Local drivers and global suppliers of GHG emissions from the city of Madrid, 2013–2019

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Objectives and motivations

Objective

Estimate the **3-scope carbon footprint** (CF) of domestic and household activities in the **city of Madrid** for the period **2013 to 2019** [2010-2021]

Motivation

It aims to support the **City Council** of Madrid in developing more effective **decarbonization strategies** (e.g., *Roadmap towards Climate Neutrality for 2050*)

Carbon footprint estimation of urban areas

- A growing literature concerned with the **disproportionate weight of urban areas in global GHG** emissions and the limitations of inventories for local mitigation policies (Wiedmann et al., 2021; Wiedmann and Allen, 2021)
- **Consumption-based**, as opposed to production-based, **carbon footprint** estimation using Environmentally Extended Input-Output (EEIO) models is well-established and used for official estimations (Miller and Blair, 2022; Ivanova et al., 2017; Eurostat, 2015; EEA, 2013)
- Global Multi-Regional Input-Output (GMRIO) databases have introduced a large **geographical disaggregation** for multiple countries/regions and **global value chain** analysis related to environmental impacts (e.g. FIGARO, WIOD or EXIOBASE)

A city-augmented Environmentally Extended Global Multirregional Input-Output model (EE-GMRIO)

- We wanted to estimate the **consumption-based** footprint of the economic activity (GDP) of and the residents in the **city of Madrid**

$$CF^f = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{y}} \tag{1}$$

- In the case of city CFs, we have **multiple missing pieces**: the vector of emissions intensities $\hat{\mathbf{e}}$ ($kgCO_2e$ per unit of output at current prices), the technical coefficients matrix ($\mathbf{A}$) and the appropriate final demand vector $\hat{\mathbf{y}}$ (e.g. household final consumption)
- Households' total CF^h includes direct emissions qua producers (CF^d) and direct and indirect emissions associated with consumption or any other final demand expenditure

$$CF^h = CF^d + CF^f \tag{2}$$

Main data sources

- *Full International and Global Accounts for Research in input-Output analysis* (FIGARO) database (Remond-Tiedrez and Rueda-Cantuche, 2019):
  - EU regular statistical product by Eurostat and the Joint Research Centre of the European Commission (T+2)
  - Covers the **period 2010 to 2022** for **47 countries**: 27 EU Member States, the United Kingdom, the United States, and 17 main EU partners, plus a "rest of the world" region
  - **64 NACE industry** breakdown
- **Eurostat**'s Air Emissions Accounts and Air Emissions Inventories
- Madrid's **regional** Supply and Use Framework
- **Municipal** economic **accounts** (AM, 2023; AM, 2013)
- **Municipal** GHG emissions **inventory** (AM, 2021)

Challenge I: Projecting an urban input-output table

- As expected, we do **not have city-scale SUTs**, but examples of how to project them (Wiedmann and Allen, 2021; Moran et al., 2018; Zheng et al., 2022; Wiedmann, Chen, and Barrett, 2016)
- We want to derive a **reasonable substitute city table to be embedded into a series of GMRIO tables**, by relying on
  - Regional SUTs framework (2013-2019)
  - Local economic accounts information (2010-2022)
  - FIGARO database (2010-2022)
  - GRAS algorithm for annual updates (Temurshoev, Miller, and Bouwmeester, 2013)
- The city table needs to be **(a)** connected via **imports and exports** with the outside world and **(b)** the derivation of a **rest of the nation** table for Spain without the city of Madrid
- Based on the Spanish international trade proportions, the proportion of domestic to non-domestic imports from the regional table, the aggregate city trade balance and the regonal distribution of exports

Challenge II: Derivating a city air emissions accounts

- Madrid do not yet have an **air emissions account** (AEA), but does publish an excellent **emissions inventory** (AEI)
- There are **two** key difference between inventories and accounts:
  - Territorial vs. residence principle
  - Incompatible functional and industrial classifications
- Fourfold process to create an AEA:
  - Adjust for **residence principle** using national bridge items and auxiliary information
  - Create **correspondence map** between different classifications (e.g. SNAP/NACE) using methodology and Annex I of Eurostat's Manual for air emissions accounts (Eurostat, 2015)
    - Allocate **emissions proportionally** using national totals
  - Derive **emissions by household activities** (heating, transport, other) using microdata (ES-HBS)
  - Adjust for the city's **economic structure**

Challenge III: Matching consumption microdata and EE-GMRIOs

- **No city consumption vector**. The challenge is to transform household survey data to match the input-output framework
- There are **two** key differences for expenditure data:
  - Purchaser's prices vs. Basic prices
  - COICOP vs. CPA/NACE
- Four-step procedure (Cazcarro et al., 2022; Mongelli, Neuwahl, and Rueda-Cantuche, 2010):
  - Correct survey weights to match **population totals**
  - Distribute the **gap** between **survey and NA totals**
  - Transform **COICOP to CPA** using a bridge matrix
  - Derive consumption vector at **basic prices**
- Use of GRAS algorithm for annual updates
- Conversion to NACE industry vector for footprint estimates

Main empirical results

- Key empirical **findings**:
  - Madrid's **GDP footprint** ($ktCO_2e$):
    - 27,963 (2010), 19,396 (2019), 17,447 (2021)
  - Residents' **consumption footprint** ($ktCO_2e$):
    - 19,424 (2010), 13,252 (2019), 13,920 (2021)
  - **Per capita** consumption-related emissions ($kgCO_2e$)
    - 5,907 (2010), 4,006 (2019), 4,193 (2021)
- **Geographical distribution of emissions**: 20% from within the city, 40% from rest of Spain, and 40% from rest of the world
- Significant **emissions inequality**:
  - **Bottom 20% 4.5 times** less than bottom 20% (34,095 $kgCO_2e$)
  - **Male-headed households emit 131% more** than female-headed
  - Largest differences in some expenditures and **private mobility** choices

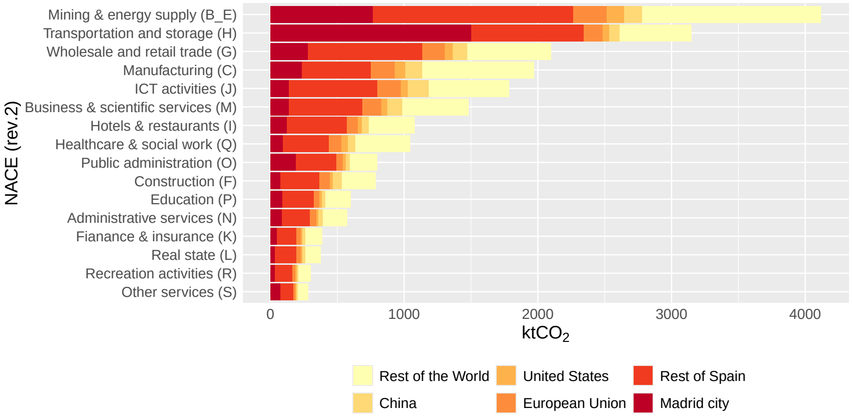

Figure: Total embedded GDP-linked emissions from Madrid by sector and geographical origin, 2019. **Note**: Agriculture and Household activities are excluded due to very low amounts.

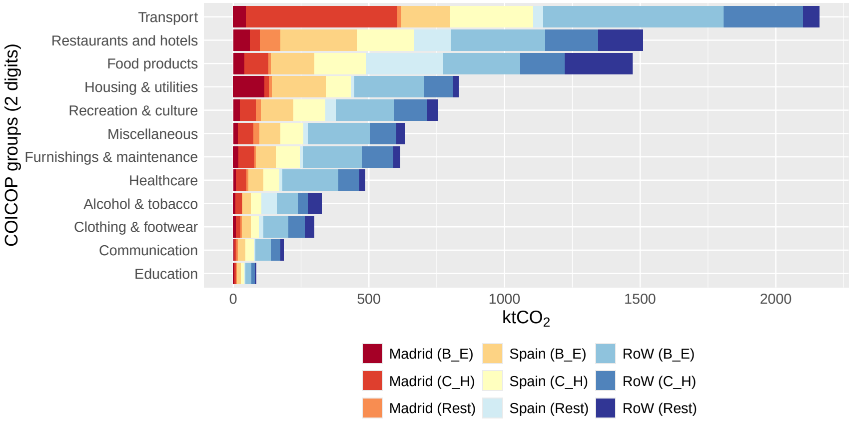

Figure: Total embedded household consumption-linked emissions from Madrid by consumption purpose, sector, and geographical origin, 2019. **Note**: Agriculture and Household activities are excluded due to very low amounts. Whenever we make reference to (the rest of) Spain, we exclude emissions and spending from Madrid.

Emissions group	Q1	Q2	Q3	Q4	Q5	15-34	35-54	55-70	+71	Female	Male
Equivalized income (€)	14684	18623	21876	25655	35070	23057	25514	26633	27265	24692	26792
Average kgCO_2e	7614	12610	17369	24343	34095	15734	21522	21161	13494	16159	21284
01 Food products	442	645	724	864	936	454	765	788	689	647	779
02 Alcohol & tobacco	110	233	339	345	525	197	318	394	230	277	334
03 Clothing & footwear	64	83	126	166	242	138	155	139	105	142	142
04 Housing & utilities	176	209	215	245	318	174	228	262	233	231	235
05 Furnishings	46	72	131	260	378	128	170	199	248	165	198
06 Healthcare	95	180	252	283	610	226	252	375	305	289	299
07 Transport	236	518	806	1223	1611	840	1034	998	566	866	977
08 Communication	65	86	90	98	108	71	89	100	89	85	93
09 Recreation & culture	59	103	152	222	420	139	228	218	134	203	203
10 Education	31	68	111	138	333	37	190	157	82	157	178
11 Restaurants and hotels	158	294	591	777	1528	523	850	766	478	627	807
12 Miscellaneous	84	106	144	194	405	177	197	188	198	220	176
Heating	984	1140	1108	1269	1466	778	1201	1283	1337	1246	1179
Transport	472	1348	2012	2693	2577	2020	2060	2141	873	1373	2180
Other	0.1	0.1	0.1	0.2	0.3	0.2	0.2	0.2	0.1	0.2	0.2

Figure: Breakdown of households' average GHG footprint of 2-digit consumption purposes and domestic activities by spending quintile, age group, and gender of household reference person in Madrid, 2019.

Structural decomposition analysis of trade shocks

- Structural Decomposition Analysis (SDA):
  - **Decomposes change** in industry-level emissions
  - Factors: emissions **intensity**, **trade**, **technology**, **consumption** demand
- Key modifications to canonical threefold decomposition:
  - **Separation of trade and technology** contributions
  - Use of Hadamard product decomposition $(C \otimes H)$
- Trade shock simulations:
  - Modify matrix C to **simulate changes in trade patterns**
  - Assess the **potential** effect of **supply chain restructuring**
- **Simulation scenarios** to **quantify potential** contributions of **trade vis-à-vis consumption** changes to emissions reduction
- Main results:
  - **Consumption** is the primary **driver of emissions growth**
  - **Offsets gains** from efficiency, trade, and technology
  - Almost **no potential gains** from **supply chain re-routing**

Figure: Structural decomposition of total ktCO_2e growth into emissions intensity, trade, technology, and consumption demand contributions for the city of Madrid. using FIGARO, ES-HBS, and municipal accounts.

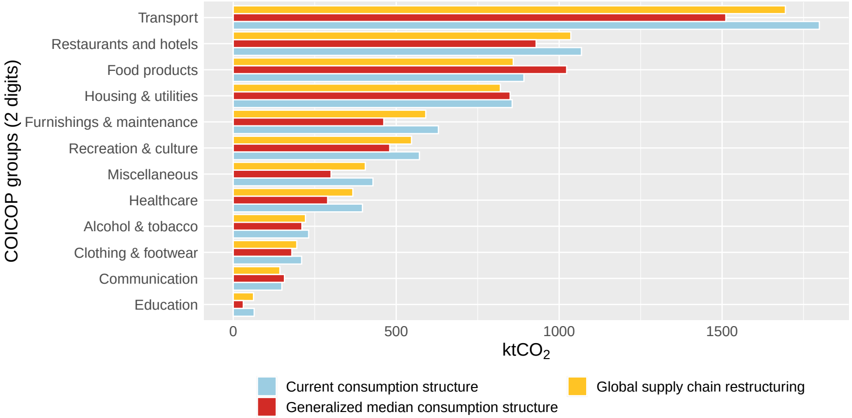

Figure: Total embedded household consumption-linked emissions from Madrid by consumption purpose before and after the hypothetical projection of the median consumption structure, 2019.

Conclusions and policy Implications

- Policy **implications**
  - Consider **global supply chain constraints** and possible shocks in decarbonization plans
  - Small to null **upside benefit from procurement policies** at city scale
  - Prioritize **consumption-focused mitigation** efforts, particularly private mobility policies have a disproportionate impact on total emissions
  - Target **high-emitting groups** (higher-income, male-headed households) for maximum emission savings
- **Limitations** and **follow-up research** objectives
  - Limited 6 year period with **relevant delay** (2013-2019): could be improved with moderate assumptions to **T+2 to track FIGARO releases**
  - Additional work on the city's and the regional **trade structure** could improve marginally trade shock estimations
  - Calculation of **uncertainty of estimates**

Thank you for your attention

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Appendix

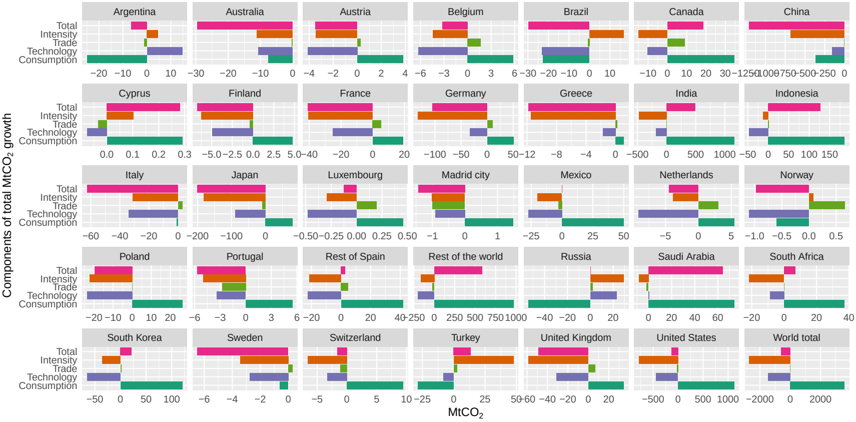

Figure: Structural decomposition of total ktCO_2e growth in several countries into emissions intensity, trade, technology, and consumption demand using FIGARO, ES-HBS, and municipal accounts.

Appendix

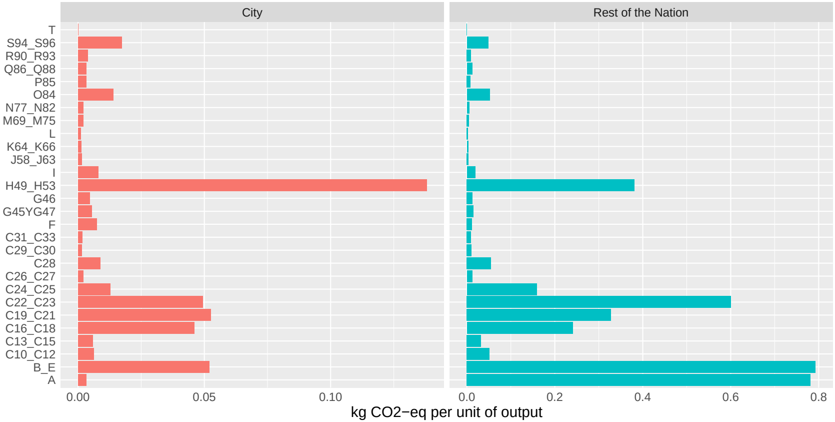

Figure: CO_2e emissions intensity factors for Madrid city and the rest of Spain using FIGARO, ES-HBS, and municipal accounts.

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