EXTENDED ABSTRACT

Title: Mapping Spanish city carbon footprints

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Abstract: *(minimum1500 words)*

1. Introduction

The importance and urgency of studies related to climate change has been increasing due to the enormous consequences it has on environmental, economic, and social areas. (EEA Report 2009). The different proposals and attempts to attack this enormous problem have not only come from the scientific, but also from the political sphere at a global level. We can find studies of different nature where in the last decade has opened the debate on the responsibility not only of the producer but also of the consumer in the production of the components related to global warming, especially greenhouse gases (GHG) (Peter 2008). The importance of considering consumption in GHG estimates ranges from improved calculations and more comprehensive measures to address this problem. (Peter 2007).

On the other hand, private consumption is the main contributor to GHGs and the main driver of global emissions over the last decade. While protocols such as Kyoto have succeeded in reducing producer-related emissions in developed countries (Böhringer 2003), consumption-related emissions continue to rise[1]. The world's cities now consume more than two- thirds of global energy and produce more than 70 percent of CO_2 emissions (World Bank Book Environment Page 194; IPCC 2014) being the richest 10 percent of the population responsible for almost half of the world´s carbon emissions, whereas the bottom 50 percent are responsible for only 15 percent of global emissions. (Hubacek, 2017). Therefore, it is important to analyze the different consumers throughout their territories.

Most emissions occur in urban areas since this is where production and consumption take place. On the other hand, the high density of cities could increase efficiency if the right policies are put in place. It is necessary to measure the carbon footprint at a small

[1] https://www.iea.org

geographic scale, such as cities and municipalities, taking into consideration the different consumers in each geographic area to achieve adequate measures.
As a case study, we analyzed Spain during 2011 for 13 different atmospheric pollutants, 62 industries, and 41 COICOP products —grouped in 12 main categories—. For presentation purposes, this paper only shows results for an aggregation of 6 GHG.

We calculated the total atmospheric pollutants embedded in the consumption patterns of Spanish households - for this first preview we consider Catalan households - by the application of an environmental extended input-output model; then we implemented the General Maximum Entropy (GME) method with some modifications to project the emissions information to the CENSUS, technique previously used for poverty indices among others. (Fernandez 2020), which allows us to have a better detail at a geographical level, thus being able to obtain the emissions of the Catalan households and their location within the different municipalities as first results.

For this purpose, we built a specific database from four statistical sources provided by the Spanish Statistic National Institute —input-output tables and environmental accounts from the Spanish National Accounts, and the microdata from the Spanish household budget survey—, and the estimation of a bridge matrix that allowed the consolidation of macroeconomic dataset with microeconomic information. Finally, to obtain the geographic detail we used the latest Population and Housing Censuses survey.

Given the above, the objective of this work is to analyze the environmental impact of the different municipalities according to the different consumption patterns of their inhabitants. This abstract extension is structured as follows. Section 2 details the Spanish database and the arrangements needed to estimate our models. Section 3 describes the methodologies. And Section 4 comments and discusses the first relevant results and some discussions.

2. Data set and data arrangements

To carry out this analysis, we constructed a database that includes information on the air pollutants included in the consumption basket of Catalan households, together with the relevant socioeconomic and sociodemographic characteristics of each household. This database combines macroeconomic statistical sources from national accounts - such as input-output tables and environmental accounts - and microeconomic information from household budget surveys. In addition to these statistical sources, we estimate a so-called bridge matrix that allows us to connect macro and micro data. Finally, we complement this with CENSUS, which provides the information at the micro geographic scale. Overall, we obtain a database for a total of about 28,337 households, the environmental impact of 13 different air pollutants from their consumption basket of 41 different COICOP products. We consider the case of Spain in 2011.

This section describes the five statistical data sources-i.e., the input-output tables (INE, 2011a), the environmental accounts (INE, 2011b), the household budget survey (INE, 2011c), the bridging matrix (Danmarks Statistik, 2011), and Spanish Census (INE, 2011d) along with all the decisions and work that went into them.

2.1 Input-Output tables

Under the input-output framework, there is an exhaustive description of the productive process and the resources-jobs balance of the national economy at a product and sector level mainly measured in monetary units. In the case of the Spanish Statistic National Institute, this framework includes a set of yearly supply and use tables (SUT) and input-output tables (IOT) every five years —from 1995 until 2017— where the accounting base changed periodically to update weightings measurements as well as to introduce some methodological variations; the last accounting change was introduced in 2019.

Whereas SUT offers information about all the inputs used by and all the products produced by each industry capturing the fact of joint or multiple-product production, IOT are a simplification of the reality by assuming single-product production. These IOT are the base to compute the Leontief inverse matrix expressed by the letter L in equation (1). According to this, we estimate the IOT for our year of interest 2011 from the SUT following EUROSTAT (2008 p. 349) using the model product-by-product IOT where it is assumed that each product has being produced in its own specific way, irrespective of the industry or sector where it is produced. This method could produce some negative values that will require the application of some numerical algorithms to adjust it. In our case we use the bi-proportional method RAS[2]

2.2 Environmental accounts

The environmental accounts are an extension of the IOT, which is consistent with the traditional Leontief model with the aim of dealing the pollution generation in the production processes. In relation with our analysis, we work with a disaggregation of 62 sectors and for each sector information about 13 different atmospheric pollutants. For the purpose of this study and for the sake of clarity in the exposition we only display results for the GHG. All the atmospheric information is presented in a compatible way with the System of National Accounts measured in physical units —generally tons—, registering the environmental elements desegregate in the different economic activities and household sector as final consumers. The emissions account is elaborated adapting the data to the NACE's classification.

The emission accounts follow the same principle of residency as the National Accounts, where the contaminant emissions to the atmosphere are the ones generated by all the activities of the resident units independently of the geographic place where these

[2] https://ec.europa.eu/eurostat/cros/content/ras-method_en

emissions have really taking place in. It takes record of the gaseous material's flow and residuals particles coming from the national economy. Besides the emissions it does not take into consideration economics agents nor the gases' absorbed by the nature.

One important characteristic of this data set is the fact that the data is delivered by industries, while the estimated IOT is a product-by-product one. Therefore, it is necessary apply a similar methodology described in section 2.1. to transform atmospheric information from industry to product environmental accounts. In this case, however, we applied the transformation model based on the industry technology assumption of each industry, according to which has its own specific way of produce emissions to the atmosphere irrespective of its product mix (EUROSTAT, 2008, p. 349)[3].

2.3 Household budget survey

The Spanish household budget survey (HBS), published by Spanish Statistic National Institute, provided annually, and handing information about the origin and destination of the different consumption's expenditure, as well as some socio-economic and socio-demographic characteristics of the households and member of the consumption unit. This survey has evolved along the years in ways such as the type of population to consider, the size of the sample, the level of disaggregation and even in the periodicity. For our interest we use the household budget surveys with base 2006 which includes the microdata of 2011

The consumption's expenditure are the monetary flows that households allocate to the acquisition of some goods and services, as well as the value of the goods received as self-consumption, self-supply, salary in kind, free or reduced meals and imputed rent to the dwelling in which the household resides. The different expenditures are recorded at the time of acquisition, regardless of whether the payment is cash or installment.

The analysis unit in these surveys are the private household residents in main family dwellings and the target population to which the data and tabulations are referred, is the set of private homes as well as the people who are part of them in Spain. The complete size of the sample taken in consideration is 21,680 households for 2011.

In contrast to IOT and environmental accounts data, the expenditure on final household consumption is registered at purchase prices, that is, at the price that the buyer actually pays for the products at the time of purchase. Therefore, it will necessarily manage this data to transform all the households' expenditure to basic prices that will be explained later.

We will find three types of files: household file, member file, and expenditure file. The

[3] The main reason to apply this strategy was the difficulty to solve the negative values with the RAS technic in this context. Although this approach is not the same as procedure followed for the IOT estimations, it does not get too far from the reality either.

household file recollects data of the households' characteristics as the size and composition of the household and other general information of the residential area —as from example autonomous community, size of the municipality, population density, etc.—. The member file shows information about all the people who are members of collaborating homes. It is possible to find information such as nationality, study level, work situation, etc. Finally, the expenditure file, as it was mentioned before, captures the households' expenditure of the different families. This file gives us the quantity, percentage and has in a differentiate way monetary expenditure, no monetary expenditure, self-consumption, self-supply, rent, etc.

2.4 Bridge Matrix

After handling all the aforementioned data, we continue with the creation of the so-called bridge matrix. This is a matrix that relates 41 COICOP products with 62 NACE products and it is essential to consolidate our macroeconomic data —such as IOT and their respective environmental accounts—and our microeconomic data about the expenditure on the consumption basket of each household we obtain from the household budget surveys. Moreover, this bridge matrix should allow for transforming expenditures of private consumption on purchase prices into basic prices.

Given the lack of publicity on this subject from the Spanish Statistic National Institute, on the bases of the bridge matrix from Denmark (Danmarks Statistik, 2011) we built our own bridge matrices for our year of interest —2011— under certain assumptions. It was necessary to apply the RAS method explained above.

2.5 Population and Housing Censuses

The Census is the largest statistical project to be developed in each country periodically. The design consists of three different censuses: The Population Census, the Housing Census and the Building Census. This research will focus on the Housing Census.

While we have the emissions of 21,680 households per Autonomous Community (CCAA) given by the HBS, the census sample contains information on 50,000 with information on geographic location at the municipality level but not on consumption details.

As mentioned above, this paper aims to estimate the emissions associated with the consumption baskets of Spanish households at the geographic micro-scale, in this case, Spanish municipalities. For this purpose, we use information from Population and Housing Censuses for the last published year 2011. The idea is to use the proposed GME estimator and the estimate of emissions per household estimated under the IO methodology.

3. Methodology

Analyzing the difference of environmental impact due to the consumption patterns of the different municipalities within Spain, first, to estimate the amount of atmospheric pollutants embedded in each consumption basket of each household, and second, analyze emissions at the micro-geographic scale, in this case at the scale of municipalities within Spain. According to these steps, this section is divided in two parts. Section 3.1 refers to all the methodological details to obtain the results of the atmospheric footprint; and section 3.2 Continues with the econometric methodologies applied for the analysis of the results at the geographic microscale under the General Maximum Entropy estimator.

Although we obtain results for all 17 different atmospheric pollutants, we only use the results of the aggregation of the six GHG embedded in the consumption basket of household in Spain 2011.

3.1 Atmospheric footprint of a consumption basket

The environmental footprint of any environmental pressure —for instance, of any atmospheric pollutant such as the well-known carbon footprint— implies the estimation of all gases generated direct and indirectly by the private consumption on any consumption unit. In other words, we account the emissions produced directly when it takes place the combustion of any energy products —i.e. driving a car— as well as all the emissions embedded in the whole production chain of the production of each product consumed —considering the emissions of a product and the emissions of the inputs needed to produce such product and so on—.

Based on Roca and Serrano (2007) indirect emissions of each consumption unit according to different g atmospheric gases and p different products $\mathbf{GHG}_{gxp}$ are defined

$$\mathbf{GHG} = \mathbf{Q} \ \mathbf{L} \ \mathbf{B} \ \hat{\mathbf{c}} = \mathbf{M} \ \hat{\mathbf{c}} \tag{1}$$

as in equation (1)[4]:

where $\mathbf{c}_{px1}$ represents the expenditure on each of the p COICOP[5] products from the consumption basket of each consumption unit; $\mathbf{B}_{nxp}$ is a composition matrix of aggregated commodity of consumption that relates n CPA[6] products with p COICOP products. Matrix **B** is essential to our analysis since it allows us to connect macroeconomic data —such as matrices **L** and **Q**— with information from

[4] Matrices are indicated by bold, upright capital letters; vectors by bold, upright lower-case letters; and scalars by italicized lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime. A circumflex indicates a diagonal matrix with the elements of any vector on its diagonal and all other entries equal to zero.
[5] COICOP is the acronym of "classification of individual consumption by purpose", it is a classification developed by the United Nations Statistics Division to classify and analyze individual consumption expenditures incurred by households, non-profit institutions serving households and general government according to their purpose.
[6] CPA is the acronym of "classification of products by activity", which is compatible with the "statistical classification of economic activities in the European Community" (NACE) —i.e. industries—. The acronym NACE come from the French *Nomenclature statistique des activités économiques dans la Communauté européenne.*

microeconomic databases like vector **c**. Matrix $\mathbf{L}_{nxn} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse, being **I** the identity matrix of appropriate dimension and $\mathbf{A}_{nxn}$ the matrix of total technical coefficients that represents the technology of the economy[7]. The Leontief inverse gathers all the sectoral interdependencies in the economy and its elements l_{ij} exposes the total output —direct and indirect— necessary from sector *i* to satisfy an extra unit of final demand from sector *j*. Finally, matrix $\mathbf{Q}_{gxn}$ represents the amount of each of the *g* atmospheric pollutants generated by one unit of product of industry *n*, the so-called matrix of emission coefficients[8].

In equation (1) matrix $\mathbf{M}_{gxp}$ summarize the emission multiplier effect defined as the total —direct and indirect— emissions generated by an extra monetary unit expended on each product of the consumption basket of the consumer unit.

It is important to pay attention to two issues regarding the model presented above. First, although any environmental footprint includes both direct and indirect emissions, in this study we only focused on the last one. Second, equation (1) is a general expression that can be applied using data from any consumption unit grouping.

3.2 Econometrics methodology

We apply a modification of the general GME estimator above as an alternative to the methods presented in Elbers et al (2003) or Tarozzi and Deaton (2009) of predicting social indicators for small areas. The GME technique proposed follows the idea of combining household surveys with population census but exploits the information in a different way. One advantage of the method proposed here is that it combines the detailed geographical information present in population census but making it consistent with some aggregates -moments- observable in the household survey.
For the sake of clarity, let us explain the procedure by assuming that our research interest is in estimating a continuous indicator in a set of small areas $d = 1, \dots D$. Our problem is that the indicators y_{ij} are not directly observable in a population census. They are observable in the household survey, but we cannot identify the small area d in which the individual lives.
Our estimates of the indicator of interest $\hat{y}_{ij}^d$ are defined as $\hat{y}_{ij}^d = \sum_{k=1}^{K} x_{cik} \hat{\beta}_k + \hat{u}_{ij}^d$, where $\hat{p}_{ij}^d$ and $\hat{u}_{ij}^d$ are the solutions produced by the GME estimator and $\hat{u}_{ij}^d = \sum_{l=1}^{L} \hat{w}_{ijl} v_l$. These estimates will be obtained by solving a GME with constraints as follows:

[7] Each element of matrix A is interpreted as all inputs —i.e. both domestic and imported— from sector *i* per unit of product of sector *j*. In formal terms it is expressed as $a_{ij} = z_{ij}/x_j$, where z_{ij} are the elements of the inter-sectorial transaction matrix that describe the deliveries though industries. The application of the total technical coefficient matrix, implies the application of the so-called domestic technology assumption. For more details about the inter-sectorial model see section 3.1 for further details.
[8] Elements of matrix Q are defined as $g_{fj} = v_{gj}/x_j$, where v_{gj} are the elements of the atmospheric pollutants matrix that describe the total amount of each atmospheric gas, measured in physical units, emitted by each industry. For more details about the environmental extension of the inter-sectorial model see section 3.2 for further details.

$$\frac{1}{n}\sum_{i=1}^{n} x_{sik} y_{sij} = \frac{1}{N}\sum_{i=1}^{N} x_{cik}\left[\beta_{ij} + u_{ij}\right] = \frac{1}{N}\sum_{i=1}^{N} x_{cik}\left[\beta_{ij} + w_{ijl} v_l\right]; j = 1, \dots, J \qquad (2)$$

Or, in matrix notation:

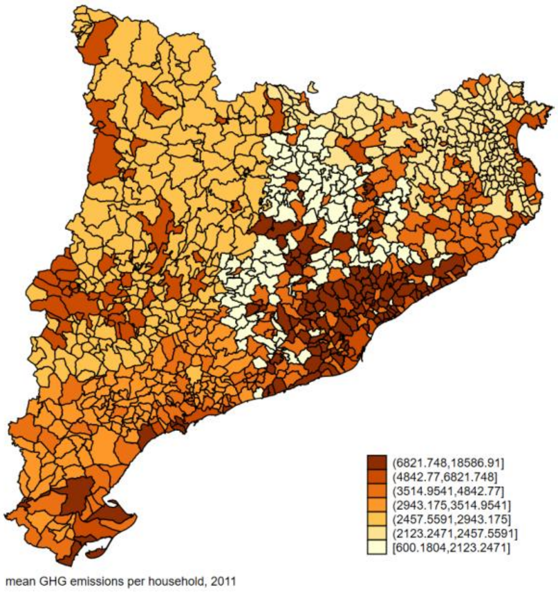
$$\frac{1}{n} X_s^T Y_s = \frac{1}{N} X_c^T [\beta + U] = \frac{1}{N} X_c^T [P + WV] \qquad (3)$$

In equations (2) and (3) the subscripts s and c refer to moments observed in the household survey and the population census respectively. Matrix X_s -together with Y_s- is collected from the information in the sample, and it has dimension $n \times K$, while matrix X_c is observable at the population census level and has dimension $N \times K$, where N is the population size. Note that the left-hand side on these equations refers to the cross-moments between Y and the covariates in X, which are observable for the sample of households surveyed. The solutions $\widehat{P}$ and $\widehat{W}$ on the right-hand side must produce, at the census level, cross-moments identical to those observed in the household sample. Since these estimates are obtained with the sufficient geographical detail, it is possible to predict $\hat{y}_{ij}^d = \sum_{k=1}^{K} x_{cik} \hat{\beta}_k + \hat{u}_{ij}^d$ and make these estimates consistent with the aggregates in $\frac{1}{n} X_s^T Y_s$.

4. First results and discussion

In this section we present the first advances in results. See Image 1, the autonomous community of Catalonia. We obtain that in aggregate this autonomous community produces on average 6.153 kg of CO_2 equivalent. It is also possible to observe the average emissions per municipality with a clear visualization of the differences between provinces within Catalonia.

Image 1: Average Greenhouse gases emissions per household in Catalonia, 2011



We can observe that households in municipalities near the coast are more emitters than those further away. On the other hand, the province of Barcelona stands out for its high emissions in the capital, but especially in what would become the crown surrounding the city. This could be explained by the displacement effect of the municipalities close to the capital. We see how emissions associated with households decrease considerably in the more rural areas.
Looking at the province of Tarragona, we see that together with Barcelona they are the provinces with the highest emission of private consumption. Lleida and Gerona are close to the average or below, except for some specific municipalities.

It is important to note that this work is intended to be extended to all municipalities in Spain, and thus obtain a detailed mapping of emissions associated with private consumption. The aim is to support environmental measures and policies aimed at the consumer.

It is also planned to observe the different characteristics of Spanish households and try to understand the differences in emissions might occur. It is also planned to expand this analysis to the European level.

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