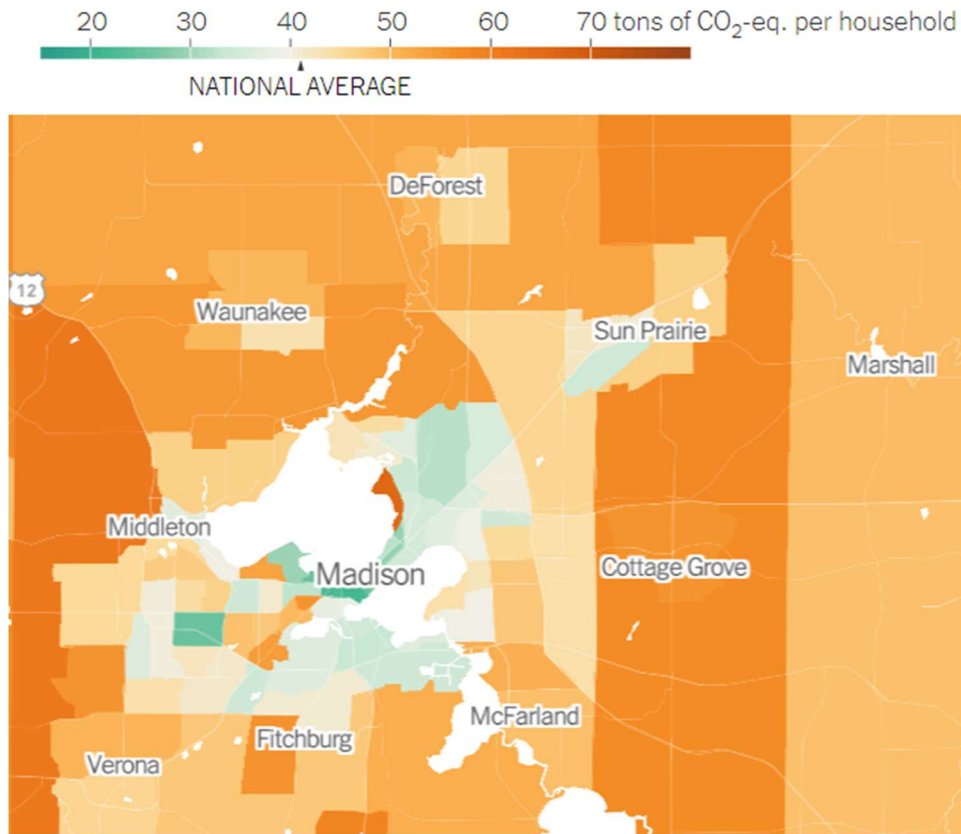


Figure 5: Estimated household consumption-based emissions within the Dane County area for 2014, as modeled by CoolClimate Network.

Key points from the NYT article for policymakers to consider with respect to emissions:

- **Population density is a key factor:** City centers usually have lower household emissions because residents tend to walk more and drive less.
- **Household income is a key factor:** Affluent geographies tend to have higher household emissions because they engage in more carbon-intensive activities like air travel and live in suburban areas that necessitate vehicle travel.

Dr. Jones also suggested that our team review the Bay Area report his team completed for a more detailed explanation of the modeling approach.

3.4 Consumption-based greenhouse gas emissions reports for other localities

We reviewed two local-scale consumption-based emissions reports to gain familiarity with the modeling approach used by CoolClimate Network/EcoDataLab. These reports also provided information about how the emissions data may be used to inform policy about climate change. The two reports reviewed were for the San Francisco Bay Area and King County [7], [8]. A third report that was recently published was also reviewed, though is not discussed as it's modelling approach and conclusions were consistent with the King County report [21].

The CBEI modeling approach used for the two reviewed reports is consistent. The San Francisco Bay Area Report summarizes past CBEI modeling approaches which relied solely on income or income and household size [7]. Building on previous efforts, CBEI modeling used by CoolClimate/EcoDataLab aimed

for improved precision. The modeling work incorporated a refined approach with respect to household surveys, input-output models, and econometrics, and considered:

- demographics (income, household size, race, education)
- home characteristics (home size, home ownership, structure type, heating fuel)
- travel behavior (vehicle ownership, commute mode, commute times),
- geographic variables (population density, weather)
- economic data (energy prices)

3.5 EcoDataLab CBEI Algorithm

EcoDataLab's process for consumption based analysis starts with the selection of a nation-wide survey to establish estimates travel behavior, consumer expenditures and energy consumption [8]. These averages are used to model consumption trends on different geographic levels. Then key household characteristics, like household size, income, vehicle ownership etc. are identified and data is gathered from sources like census and ACS. The survey results and household characteristics are run through a multiple linear regression (Equation 1), to identify how strongly these variables correlate with each other. The program is built to seek household and geographic characteristics and learn to predict survey results.

$$y = m_1x_1 + m_2x_2 + m_3x_3 + \dots + b \quad (1)$$

where in this case, each x (x_1 , x_2 , x_3 , etc.) is a different household or geographic characteristic, with its own unique correlation (m_1 , m_2 , m_3 , etc.) that together add up to make the overall result. The number of x variables depends on the sub-model and available data. EcoDataLab's sub-models use at least six variables. Nonlinear effects from household characteristics are also considered, meaning equations have variables which can be natural logarithms of x .

Once a predictive model is built, it is run using local data, gathered from a variety of sources, and based on client request. Adjustments are made based on availability of data and its level of accuracy. The model calculates consumption for a given geography. Using US EPA's USEEIO Model and EIA's eGrid emission factors, final emissions are calculated [22], [23].

3.5.1 San Francisco Bay Area Report [7]

EcoDataLab estimated CBEIs for the San Francisco Bay area for the years 1990 to 2015.

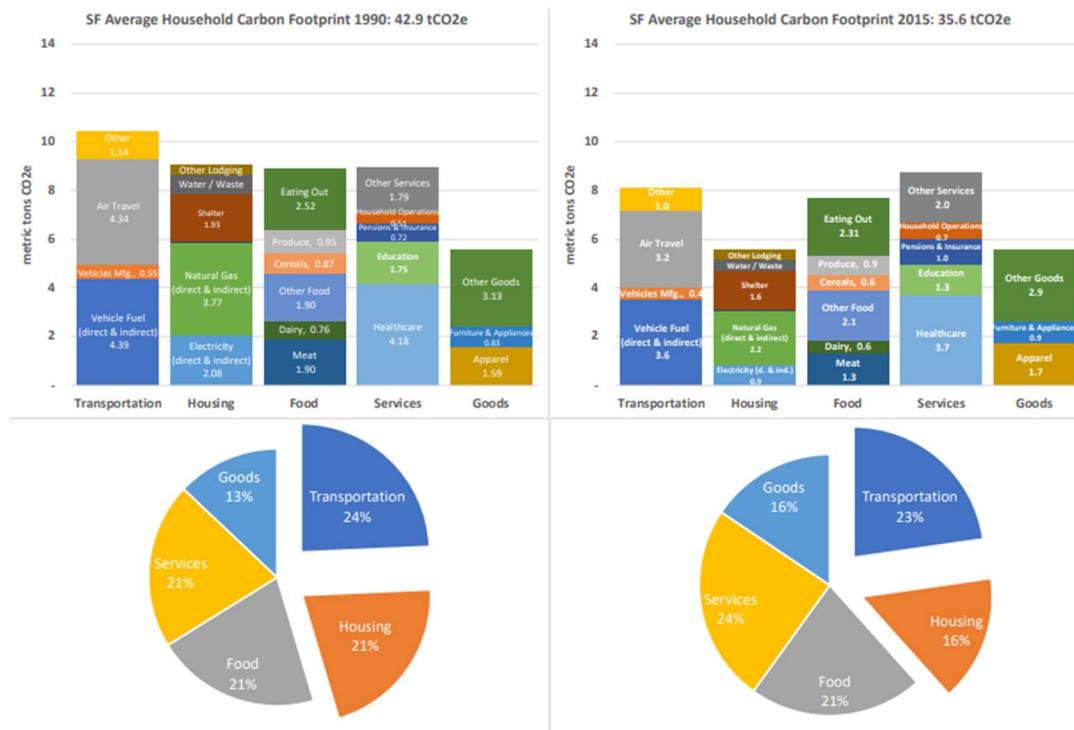


Figure 6: Average San Francisco Household Carbon Footprints in 1990 and 2015 [5].

Key findings from the total city-wide consumption-based emissions from 1990 and 2015 were that the average household footprint remained steady over that period, and any decrease in emissions was eclipsed by population growth. Of note, while higher income and education levels are typically correlated with increased consumption, San Francisco consumption is not in line with this trend. Factors unique to San Francisco include low rates of vehicle ownership, small home (building) size, small household size, low rates of home ownership, high population density, moderate climate, and low-carbon electricity.

This report provided the most information regarding methodology and data inputs in the model used for the performed CBEI, which are included in its appendices.

3.5.2 King County Report [8]

The modeling approach for the King County report was consistent with the Bay Area report. However, the King County report also considered abatement potential for consumption-based emissions. The PSREA Consumption-Based Emissions Abatement Analysis (CBEA) tool was used to model local emissions reductions that can result from a combination of policies, changes in household consumption, and other economy-wide decarbonization efforts. A wedge diagram for King County was used to show potential emissions reductions based on household consumption changes and decarbonization of supply chain, which is shown in Figure 7 below. Figure 7 also indicates that King County is not currently on track to meet its

emissions reduction targets, even after the effects of existing policy changes, consumption changes, and supply chain decarbonization are realized.

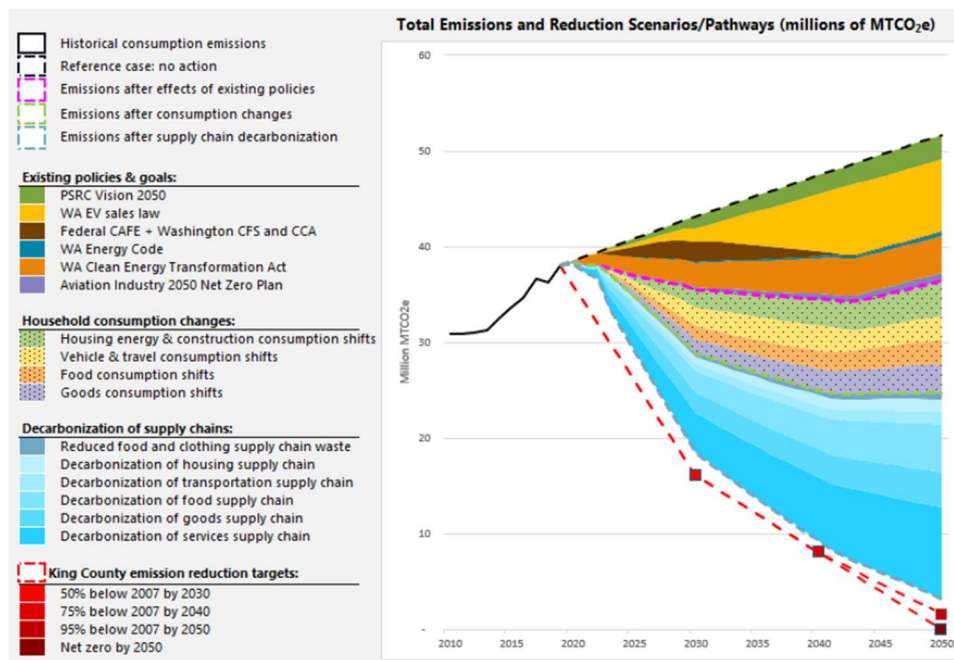


Figure 7: CBEA wedge diagram showing the contribution of different abatement measures for King County .

4 Interview with Dr. Chris Jones

Our team had a virtual meeting with Dr. Chris Jones from CoolClimate Network (and privately held EcoDataLab) on March 3, 2023. Kathy Kuntz, Director of the Office of Energy & Climate Change for Dane County, also attended the meeting.

We learned that CoolClimate Network has 20-40 University of California-Berkeley students working on consumptions-based emissions modeling to generate the household emissions maps. Students typically have a data science background, often complemented with some environmental studies education. The model results are projected at a city-block resolution. The model is still evolving, and a future vision is to use the emissions data to develop a metabolic analysis of emissions across geographies.

We also had a follow-up email exchange with Dr. Jones to inquire about a CoolClimate Network consumption-based emissions project that had been started and then paused by the City of Austin. Our team wanted to know if there were any specific challenges associated with that project. Dr. Jones responded that the project had stalled due to staffing issues.

5 Dane County Production- versus Consumption-Based Emissions

Based on the literature review, our group was interested in quantifying the differences between consumption-based and production-based total emissions for Dane County. Dane County's Office of Energy and Climate Change provided a county-level production-based inventory report from 2016, along with total emissions as computed by CoolClimate Network's algorithm for consumption-based accounting from 2013 [24], [25]. The total emissions reported through the consumption-based approach in 2013 were extrapolated linearly to 2016 to compare the values in the same base year. The extrapolation is done as a function of population only, while change in consumer behavior and other effects of demographic patterns have not

been considered [26]. Figure 8 shows the population trends in Dane County from 2013 to 2022, along with emissions from consumption and production-based approaches in 2013 and 2016 (linear extrapolation). Consumption based approach records total emissions 24% higher than production inventory.

Table 1: Emissions and consumption inventories for Dane County

Agency	Method	Publishing Year	Total Emissions (tons of CO2 per year)
Dane County	Production based	2017	7,439,781.397
CoolClimate Network	Consumption based	2014	9,215,735

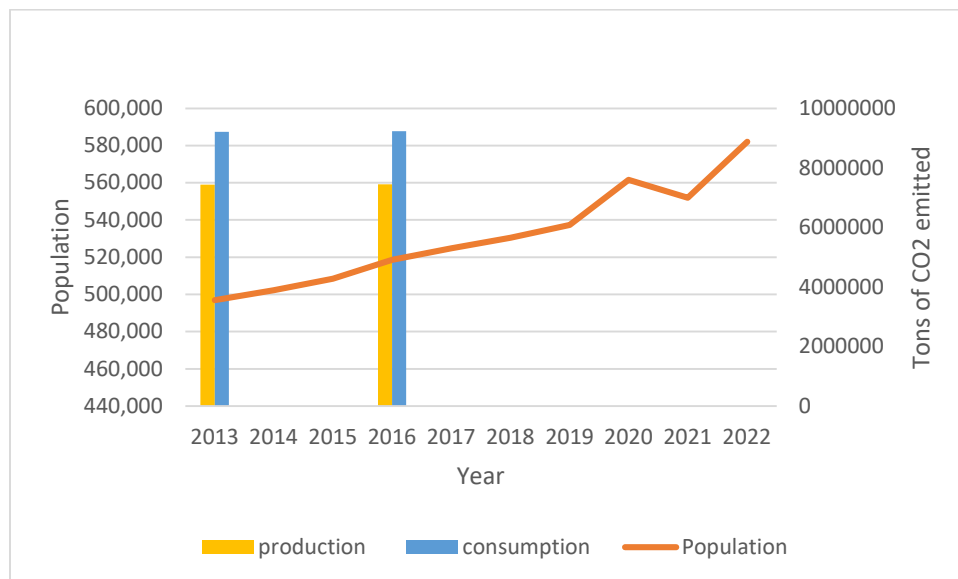


Figure 8: Extrapolated consumption and production emissions data.

Dane County will need to identify where emissions are double counted if the county pursues both CBEI and PBEI. There is an increasing issue of double counting GHG emissions due to the lack of consensus on inventory methodology, especially when considering that many firms are performing their own inventories according to federal regulations. With a growing number of cities making emissions reductions commitments, such as with the U.S. Conference of Mayors Climate Protection Agreement, the issue of double counting will become a growing problem especially with respect to agreement between municipal and firm inventories [27]. Currently, the U.S. Environmental Protection Agency has adopted the basis of the Greenhouse Gas Protocol which is spearheaded by the World Resources Institute. This methodology divides emissions into three categories [14]:

- Scope 1: Direct emissions occurring from sources owned or controlled by the reporting entity, including its industrial activities and any onsite energy production.
- Scope 2: Indirect emission that result from activities of the reporting entity but occur at sources owned or controlled by another entity (e.g., purchased electricity, heat, steam)
- Scope 3: All other indirect emission that are associated with a company's activities and not included in Scopes 1 and 2

Currently within the United States, firms are required to include Scopes 1 and 2 as part of their GHG inventory, while Scope 3 is optional to report—though this may change as the U.S. Securities and Exchange Commission is actively pushing for amendments to reporting requirements for enhanced transparency [28]. Typically, municipalities will account for Scope 1 and 2 emissions using the PBEI framework despite

having little control over those sources. While it is true that government operations fall under their control, these typically amount to a “small percentage of community-wide emissions” [27]. In this way, a local government is only made of Scope 3 emissions as the sources are not within their control. Yet, due to emission reductions commitments, municipalities are obligated to reduce emissions from these uncontrolled sources along with city operations. Therefore, when a business or industry inventories Scope 1 and 2 emissions per federal requirements, the overall emissions profile of the city cannot be accurate as emissions would be double counted as industry emissions were already accounted for by the city. This problem becomes exacerbated if municipalities choose to utilize the CBEI method as there is typically an observed 20% difference when compared to the PBEI method [3].

To overcome this issue, cities and counties are outsourcing CBEI’s while performing their own PBEI’s, as neither method has a unique solution to double counting; it is a pervasive issue in all emission inventory methods. These inventories are then compared in conjunction with publicly-released PBEI emissions reports from local industries and businesses to compare shortcomings and manually handle double-counting [2], [7], [8]. This is done to resolve occurrences of double-counting and better depict regional emissions. Furthermore, due to the complexity of CBEI’s along with the relative ease of PBEI’s, this hybrid method is preferred as many local governments are understaffed in their energy and climate departments. As a result, Scopes 1, 2, and 3 are well-captured along with well-informed predicted emissions in the short and long-term. It would be advisable for Dane County to pursue similar workflows to ensure accurate emissions inventory.

While it might be thought that utilizing CBEI exclusively might remove the problem of double-counting there is a secondary consequence to consider; a portion of the emissions in a CBEI take place outside of the politically administered region where consumption is considered [29]. This changes the political component to climate mitigation across all regional scales [30]. Ideally, these changes would manifest via mitigating carbon leakage through imports which highlights inequities in consumer behavior that are often undiscussed. Indeed, carbon-leakage is the likely culprit that leads to such large discrepancies observed in municipalities [17] that are not observed on the national scale for some countries [5], [6]. Yet, due to egregious GHG emitters likely lying beyond a region’s political domain, it is unclear how legislation could be effectively implemented to develop improved emissions reductions when compared to legislation derived from current PBA methods. There are uncertainties regarding responsibility for emissions that could have broader political implications on both the local and national scale. For these reasons, the political dimension would hinder CBA as an exclusive accounting method.

A comparison of both methods calls into question who should be accountable for the emissions that result from a certain action. Should the burden be placed on production facilities and hence be the area's responsibility, where it is based? Or should it be distributed across the geographies of all the consumers of said good? Is it possible to distribute the burden so that both parties are held accountable? Currently we advocate for emissions accounting to include both CBEI and PBEI. Important to note, there are some challenges associated with CBEI. For instance, when consumers become more conscious about the environment and question the sources and ethics of products before consumption, a consumption-based approach is more accurate for painting a picture of how the collective social behavior impacts the carbon footprint of a community. However, even advanced models like those developed by EcoDataLab only look at total expenditures having a direct impact on emissions. In the real world, people are spending an extra dollar to ensure better manufacturing methods or waste reduction, which goes completely unnoticed in these algorithms. The next steps for consumption-based calculation methods would be to account for these nuances, to get closer to the real story of emissions.

6 Feasibility for county-led consumption-based inventory

EcoDataLab has built a robust model over years of experimenting. Recreating a model similar to that is a time and resource intensive job that may be beyond the current capacity of Dane County. The county is currently understaffed and underfunded, which further eliminated the need to start this analysis from scratch. Currently the county outsources projects to make a production-based emissions inventory, the same resources can be diverted toward organizations like EcoDataLab and providing them with any data that removes assumptions to get a more accurate estimate.

However, it is important to note that despite the complexity and continual growth of the EcoDataLab model, there are no third-party auditing capabilities to verify the accuracy or validity of their product as it is proprietary. Typically, software that aims to model a certain phenomenon is benchmarked against validated cases to ascertain a certain range of uncertainty that the model will induce. While EcoDataLab can report uncertainties with their inventories, this would effectively need to be taken at face value as there have been no published efforts thus far in replicating or validating EcoDataLab work.

7 Impact on the six additional priorities identified by CAP in addition to emission reduction

In addition to the evaluation of the merits of pursuing consumption-based carbon accounting for emissions reduction, the impacts consumption-based carbon accounting can have on the six additional priorities identified by Dane County's Climate Action Plan were also evaluated. The six additional priorities are: (1) equity; (2) economic benefits; (3) health benefits; (4) resilience; (5) rural-urban cooperation; and (6) ecosystem benefits. A coupled CBA and PBA approach to emissions accounting can be used to strike a balance between producer and consumer responsibility for emissions, particularly at the local level. The emissions-related information yielded from both accounting methods can guide local policy and actions to meet emissions targets. Table 2 shows the six additional priorities, their potential actions (policy) and outcomes. Note, the potential actions and respective potential outcomes are based on policy or program initiatives that may be pursued in light of coupled CBEI and PBEI results. Actions that are more exclusive to CBEI results alone are highlighted.

Table 2: Actions and results related to the six additional priorities for Dane County, as informed by consumption-based carbon accounting results.

Six Additional CAP Priorities for Dane County	Potential Actions	Potential Outcomes
1. Equity	a. Zoning requirements and building codes. b. Access to low-cost clean energy programs.	a. An increase in housing density with access to public transportation will improve equitable access to jobs and affordable housing. b. Lower utility bills for those that need it most.
2. Economic benefits	a. Circular economy and local supply chain support. b. Workforce training for new "green energy" jobs	a. More local industry/supply chain may lead to local business/economic development. b. Job creation for potentially higher wage jobs.
3. Health benefits	a. Renewable energy access (and discontinued coal use) b. Zoning requirements	a. The phase out of coal will result in less air pollution, which has disproportionate negative healthy consequences for low-income, minority communities. b. More walkable, bike-friendly cities will lead to a healthier population from increased walking/biking.
4. Resilience	a. Decentralization of the electric grid (make clean energy microgrids available)	a. Creating microgrids that use clean energy and have backup energy sources available will lead to a resilient grid when needed.

5. Rural-urban cooperation	a. Electric vehicle (EV) charging stations to promote EV transition, particularly in more rural areas b. Clean energy development in rural areas (wind and solar)	a. EV usage in lieu of combustion engine vehicles will require joint rural-urban coordination and planning to ensure transportation reliability across geographies. b. Clean energy advancements will lead to new revenue streams in rural areas and clean energy access for both rural and urban populations.
6. Ecosystem benefits	a. Thoughtful zoning and natural habitat protection when considering new developments/construction b. Agrivoltaics development	a. Preserving natural resources that enhance carbon sequestration (i.e. forests and bogs) will help mitigate the effects of climate change b. Pollinator-friendly native plants and soil rehabilitation

As indicated by Table 2, the main differentiator between actions informed by CBA vs PBA is that CBA prompts focus on circular economy initiatives, whereas PBA does not account for this. It is important to note, while circular economy initiatives appear as one line item within the table, they play a significant role reducing emissions. As mentioned earlier in the literature review, ICLEI has asserted that 45% of emissions are related to consumption.

While we present potential policy actions and outcomes that can be informed by CBA and PBA, there are still significant research gaps regarding the economic and social impacts and inequality outcomes of climate mitigation policies. Furthermore, inequality often intersects with health status, education level, and income, which are typically mutually reinforced [31]. These intersections of inequality, health, education, and income will need to be considered holistically to achieve an equitable transition to a Green Economy. Ramboll Management Consulting recently evaluated a wide variety of climate mitigation policies and the respective short-term and long-term social impacts and inequality outcomes within the European Union. This report may prove useful to Dane County as a framework to address equity through climate action plans [32].

8 Conclusions and Recommendations

While we advocate for Dane County to incorporate CBEI into its emissions accounting strategy, it is important to consider the advantages and disadvantages of consumption-based carbon accounting. A consequence of using consumption-based carbon accounting is that a portion of the emissions occur outside of the political administered region where the consumption occurred [29]. While this opens new options for mitigation, it also changes the political economy of climate mitigation [30]. It is difficult to understand how purely consumption-based carbon accounting may lead to deeper emission reductions than production-based inventories. Despite the advantages of using consumption-based accounting, the political dimension may hinder them as the sole accounting method. Therefore, we do not recommend pursuing CBEI as a replacement for PBEI.

Key advantages of consumption-based carbon accounting include eliminating carbon leakage through imports, covering more global emissions with limited participation, consistency between consumption and environmental impacts, increasing mitigation option and highlighting inequities in consumer behavior which is often undiscussed. Furthermore, while it is true that inventories for consumption and production-based methods can be similar on a national scale as noted by Refs. [5], [6], carbon-leakage is what exactly leads to such large discrepancies for municipalities such as those shown in Figure 2[17]. For these reasons, we advocate for the combined CBEI/PBEI approach.

Specifically:

1. Dane County should pursue emissions-based accounting in addition to production-based accounting. In addition to helping inform policy and practices for emissions reductions, this

information will guide policy decisions regarding the six additional priorities identified by the Dane County Climate Action Plan.

2. The ICLEI consumption-based emissions cohort schedule may serve as a useful tool to develop and advance climate change policy initiatives. Moreover, this cohort template may be used to facilitate collaboration amongst multiple localities within Wisconsin, so that local communities can work together to drive policy change at the state level.
3. Transparency in methodology and reproducibility of results are of the utmost importance to validate emissions findings and subsequent policy recommendations, particularly when the stakes are so high considering climate change. If Dane County pursues evaluation of consumption-based emissions at the county level, our team strongly advocates for transparency in methodology and reproducibility of results.
4. Related to recommendation 3, increased transparency in methodology and reproducibility of CBEI results may be achieved through work completed at the University of Wisconsin. We encourage a research group at the University of Wisconsin to develop an open-source, local-level CBEI model (and secure funding for this research and development). Furthermore, the development of an open-source model is an equitable approach to information availability with respect to helping all communities address climate change.
5. Reliable consumption-based emissions results should be used to prioritize actions and inform policy. For instance, if food waste is found to be a main contributor of consumption-based emissions in Dane County, then the county should prioritize policies that reduce food waste. Moreover, these results can be used to understand how current policies, programs, and incentives will impact future Dane County consumption-based emissions, as well as guide new targets for respective emissions categories. New emissions targets that consider consumption-based emissions for Dane County should guide new policies, programs, and incentives to further mitigate emissions at the county (and potentially state) level.

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