

# Urban agriculture may change food consumption towards low carbon diets

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## ABSTRACT

The mitigation of greenhouse gases in the agri-food sector depends on production and consumption patterns. This study focuses on the impact of urban gardening activities on food consumption and the carbon footprint. Changes in the food habits of citizens involved in urban agriculture activities in the city of Madrid were assessed over a five-year period using an online survey. The impact of habit change on the average carbon footprint from food consumption was assessed using a life-cycle approach. The results display a potential reduction of up to 205.1 kg CO<sub>2</sub>e/year per person (12.1%), which can mainly be achieved with a reduction in animal source foods. The results suggest that urban gardens could be used as social catalysts for pro-environmental behavior and greenhouse gas mitigation in urban areas.

## 1. Introduction

### 1.1. Consumer cities and GHG accounting

Cities are highly dependent on large supplies of exogenous products, energy, and materials (Cui et al., 2019; Goldstein et al., 2016; Kennedy et al., 2015). The urban population already exceeds the rural population, with projections indicating that approximately 70% of the global population will live in cities by 2050 (UN DESA, 2018). This growth in the urban population will further increase the demand for basic goods such as food products. Consequently, even considering expected efficiency improvements within the food supply chain, the environmental footprints of food consumption in cities are expected to increase significantly (Hedenus et al., 2014; Kriewald et al., 2019; Pradhan et al., 2020).

The agri-food sector accounts for 21–37% of global greenhouse gas emissions (GHGe) (Mbow et al., 2019; Rosenzweig et al., 2020). From a consumption perspective, food is responsible for 11–32% of the carbon

footprint in European households—excluding GHGe from food storage and cooking—(Ivanova et al., 2017). When hotels and restaurants are considered, food-related sectors are responsible for up to 40% of the GHGe from consumption in Europe (Tukker et al., 2006).

In high-income cities, outsourced GHGe are greater than the production-based ones (Sudmant et al., 2018). Thus, the traditional focus on production in GHG accounting diverts attention towards this component of the production-consumption chain. As food emissions are monitored in the country of origin, there is a generalized misconception of the unsustainability of food consumption patterns and trends in high-income economies where the majority of agricultural goods are imported (Foley et al., 2011; Garnett, 2011; (Poore and Nemecek, 2018)). This may negatively affect the effectiveness of mitigation strategies (Davis and Caldeira, 2010; Peters et al., 2009; Rothman, 1998; Weber and Peters, 2009).

Behavioral change is a key component of emission trends (Moss et al., 2010), as well as a driver of future climate scenarios. Recent studies have revealed that the inclusion of human behavioral changes in

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climate models could account for up to 1.5 °C on the projected global average temperature for 2100 (Beckage et al., 2018; Bury et al., 2019), and that the influence of social learning (e.g., new behaviors, values, and opinions from pairs) is a major determinant of the expected impact (Reed et al., 2010). Therefore, the consumption (or demand) component in GHG accounting needs to be considered, particularly when designing climate change mitigation strategies. A focus on consumption in emission accounting could be useful to define specific measures that trigger social learning and change individuals' values, attitudes, and behaviors toward lower environmental footprints and positive feedback loops at a larger scale.

Several policy initiatives, from local to national levels, have been recently designed to promote an ambitious transformation in food demand, linking health, sustainability and climate change (C40 Food Systems Network, 2019; Fabbri, 2017; Mijatović et al., 2018; United Nations, 2015). The Milan Urban Food Policy Pact (2015) was launched to promote sustainable and resilient agri-food systems in urban food policies. As one of the 211 signatory cities, Madrid has developed a food strategy as part of its commitment (Madrid City Council, 2018). Among its main action axes, Madrid's Food Strategy shapes actions to strengthen the presence of urban agriculture in the city.

### 1.2. Modern urban gardening and social learning

The history of urban gardening in Madrid has evolved from the establishment of subsistence gardens—during the civil war, from 1936 to 1939, and the subsequent 40 years' dictatorship—to its current social and leisure form. Unlike in European and North American cities, where leisure-oriented urban agriculture appeared in the '70s, in Madrid it emerged in the late '90s. Its consolidation was linked to the 2008 economic crisis and related social movements against political decisions on austerity (e.g. the anti-austerity "15-M" movement). In 2010, several grassroots initiatives around urban agriculture created Madrid's Urban Communitarian Gardens Network (Rehdmad) to gain visibility and provide self-support. In Madrid, the City Council decided to give its support, by establishing the Program for Urban Communitarian Gardening in 2014. This program supplies technical and material support to Rehdmad and other new initiatives on urban gardening under organic management, in addition to providing the necessary legal permits. One important aspect of the municipal program is that it relies on urban gardens' autonomy, which seems to be one of the reasons behind the success of urban gardening in Madrid (Casadevante and Moran, 2015).

Urban agriculture may have an influence on citizens' food decisions in two ways. First, participation in communitarian gardens can increase social identity, perceived behavioral control, and awareness of the impact of participatory actions. These aspects are signaled as determinants of pro-environmental behavior, providing the necessary motivation to transform pro-environmental self-identity into real acts (Bamberg et al., 2015; Tharrey et al., 2019).

Introducing food literacy is the second way in which urban agriculture may influence consumers' habits. One of the factors leading to the unsustainability of food consumption is the disconnection of consumers from food production processes, which is particularly important in big cities (i.e., >50,000 inhabitants) (Calori and Magarini, 2015; Goldstein et al., 2016; Jia et al., 2019). Urban gardens could have a role as cognitive reconnectors between urban populations and food production, fostering behavioral changes towards sustainable decisions. Recent research has revealed the impact of urban agriculture on nutrition literacy and preference for vegetables and garden produce (Mitchell et al., 2019; Petrovic et al., 2019).

This study aims to assess the changes in food consumption habits of people involved in communitarian gardening activities and to estimate the impact of these changes on the carbon footprint of an average consumer. The ultimate aim of this research is to evaluate the viability of upscaling sustainable consumption patterns and the climate change

mitigation potential of urban policies supporting communitarian gardening.

## 2. Methodology

The methodology consisted of three steps. First, the average food habits in 2012 were defined, comprising the main food-related choices that a regular consumer can make. Second, the carbon footprint for the different stages of the food chain was assessed using a life cycle approach. Third, a survey was conducted to estimate the changes in the food habits of urban gardeners and the general population over a 5-year time period (2012–2017).

### 2.1. Scope definition

The system studied is the household food consumption, defined as all the food acquired in households and the processes involved in their production, distribution, consumption, and disposal (Fig. 1). The system boundaries are "cradle to grave", covering all the stages comprising the production of inputs used in the farm and households' food waste disposal, with the exception of home refrigeration and cooking. The components of the system studied are (i) pre- and in-farm production; (ii) processing; (iii) packaging; (iv) commercial transport; (v) retail; (vi) home transport; and (vii) waste management. The emission factors were based on two types of units: kg CO<sub>2</sub>e/kg edible food and kg CO<sub>2</sub>e/km. The functional unit of the study was kg CO<sub>2</sub>e/year per capita.

### 2.2. Carbon footprint method

To estimate the carbon footprint, food products were classified into 10 categories and 29 subcategories (Table A. 1.), based on the data from the Spanish Panel on Household Consumption of the Ministry of Agriculture, Food and Fisheries (MAPA, 2020) for the Madrid region. It was assumed that dietary choices in Madrid City follow a similar pattern to that of the entire province (NUT3). Average per capita annual consumption was calculated using data from 2011 to 2013, which are the years prior to the launch of the Program for Urban Communitarian Gardening. Almost all (c. 94%) food products consumed by the households were included in the study. Beverages—other than dairy—were excluded.

#### 2.2.1. Pre- and in-farm production

Pre- and in-farm production includes all the inputs and processes that are needed to produce the crops and livestock that comprise food consumption in households. In order to estimate the amount of raw materials used in the production of milk derivatives and olive oil, a conversion factor was calculated based on dry matter content (for dairy) and oil content (for olive oil, Table A. 2.). The distinction between organic systems and conventional ones, as well as between Mediterranean and global production, has been done when emission factors were available (Table A. 3.). Further details on the life cycle assessment can be found on Appendix A.

#### 2.2.2. Processing

Processing comprises all transformative processes applied to crops and livestock products prior to their commercialization and that allow their consumption, such as cheese or bread making, desiccation, preservation, etc. We used specific GHG emission factors for each food subgroup based on Poore and Nemecek (2018).

#### 2.2.3. Packaging

Packaging comprises all the materials and procedures used for food packaging. Two options were considered, (i) packed products; and (ii) bulk products. For bulk products, the GHG emission factor was considered to be 0. For packaged products the GHG emission factors estimated in Poore and Nemecek (2018) were used.

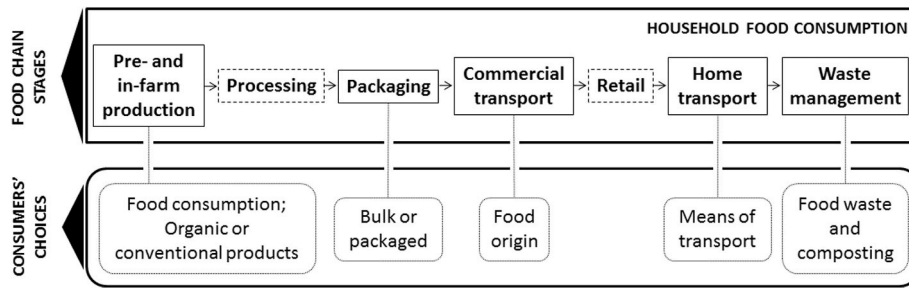


Fig. 1. Framework of the study: food stages assessed and consumption options considered.

#### 2.2.4. Commercial transport

Commercial transport comprises the transportation of food products from the location where they are produced to Madrid. Two different situations were considered, (i) “international products”, comprising the imported food from international origins, and (ii) “national products”, comprising food produced in Spanish regions. The global warming impact of food transport to Madrid city was estimated with an adaptation of the methodology applied by Pérez Neira et al. (2014). Specific emission factors for imported and nationally produced foods were calculated for 16 subcategories (Table A. 3.). The distribution food imports by its region of origin is presented in Table A. 4.

#### 2.2.5. Retail

Retail comprises all the processes included in food sale to public, such as cold storage. We used the GHG emission factors estimated in Poore and Nemecek (2018) for the different food subgroups.

#### 2.2.6. Home transport

This category comprises the transportation of food products from food stores to households by consumers. Per capita annual distances covered by different modes of transport for food shopping was calculated using the latest official data (Ministerio de Fomento, 2006). Average speeds for the different transportation methods are shown in Table A. 5. Emission factors were estimated based on DEFRA (2008).

#### 2.2.7. Waste management

Waste management refers to the treatment processes applied to not eaten food products. To assess consumers’ impact, waste management was separated into two categories, (i) food waste generated and collected through municipal collection systems; and (ii) households’ food waste composting. Per capita food waste production in the baseline was assessed based on the data from the Spanish Panel on Household Consumption (MAPA, 2020) and the kitchen waste factor estimated by Muñoz et al. (2010). Specific emission factors were calculated for waste treatment through the municipal system and composting (Table A. 3.).

### 2.3. Assessment of carbon footprint change

#### 2.3.1. Assessment of food habits change

First, a discussion group was organized to obtain information about the habits perceived by urban gardeners (UG) as having changed due to their participation in urban gardens. After the analysis of the conversation, the following aspects were selected for the assessment of habit change: dietary patterns, food origin, organic consumption, personal transport, product packaging, and waste management.

Next, a survey (n = 245) was conducted using an online platform (SurveyMonkey) between July 14 and August 8, 2017. The questionnaire was distributed among Madrid’s urban gardeners and a control population based on a convenience sample. The survey was completed by 90 UG involved in 45 different gardens in Madrid, and by 155 participants from the control population. Around 75% of the answers from the UG come from 26 gardens located in six districts (out of 20), where

approximately 30% of the total population of the city lives, with per capita annual income ranging from 13,600 to 26,300 €/year (average income in Madrid in 2017 was 18,750 €).

The respondents were asked to define any habit change in 36 aspects grouped into five blocks, (i.) mobility behavior; (ii.) dietary changes; (iii.) consumption of organic, bulk, and national products; (iv.) waste management habits; and (v.) energy consumption. UG were also asked about their dedication to urban gardening activities and the amount of vegetables from the urban garden that they consumed each month. However, the response to this question overlaps with the question about organic consumption, which is common to the two populations. Consequently, to avoid double counting, the information on vegetable consumption from the urban gardens has not been used in the study.

Average consumption levels in 2017 for urban gardeners and control group were estimated by modifying the baseline values with the previously calculated change in habits, using equations (1)–(5):

$$C_{f,1} = C_{f,0} \cdot (1 + Cch_f) \quad (1)$$

Where  $C_{f,1}$  and  $C_{f,0}$  are consumption of food products in 2012 and 2017 (kg), and  $Cch$  is the change in consumption.

$$CM_{f,1} = TC_1 \cdot \%CM_{f,0} \cdot (1 + Cch) \quad (2)$$

Where  $CM_{f,1}$  is consumption of food product  $f$  from  $M$  modality (organic, bulk, international, in kg) in 2017,  $TC_1$  is total food consumption in 2017;  $\%CM_{f,0}$  is the percentage of food product  $f$  from  $M$  modality consumed in 2012, and  $\%CM_{T,0}$  is the percentage of all food consumed from  $M$  modality in 2012.

$$T_{t,1} = T_{t,0} \cdot (1 + Cch_p) \cdot \%t_{t,0} \quad (3)$$

Where  $T_t$  is the distance made for food shopping using the transport  $t$  (km): public, private or foot/bike.

$$Fw_1 = TC_1 \cdot \%w_0 \cdot (1 + Cch) \quad (4)$$

Where  $Fw$  are the kg of food wasted.

$$Fc_1 = Fc_0 \cdot (1 + Cch) \quad (5)$$

Where  $Fc$  are the kg of food waste that are composted.

#### 2.3.2. Impact of habit changes on carbon footprint

Food habits in 2017 were estimated based on average behavior in 2011–2013 for Madrid citizens (Appendix B) and the reported changes from the survey in each of the two populations.

Global warming impacts from processing and retail were included in the carbon footprint assessment for a broader picture of the food chain, however, habit change for those stages was not integrated in the assessment, as it was not mentioned from the participants in the focus group and the assumption that citizens have a lower capacity to influence GHGe at these stages. Further details on the estimation of the impact of habit changes in carbon footprint can be found in Appendix A.

### 2.3.3. Sensitivity analysis

A sensitivity analysis was conducted by testing the impact of different methodological choices on the difference in emissions between the Urban Gardeners 2017 group and the control population 2017 group. These methodological choices involved two factors: (1) the source used to calculate baseline emissions, and (2) the source of emission factors for farm and pre-farm, processing, packaging and retail stages. FAOSTAT food supply data (FAO, 2021) was tested to calculate baseline emissions, as compared to the consumption survey data used in the main analysis MAPA (2020). These two baseline estimated were combined with five sets of emission factors. (i) Spanish – Various: this is the set of factors used in the main analysis, which were selected for being the closest to Madrid, and include Spanish emission factors for farm-and pre-farm stages in nationally grown products, and factors from various sources for international products, (ii) Spanish – Clune, where Spanish factors for national products were combined with Clune et al. (2017) factors for the rest; (iii) Clune – Clune, where only Clune et al. (2017) factors were used, (iv) Spanish – Poore, where Spanish emission factors were used for farm-and pre-farm stages in nationally grown products and Poore and Nemecek (2018) factors for the rest; and (v) Poore – Poore, where only Poore and Nemecek (2018) factors were used. Table A. 3 shows the emission factors used in the main analysis.

An additional sensitivity analysis was performed to assess possible misperceptions about real changes in food consumption. This involved a carbon footprint analysis for an average citizen in Madrid (2016–2018) using official data (MAPA, 2020). The deviation of this carbon footprint from the Control group could be a proxy for any misperception by survey respondents about their changes in food habits within the period 2012–2017.

## 3. Results

Behavioral changes towards low C options were reported to be higher in urban gardeners than in the control group (Table 1 and A. 6.). The results of the survey (n = 245) indicated that the largest relative changes in food habits were made in organic food consumption, food origin, and, exclusively for urban gardeners, in waste composting (with an increase of 40.7% compared to a 4.5% increase in the control group) (Table 1.). Urban gardeners also indicated to have reduced their waste generation by 14.4%, whereas the control group indicated no change (Table 1.).

**Table 1**

Consumption shares of the different food consumption options in 2012 and habit change for the studied population (urban gardeners) and the control group. Shares are assessed in kilograms of product for Diet Composition, Production modality, Packaging, Food Origin and Waste Management, and in kilometers for Shopping Transportation. For Diet Composition, Low CF refers to less than 1 kg CO<sub>2</sub>e/kg product and High CF to equal or more than 1 kg CO<sub>2</sub>e/kg product.

|                         |                  | Habit share | Habit change 2017 |                 |
|-------------------------|------------------|-------------|-------------------|-----------------|
|                         |                  | 2012        | Control           | Urban gardeners |
| DIET COMPOSITION        | Low CF           | 57.6%       | +8.8%             | +13.6%          |
|                         | High CF          | 42.4%       | −11.6%            | −18.1%          |
| PRODUCTION MODALITY     | Organic          | 1.9%        | +1.4%             | +37.3%          |
|                         | Conventional     | 98.1%       | −0.0%             | −0.7%           |
| PACKAGING               | Bulk             | 41.7%       | +3.9%             | +9.4%           |
|                         | Packed           | 58.3%       | −2.8%             | −6.7%           |
| FOOD ORIGIN             | National         | 73.6%       | +19.0%            | +29.0%          |
|                         | International    | 26.4%       | −52.9%            | −80.6%          |
| SHOPPING TRANSPORTATION | Foot/bike        | 13.1%       | −9.6%             | +4.1%           |
|                         | Public transport | 31.5%       | +20.8%            | −2.7%           |
| WASTE MANAGEMENT        | Private vehicle  | 55.4%       | +2.4%             | −4.9%           |
|                         | Generation       | 23.0%       | +0.2%             | −14.4%          |
|                         | Composting       | 0.0%        | +4.5%             | +40.7%          |

The reported changes are associated with larger reductions in the carbon footprint by UG. Such changes would generate a 12.6% decrease in food carbon footprint, whereas the reported changes in the control group would represent a 3.6% decrease (Table 2.). The largest changes in the carbon footprint following urban gardeners' behavior were associated with the commercial transport of food (43.8% reduction). The impact of habit change on pre- and in-farm and packaging stages would reduce emissions by 10.5% and 14.2%, respectively, in those stages. The largest divergences in food related carbon footprint between the two populations were observed in commercial transport, waste management, packaging, and home transport. Over the entire food chain, consumption changes from urban gardeners are associated with a 9.3% larger reduction than the control population's changes, representing the avoidance of around 147 kg CO<sub>2</sub>e per person (Table 2.).

The largest impact on the carbon footprint results from the changes in dietary patterns. Around 60% of the avoided GHGe were associated with pre-farm, in-farm, processing, and retail (Fig. 2.), stages where the carbon footprint change was exclusively determined by dietary choice (due to the low rate of organic consumption at the baseline). Carbon footprint changes in commercial transport—determined by food origin—and consumers' transport represent 18.2% and 16.2% of avoided emissions, respectively, whereas changes in packaging and waste management are estimated to reduce food-related carbon footprint by 3.9% and 1.4%, respectively.

Reduction in meat consumption was the dietary change with the largest impact on the carbon footprint. More than 70% of the avoided emissions were associated with animal source food products, and 43.4% were linked to changes in meat consumption alone (Table 3.). For comparison, the change in consumers' transport behavior and food origin would respectively explain 15.9% and 17.7% of the overall carbon footprint reduction, respectively.

To better understand the relationship between each of the changes in consumption and the reduction in carbon footprint, individual assessments for each of the food habit changes were conducted. This analysis serves to eliminate cross-influences between habit changes, for example, the impact of dietary change on the emissions associated with commercial transport emissions, due to the differences in the global warming potential of transport for the different food groups. The assessment indicated that the dietary change reported by urban gardeners would correspond to an annual reduction of 106.3 kg CO<sub>2</sub>e per person (Table 4.). This analysis confirms that dietary change would be the largest contributor to GHGe reduction, followed by food origin, with a reduction of 69.7 kg CO<sub>2</sub>e per person (Table 4.).

The sensitivity analysis in farm and pre-farm, processing, packaging, and retail stages showed reductions above 100 kg CO<sub>2</sub>e per person in all scenarios (Figure A. 2.) The results from the main analysis were at the lower end of the range of carbon footprint reduction values obtained with the different methodological choices assessed, including consumption sources and emission factors. In general, the reductions were higher when FAOSTAT data was used as the baseline consumption, given that this source includes all domestic food supply, not only household consumption. The use of factors from Poore and Nemecek (2018) for international or for all products led to higher carbon footprint reductions than the use of factors from Clune et al. (2017) or the Spanish-specific ones.

The comparison of average home food consumption carbon footprint (2012–2017) in Madrid, using official data (MAPA, 2020), showed a larger reduction in GHGe than the estimated based on survey answers from the control population. Whereas survey-based estimation reflected a 1.1–7.1% reduction in carbon footprint from 2012 to 2017, the assessment based on official statistics showed a 10.7–13.6% reduction (Table A. 10.).

**Table 2**

Carbon footprint for the different stages of the food chain in 2012 and in 2017 for urban gardeners (UG) and control group (C), and change in carbon footprint relative to 2012 (2012 → C and 2012 → UG) and relative to the participation in urban gardens (C → UG). “Total (all)” refers to the addition of GHGe and carbon footprint change from all the food chain steps, whereas “Total (assessed categories)” corresponds to the addition of the GHGe and the carbon footprint change for the categories included in the survey.

|                             | Carbon footprint (kg CO <sub>2</sub> e/yr/pc) |              |                      | Carbon footprint change (%) |           |        |
|-----------------------------|-----------------------------------------------|--------------|----------------------|-----------------------------|-----------|--------|
|                             | 2012                                          | 2017 Control | 2017 Urban gardeners | 2012 → C                    | 2012 → UG | C → UG |
| Pre- and in-farm production | 1127                                          | 1090         | 1009                 | −3.3%                       | −10.5%    | −7.4%  |
| Processing                  | 101                                           | 97           | 92                   | −4.2%                       | −9.5%     | −5.6%  |
| Packaging                   | 50                                            | 49           | 43                   | −2.9%                       | −14.2%    | −11.7% |
| Commercial transport        | 135                                           | 103          | 76                   | −24.1%                      | −43.8%    | −26.0% |
| Retail                      | 45                                            | 47           | 44                   | +3.5%                       | −2.7%     | −6.0%  |
| Home transport              | 220                                           | 234          | 210                  | +6.4%                       | −4.4%     | −10.2% |
| Waste management            | 14                                            | 15           | 13                   | +13.2%                      | −2.1%     | −13.5% |
| Total (all)                 | 1692                                          | 1634         | 1487                 | −3.4%                       | −11.1%    | −9.0%  |
| Total (assessed categories) | 1546                                          | 1491         | 1352                 | −3.6%                       | −12.6%    | −9.3%  |

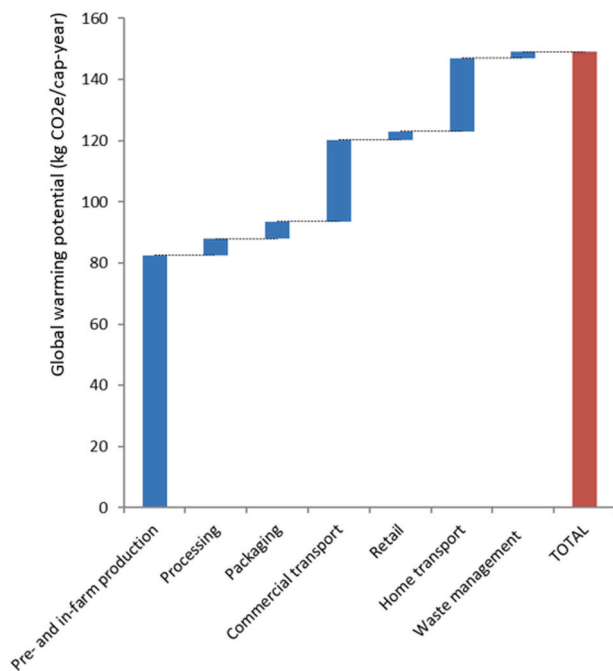


**Fig. 2.** Potential avoided GHG emissions (kg CO<sub>2</sub>e/year) associated to the participation in urban gardens in each of the food chain steps compared to control group.

## 4. Discussion

### 4.1. Environmental implications of urban gardening through behavioral change

The results of our carbon footprint assessment (c. 1.7 t CO<sub>2</sub>e/year per capita) are similar to those from other studies (Goldstein et al., 2016; Notarnicola et al., 2017; Sáez-Almendros et al., 2013; Santacana et al., 2008). Muñoz et al. (2010) conducted a life cycle assessment of an average Spanish diet, including human excretion, as well as home storage and cooking (not included in this study). They obtained a global warming impact of 2.1 t CO<sub>2</sub>e/year per capita. The difference with our study can be attributed to the food chain stages not assessed here (home refrigeration and cooking), which represent approximately 25% of the

**Table 4**

Changes in carbon footprint associated to the isolated modifications in food habits of the two populations, and avoided emissions related to urban gardeners' changes in consumption.

|                          | CF change     |                 | Avoided emissions |                            |
|--------------------------|---------------|-----------------|-------------------|----------------------------|
|                          | Control group | Urban Gardeners | %                 | kg CO <sub>2</sub> e/yr/pc |
| Diet composition         | −0.9%         | −5.9%           | 5.9%              | 106.3                      |
| Organic consumption rate | +0.0%         | −0.0%           | 0.0%              | 0.6                        |
| Packaging                | −0.1%         | −0.2%           | 0.2%              | 2.7                        |
| Food origin              | −2.5%         | −3.9%           | 3.9%              | 69.7                       |
| Transport home           | +0.8%         | −0.5%           | 0.5%              | 9.7                        |
| Waste management         | +0.0%         | −0.1%           | 0.1%              | 2.2                        |

**Table 3**

Impact of urban gardeners' carbon footprint change on carbon footprint (kg CO<sub>2</sub>e/year/pc) and relative weights of the avoided emissions (%).

|                  | CARBON FOOTPRINT CHANGE (kg CO <sub>2</sub> e/year/pc) |             |             |                      |             |                |                  |        |                 |       |
|------------------|--------------------------------------------------------|-------------|-------------|----------------------|-------------|----------------|------------------|--------|-----------------|-------|
|                  | Agricultural Production                                | Processing  | Packaging   | Commercial transport | Retail      | Home transport | Waste management | TOTAL  | AVOIDED - ADDED | ADDED |
| Cereals          | −0.8 (0.6%)                                            | +0.3        | +0.2        | −3.9 (2.6%)          | +0.1        |                |                  | −148.4 | −147.1          | +2.5  |
| Eggs and dairy   | −2.8 (1.9%)                                            | −0.3 (0.2%) | −0.2 (0.1%) | −3.6 (2.4%)          | −0.2 (0.1%) |                |                  |        | (100%)          |       |
| Fish and seafood | −22.5 (15.0%)                                          | −0.7 (0.5%) | −2.6 (1.8%) | −8.2 (5.4%)          | −1.4 (0.9%) |                |                  |        |                 |       |
| Fruits           | −0.6 (0.4%)                                            | +0.0        | +0.1        | −7.5 (5.0%)          | +0.2        |                |                  |        |                 |       |
| Meat             | −53.7 (35.7%)                                          | −4.9 (3.2%) | −3.5 (2.4%) | −1.4 (0.9%)          | −1.8 (1.2%) |                |                  |        |                 |       |
| Vegetables       | +0.8                                                   | +0.1        | +0.3        | −1.8 (1.2%)          | +0.3        |                |                  |        |                 |       |
| Other products   | −1.1 (0.7%)                                            | +0.0        | +0.0        | −0.5 (0.3%)          | +0.0        |                |                  |        |                 |       |
| TOTAL            | −80.7 (53.6%)                                          | −5.4 (3.6%) | −5.7 (3.8%) | −26.7 (17.7%)        | +2.8 (1.8%) | −23.9 (15.9%)  | −2.1 (1.4%)      |        |                 |       |

carbon footprint in Muñoz et al. (2010). Ivanova et al. (2017) also obtained higher results for food and beverage carbon footprint in the Madrid region (2.6 t CO<sub>2</sub>e/year per capita), however, their results focused on (solid) food consumption (1.4 t CO<sub>2</sub>e/year per capita), which are similar to the results obtained in our assessment (Table A. 7.). It should be highlighted that this carbon footprint does not include food consumed outside of the households, representing approximately 15% of the food consumption in Spain (MAPA, 2019).

Our results point out how small changes in food habits associated with participation in communitarian urban gardens can have a substantial impact on food-related carbon footprint. Urban gardeners' behavior after the study period does not present a radically different picture from the baseline or the control group (Fig. 3.); however, the reduction in the carbon footprint is noteworthy. At a larger scale, although it is a broad assumption, a proportional reduction in the carbon footprint of all Madrid citizens (3.2 million people in 2017; INE, 2017) would avoid the emission of 652.9 kt CO<sub>2</sub>e each year. This is 6.3% of the total direct and indirect GHGe of Madrid City, or sufficient to completely offset the emissions from the industrial sector (F2I2, 2018; Table A. 8.).

The habit change that has the largest influence on carbon footprint reduction is the reduction of animal source food consumption, especially the decrease in meat consumption (Table 3.). Although both habit change and carbon footprint change are larger in other food chain stages or choices, such as organic consumption, waste management, or packaging (Table 1 and 4), their contribution to the total carbon footprint change is smaller. The assessment of the impact of changes in organic consumption could be affected by the lack of specific emission factors for organic meat and dairy products. Further research is needed to assess the climate change impacts from the organic livestock sector (Aguilera et al.,

2018). Besides, organic consumption only represents 1.9% of total consumption at the baseline (Table 1.) therefore, even if the consumption change is large, organic food consumption would still be very low (2.6%, Fig. 3). However, urban gardeners reported consuming an average annual amount of 50.1 kg of organic vegetables from their urban gardens, which represents 9.0% of the total food consumption. Thus, it appears that the methodology used in this study, although allowing us to compare the two populations, underestimates the level of organic food consumed by urban gardeners and its impact on their carbon footprint. In the case of waste management and packaging choices, although the reported change towards low C behaviors was high (Table 1.), the weight of these stages over the food carbon footprint was minor (Table 3 and Table A. 7.), so the habit changes only have minor impacts on carbon footprint change (Table 3.).

These results also illustrate that the best way to pursue climate change mitigation through food consumption should focus on performing changes in several habits, especially dietary patterns, food origin and mobility behavior. Focusing only on one aspect decreases the potential for carbon footprint mitigation, passing from 205 kg CO<sub>2</sub>e/year per capita to 106 or 70 kg if behavioral change is restricted to diet or food origin, respectively (Table 4.).

Although this research focuses on the carbon footprint, it is noteworthy to highlight here the potential implications of urban gardening on other environmental sustainability-related issues. This is the case, for instance, of the alteration of biogeochemical cycles. As it has been already stated in several studies in recent years, the incidence of the agri-food system in the disruption of nutrient cycles is vast (e.g. Spingmann et al., 2018; Willett et al., 2019). The agri-food sector is estimated to be the main source of reactive N in the environment, with a major

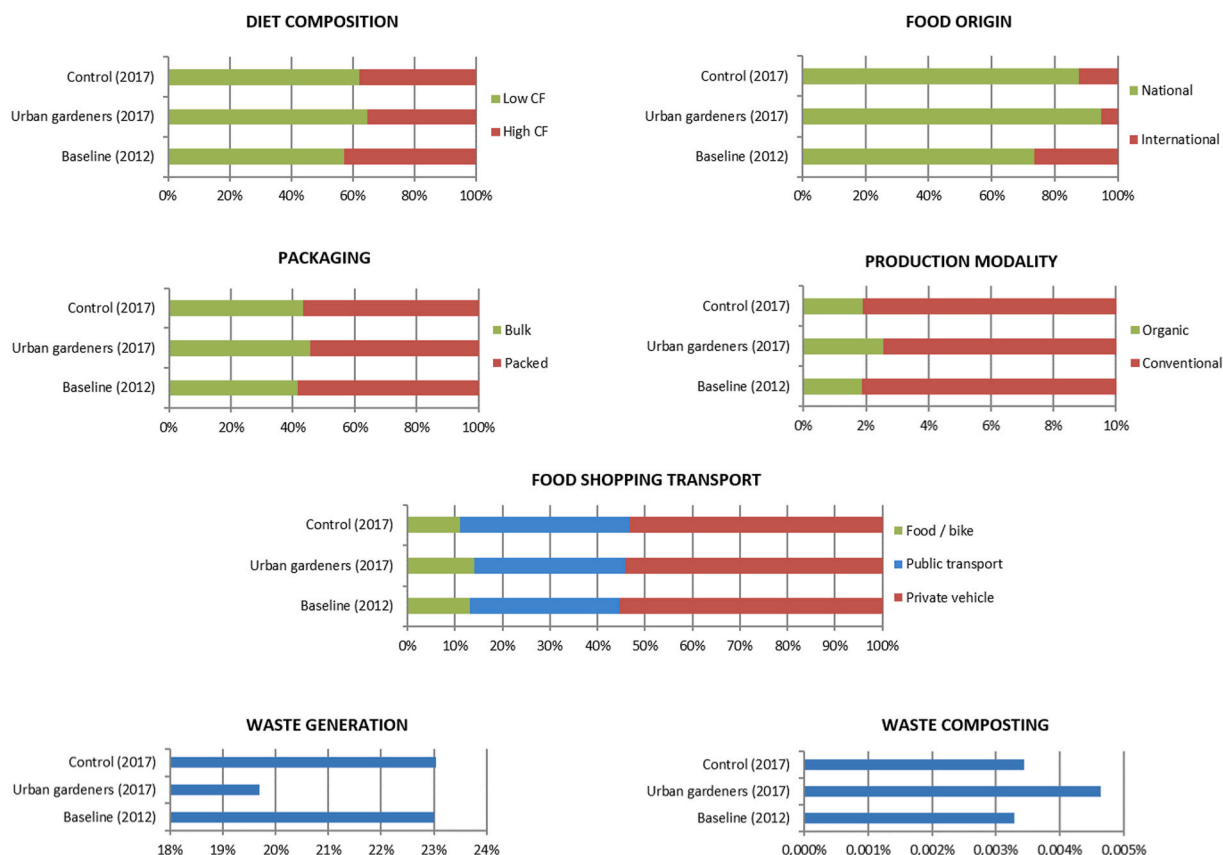


**Fig. 3.** Habit change: consumption shares for the different consumption options in each of the studied habits of the food chain in 2012 and impact of the reported changes of the two population on consumption patterns. Shares are assessed in kilograms of product for Diet Composition, Production modality, Packaging, Food Origin, Waste Generation and Waste Composting, and in kilometers for Food Shopping Transport. For Diet Composition, Low CF refers to less than 1 kg CO<sub>2</sub>e/kg product and High CF to equal or more than 1 kg CO<sub>2</sub>e/kg product.

incidence of dietary choices. Since human consumption is responsible for 6–225 kg of nitrogen lost per capita every year (Leip and Uwizeye, 2019), it is expected that the observed changes in food habits driven by urban gardening in the city of Madrid would not only decrease carbon footprint but also the nitrogen footprint. Based on the LCA factors of Leip et al. (2015), the estimated reduction in our case would be of 11.3% (2.7 kg N/ca/yr, Table A. 9.), predominantly due to the observed decrease in animal-based food by urban gardeners.

#### 4.2. Policy implications

Urban communitarian gardens can provide the necessary conditions for social learning and the adoption of sustainable food habits. Recent research has assessed the impact of social learning on climate change projections, coming with remarkable results (Bury et al., 2019). The habit change associated with the participation in urban gardens and its impact on the reduction in food carbon footprint, as revealed in this study, indicates that the support of these communitarian initiatives has an important potential for the reduction of GHGe from cities.

The behavioral change leading to the largest modification in food related carbon footprint is the reduction in the intake of animal source foods. Dietary change towards balanced and vegetable-rich diets is being increasingly recognized as a necessary measure to comply with the Paris Agreement goals and avoid trespassing planetary boundaries (de Coninck et al., 2018; Jia et al., 2019; Poore and Nemecek, 2018; Smith et al., 2019; Springmann et al., 2018; Willett et al., 2019). However, the implementation of measures aimed at reducing meat and dairy demand where consumption levels are higher than recommended turns out to be a delicate action (Chiles and Fitzgerald, 2018; De Boer et al., 2014; Graça et al., 2015a, 2015b; Macdiarmid et al., 2016; Pfeiler and Egloff, 2018; Rothgerber, 2012). Taxation or other authoritative policies can encounter strong opposition from citizens, and research suggests that positive measures such as information and consciousness raising could be effective in achieving dietary changes toward a reduction in GHGe (Bonnet et al., 2018; Carfora et al., 2019; Reynolds et al., 2019; Zech and Schneider, 2019). Based on the results of this study, local policies supporting the appearance of communitarian urban gardens can be an effective tool to reduce the demand for high C (and N) food products in a positive and inclusive way, due to their role as social learning catalysts and their multiple co-benefits (Bamberg et al., 2015; Mitchell et al., 2019; Petrovic et al., 2019; Tharrey et al., 2019; White et al., 2019).

Cultural factors and by the nature of the policy itself may influence the impact of public policies on urban gardening. The present study was based on a type of urban gardening characterized by an active citizen's role and a non-interventionist public policy. Urban gardening in Madrid flourished with the action of spontaneous citizens who took the lead in the management of abandoned public spaces and the creation of resilient social networks. A stronger intervention by government bodies could weaken citizens' agency, affecting the social interactions and learning that take place at the grassroots urban gardens (Becker et al., 2018; Celata and Coletti, 2018), as could have happened in the past (Casadevante and Moran, 2015). On the other hand, food policies that foster carbon footprint reduction through dietary change must avoid the offsetting of its impacts by increasing in the consumption of other high-carbon food products (e.g. processed or non-seasonal food).

In the light of the results of this study, showing an approximate 12.1% potential reduction in the carbon footprint of food consumption associated with the participation in urban agriculture activities, the implementation of urban policies supporting communitarian gardens could also have positive effects on other key environmental issues such as nitrogen pollution (Martinez et al., 2019), water scarcity (Blas et al., 2016, 2019), agricultural land use and biodiversity (Henry et al., 2019), as well as on public health (Blas et al., 2019; Sáez-Almendros et al., 2013; Willett et al., 2019). Besides, urban gardens bring important social benefits, including stress management, well-being, and the strengthening of social bonds within the neighborhood (Petrovic et al., 2019;

White et al., 2019).

The accounting of GHGe (at national, regional and local levels) generally focuses on emissions and removals derived from the production of goods or services within the borders of the accounted territory (Rypdal et al., 2006). Promoting consumption-based GHG inventories would be useful in reducing international GHGe leakage from rich to poor nations (Davis and Caldeira, 2010; Guan et al., 2009; Lassaletta et al., 2014; Rothman, 1998; Weber and Peters, 2009) and to stimulate the development of consumption-based mitigation strategies, such as the support of communitarian urban gardening or other participative initiatives that favor social learning. In the agri-food system, it could also result in the fastest mitigation rates at the global scale, as the dependence of GHGe reduction on food production is constrained by technical limitations (Hedenus et al., 2014) and increasing purchasing power (Gore, 2015).

#### 4.3. Barriers for change

The impact of urban gardens as pro-environmental behavior catalysts is limited by structural barriers and social norms. The social learning effect in reducing individuals' carbon footprint is very fast in contexts where social learning is low, however, after a certain threshold, the impact of social learning weakens and the effect of decreasing mitigation costs will be stronger (Bury et al., 2019). This is particularly relevant in aspects that have structural barriers, such as mobility habits or the acquisition of local food products. The results of this study reveal that urban gardening has positive impacts on both the reduction of carbon footprints associated with commercial transport, through the shift towards more local foods, and consumers' urban mobility. The environmental and climate benefits of increasing food transportation efficiency by the prioritization of seasonal and locally produced food products have been studied in previous research (Edwards-Jones et al., 2008; Jia et al., 2019; Michalský and Hooda, 2015; Pérez Neira et al., 2014; Tobarra et al., 2018), although the production and transportation scale should not be neglected (Schlich and Fleissner, 2005). However, there are obvious barriers to the increase in local food consumption, such as the higher costs of acquiring local products than delocalized ones (Pelto and Pelto, 1983). In this situation, only high-income and committed individuals would adhere to local options (Van Loo et al., 2014). The same applies to urban mobility habits: unless public policies support biking and walking in cities, large-scale changes in urban mobility behavior will be inhibited (Kollmuss and Agyeman, 2002; Whitmarsh and O'Neill, 2010). The scaling of pro-environmental behaviors is not only blocked by structural barriers, social norms and majority behavior also have a strong influence on habit change (Bury et al., 2019).

Climate change and food strategies will benefit from transversal coordination with urbanization and agricultural policies. At the regional and national levels within the European Union, the promotion of re-regionalization of food production and consumption through agricultural policies (e.g. Common Agricultural Policy) could increase consumers' access to local and seasonal food consumption. This would also have co-benefits for rural development and territorial structuring (Mundler and Laughrea, 2016). In the same vein, food policies should coordinate with urban planning policies to guarantee walking and cycling distances between households and food markets.

#### 4.4. Limitations of this research and sources of uncertainty

The limitations of the study are derived from the sample size and the use of a convenience sample for the control group. However, we consider the convenience sample, composed of students, technicians, researchers, and university staff not too distant from the Madrid City population. However, using a more representative control sampling methodology might, if anything, reveal a larger impact of urban gardening on consumption carbon footprint, because, one of the main

distinctions of university communities is a higher formal education level, linked to pro-environmental behavior in food consumption (Whitmarsh and O'Neill, 2010).

Regarding to potential misperceptions by survey respondents about their changes in food-related habits, the larger reduction in the carbon footprint observed with official data could indicate that there is an underestimation of food consumption changes among survey respondents. We assume that this misperception was shared by the two populations participating in the survey. The reduction in carbon footprint due to participation in urban gardens would not be lower than the estimated in this study (i.e. 12.1%), but it could be larger than this figure if the difference observed for the control population would be extrapolated to urban gardeners (Table A.10.).

On the other hand, it is expected that the inclusion of various aspects of food consumption not addressed in this study would reveal a larger impact on the carbon footprint associated with urban gardeners' behavioral change. First, the assessed change in the carbon footprint is limited to households' food consumption. However, an approximate 15% of the overall food and beverages consumption in the studied community is made outside the house (MAPA, 2019). Furthermore, the assessment of the impact of waste management in the carbon footprint did not include GHGe from food packaging treatment and pre-treatment, associated with important GHGe (Dilkes-Hoffman et al., 2018; Fresán et al., 2019). The inclusion of packaging waste management is expected to show a larger change in urban gardeners' behavior (due to their higher increase in bulk consumption), thus increasing the potential for climate change mitigation through the upscaling of this behavior to the rest of the citizenships.

## 5. Conclusions

Efforts to mitigate climate change within the agri-food sector would benefit from a stronger focus on food consumption choices. This is especially relevant in high-income populations and urban environments, due to the dominance of outsource—or consumption-based—GHGe over production-based ones. Our results have shown that participation in urban gardens has an impact on food consumption decisions, thus catalyzing a reduction of individuals' carbon footprint in such a way that approximately 205 kg CO<sub>2</sub>e/year per capita (i.e., a decrease of 12.1% in food carbon footprint) could be avoided. The largest reported relative

changes in food habits were (i) the amount of composted food waste, (ii) the rate of organic products consumption, and (iii) the purchase of local food products. However, the largest contribution to carbon footprint reduction is related to the dietary changes (approximately 60% of the carbon footprint reduction). The reduction of animal source foods consumption was behind 89% of GHGe avoided from the pre-farm to retail stages. The impact assessment of the change in organic consumption was hindered by the low rate at the baseline (1.9%). The changes in the majority of the studied habits are not drastic; yet, the potential impact of its upscaling would have significant impacts on climate change mitigation at the urban level. This has positive implications for food and climate change mitigation policies, indicating that urban gardens are effective tools for catalyzing changes in consumption patterns, especially in areas that are difficult to address, such as those related to personal dietary choices.

## Declaration of competing interest

The co-authors of the MS entitled "Urban agriculture may induce changes in food consumption towards low carbon diets" confirm that there are not conflicts of interest with this manuscript.

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## APPENDIX A

### 1. METHODOLOGY DETAILS

#### 1.1. Carbon footprint method

**1.1.1. Pre- and in-farm production.** The life cycle assessment was performed based on Spanish, European and global GHG emission factors (Aguilera et al., 2015a, 2015b; Clune et al., 2017; Weiss and Leip, 2012), differentiating among imported and national products when emission factors were available (Table A. 3.).

In the case of GHG footprints for food products derived from crops, the assessment considered the percentage of organic consumption for each food group. This distinction was not made for animal products, as literature indicates that average global differences between conventional and organic livestock systems are not significant (Poore and Nemecek, 2018), and there is a lack of research studies comparing organic and conventional livestock systems under Mediterranean conditions (Aguilera et al., 2018). Organic consumption shares were estimated for 16 food subgroups based on 2011–2013 statistics (Appendix B) (EcoLogical, 2016; Mercasa, 2012, 2013, 2014).

**1.1.2. Packaging.** Bulk consumption shares were estimated for the 10 groups and 14 subgroups based on available data for national consumption (Appendix B) (MAPA, 2020; Mercasa, 2014, 2013, 2012; Psyma, 2017).

#### 1.1.3. Commercial transport.

Imported products

Imported weights for the different food products, origins and transportation modes were estimated using 2011–2013 data from the Spanish Foreign Trade Database (DataComex, 2019) for Madrid Region (Table A. 4.).

For the calculation of the emission factors, it was assumed that food products traveled through the shortest route to Madrid from the locations registered by DataComex (2019) and that these locations were the initial origin of food products. Trade detours and routes followed before the location immediately preceding load entrance in European Union territory were not considered, as DataComex (2019) only registers this location and not previous origins.

Travel distances were estimated for all imported loads transported by sea, road, railroad and air, using the online distance calculation tools applied in Pérez Neira et al. (2014). Several assumptions were made for the different modes of transport: (i) for sea transport, the load arrives to Valencia's port and travels to Madrid by road; (ii) for air transport, the load travels from the capital cities of the countries of origin to Madrid; (iii) for road and railroad food transport, the load travels from the countries of origin's capitals to Madrid, except when land connection does not exist. In the case of road and railroad transported foods from origins not connected to Madrid by land, it was assumed that load arrives to Turkish Mersin port by sea and from there to Madrid by road or railroad. Mersin port was selected attending its size (one of the largest ports close to the European Union) and closeness to European Union borders (World Port Source, 2019). In some exceptional cases, the calculation tool for road and railroad (Via Michelin, 2019) was not able to estimate the distance to Madrid, and these loads were dismissed (0.01% of imported weight). Internal routes within the countries of origin (e.g., from farm to port) were also dismissed.

### National products

To assess the impact of national food consumption, it was considered that it followed the same distribution pattern of food production in Spanish territories. Production distribution was estimated using Spanish 2011–2013 average data for crop production, fisheries and livestock slaughter (MAPA, 2019a; 2019b; 2019c). Emission factors were calculated for 16 subcategories (Table A. 3.).

Domestic food products were assumed to be transported to Madrid by road, except for locations not connected to Madrid by land. In those cases, it was assumed that food traveled by sea from the origin to the nearest port in the peninsula—and by road from there to Madrid—except for fish and seafood, where it was assumed to be airfreight. For fish and seafood products with origin in a peninsular region, the largest port in the region was assumed to be the origin; for insular cases, the capital of the region was assumed to be the origin.

### Allocation of imported and national consumption

The distribution of food consumption from international and national origins in Madrid City's households was estimated using FAOSTAT (FAO, 2021) and Spanish governmental data (MAPA, 2019a; 2019b; 2019c) for the different food subcategories (Appendix B). The share of international consumption was estimated assuming the same ratio of imports vs. domestic production at the national level (FAO, 2021).

**1.1.4. Home transport.** It was assumed that 75% of time allocated to shopping is dedicated to the acquisition of food products, and that Madrid's citizens present the transportation behavior categorized as "other reasons" in food purchasing. It was assumed that 20% of foot or bike displacements were made by bike and 80% by foot.

**1.1.5. Waste management.** Global warming factors for food waste generation and waste composting were calculated based on the treatment and pre-treatment processes followed by the organic fraction in Madrid City and the C footprints of Madrid's solid waste treatments calculated by Pérez et al. (2018, 2017a, 2017b) (Table A. 3.).

This estimation of kitchen waste includes the amount of edible food that is discarded due to the expiration date, leftovers, etc., as well as the percentage of non-edible portion of food diets in Spain (Muñoz et al., 2010). Average composting rate for Madrid's citizens was estimated using data from local council program on organic waste composting (Madrid City Council, 2016).

## 1.2. Assessment of carbon footprint change

**1.2.1. Assessment of food habits' change.** A discussion group was organized with the support of Madrid's urban gardening network – Rehdmad, and a total of 6 people attended the activity. The members of the discussion group had not met beforehand. A sociologist moderated the session, asking attendants to talk about the main changes that they had experienced since the start of their participation in the urban garden. The moderator kept his intervention to a minimum. The conversation was registered and analyzed to extract the habits related to food consumption signaled by the participants and that had an impact on GHGe: dietary patterns, food origin, organic consumption and personal transport. As a result of the observation of recent trends in Madrid and its potential impact on food related C footprint change, the following aspects were additionally incorporated to the list: product packaging and food waste management.

A questionnaire was subsequently designed and distributed among Madrid's UG via the urban gardening network. The same survey was shared among the personal networks of the research team and Universidad Politécnica de Madrid's community, composed by researchers, technicians and students, as a control group.

Questions were answered using a slide control (Figure A1), where the center represents the invariability of the habit, and the extremes correspond to reductions (left extreme) or increases (right extreme). Larger distances from the center correspond to larger changes. As the value of the bar center was 50, and the extremes were 0 (left extreme) and 100 (right extreme), the estimation of the habit change in percentage was calculated following

equation 1.A:

$$Cch = (Bv - .50) \cdot 2 \cdot 100 \quad (6)$$

Where Cch is the change in habit (in percentage) and Bv is the survey result as indicated with the slide control.

The time reference for the questions in the survey was indicated at the start of the questionnaire and was the beginning of the participation in the urban garden (for urban gardeners) or 5 years earlier (for the control group). Survey answers can be found in Table A. 3.

1.3Impact of habit changes on carbon footprint.

Total food-related C footprint was calculated as the sum of the estimated C footprint in the different food stages using equation 2.A–12.A:

$$CF_{food} = \sum AP_f + \sum Pr_f + \sum Pk_f + \sum Trad_f + Ret + Th + W \quad (7)$$

Where  $CF_{food}$  is food related C footprint; AP are pre- and in-farm GHGe; Pr are processing GHGe; Pk are packaging GHGe; Trad are GHGe from commercial transport of food to Madrid; Ret are retail GHGe; Th are GHGe from food transport to homes; W are GHGe from waste management.

$$AP_f = APC_{fi} + APC_{fn} + APO_f \quad (8)$$

$$APC_{fn} = (C_f - CO_f) \cdot \%C_{f,n} \cdot EFC_{fn} \quad (9)$$

$$APC_{fi} = (C_f - CO_f) \cdot \%C_{f,i} \cdot EFC_{fi} \quad (10)$$

$$APO_f = CO_f \cdot EFO_f \quad (11)$$

Where  $APC_{fn}$  and  $APC_{fi}$  are cradle to farm gate GHGe from national and international origin and conventional systems, and  $APO_f$  are GEGe from organic farming systems; C is total consumption, CO is the organic consumption; and EFC and EFO are the GHG emission factors for conventional and organic cradle to farm gate, respectively.

$$Pr_f = C_f \cdot EFpr_f \quad (12)$$

Where: EFpr are food processing GHGe.

$$Pk_f = (C_f - Cb_f) \cdot EFPk \quad (13)$$

Where: Cb is consumption of bulk products and EFPk is the emission factor of packaging. The emission factor for bulk products was considered to be 0.

$$Trad_f = Ci_f \cdot EFi_f + Cn_f \cdot EFn_f + Cr_f \cdot EFr_f \quad (14)$$

Where: Ci, Cn and Cr is the consumption from international, national and regional origin, respectively, and EFi, EFn and EFr are the corresponding GHG emission factors.

$$Ret = C \cdot EFret \quad (15)$$

Where: EFret is the GHG emission factor for retail.

$$Th = Dpr \cdot EFpr + Dpb \cdot EFPb \quad (16)$$

Where: Dpr and Dpb are the distances made for shopping by private and public transports, respectively, and EFpr and EFPb are the corresponding GHG emission factors. Biking and food shopping GHG emissions were considered to be 0.

$$W = Fw \cdot EFow + Fc \cdot AFC \quad (17)$$

Where: Fw are the kilograms of food wasted; EFow is the GHG emission factor for organic waste; Fc is the amount of food waste that is composted, and AFC is the CO<sub>2</sub> absorption factor from organic waste composting.

## 11. Now you eat FISH:

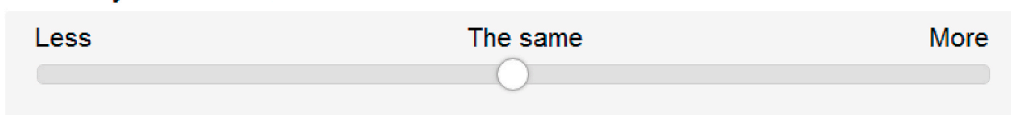


Figure A. 1. Slide control used to indicate the changes in food habits in the survey.

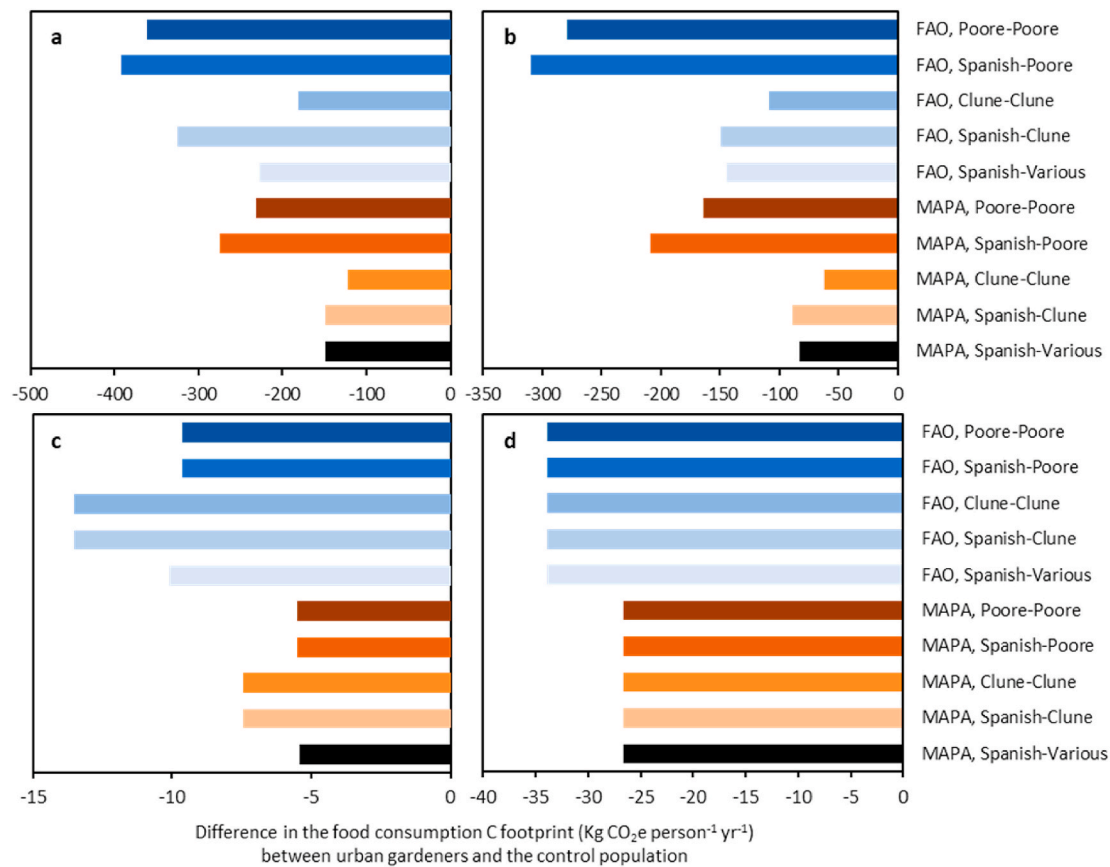


**Figure A. 2.** Sensitivity analysis of the effect of using different reference consumption sources and different emission factors on the differences in the C footprint between urban gardeners and the control group. The household consumption from official survey data used as the reference consumption in the main analysis (MAPA) was compared to the domestic food supply reported by FAOSTAT (FAO). The combinations of emission factors were the following: Spanish-Variou corresponds to the main analysis, based on the selection of emission factors closest to food consumption patterns in Madrid; Spanish-Clune to Spanish emission factors for farm-and pre-farm stages in nationally grown products and Clune et al. (2017) for the rest; Clune-Clune to Clune et al. (2017) factors for all; Spanish-Poore to Spanish emission factors for farm-and pre-farm stages in nationally grown products and Poore and Nemecek (2018) factors for the rest, and Poore-Poore to Poore and Nemecek (2018) factors for all. The assessed emissions include total food-related emissions (a), farm emissions (b), processing emissions (c) and transport emissions (d).

**Table A. 1**

Equivalence of food categories for the different stages and sources used. Sources: (a) MAPA (2020); (b) EcoLogical (2016); (c) Mercasa (2014, 2013, 2012); (d) Psyma (2017); (e) FAO (2021); (f) MAPA (2019a); (g) MAPA (2019b); (h) MAPA (2019c); (i) Aguilera et al. (2015a); (j) Aguilera et al. (2015b); (k) Clune et al. (2017); (l) Weiss and Leip (2012); (m) DataComex (2019).

| FOOD GROUPS AND SUB-GROUPS |                            | CONSUMED WEIGHT                                                                        |                                   |                        | PRODUCT ORIGIN                |                                      | EMISSION FACTORS               |                                                                                                                |
|----------------------------|----------------------------|----------------------------------------------------------------------------------------|-----------------------------------|------------------------|-------------------------------|--------------------------------------|--------------------------------|----------------------------------------------------------------------------------------------------------------|
|                            |                            | HOUSEHOLDS' FOOD CONSUMPTION (a)                                                       | ORGANIC PRODUCTS (b, c)           | BULK PRODUCT (a, c, d) | NATIONAL OR INTERNATIONAL (e) | SPANISH REGIONS (f, g, h)            | FARM AND PRE-FARM (i, j, k, l) | INTERNATIONAL IMPORTS (m)                                                                                      |
| EGGS                       | Fresh eggs<br>Egg products | Fresh eggs.<br>Egg products                                                            | Other animal source food products | Eggs for self-supply   | Eggs                          | Eggs                                 | Eggs                           | Division 025: Eggs, birds', and egg yolks, fresh, dried or otherwise preserved, sweetened or not; egg albumin. |
| MEAT                       | Cow meat                   | Fresh bovine Meat; Bovine offal; Frozen bovine meat.                                   | Meat and meat derivatives         | Bulk meat              | Bovine meat                   | Cow meat (carcass weight)            | Beef                           | Division 01 - Meat and meat preparations.                                                                      |
|                            | Goat or sheep meat         | Fresh Mutton and goat meat; Mutton offal.                                              |                                   |                        | Mutton and goat meat          | Goat and sheep meat (carcass weight) | Sheep + goat meat              |                                                                                                                |
|                            | Pig meat                   | Fresh pigmeat; Frozen pigmeat; Frozen meat meals; Pig offal; Meat offal; Prepared meat |                                   |                        | Pigmeat                       | Pig meat (carcass weight)            | Pork                           |                                                                                                                |

(continued on next page)

Table A. 1 (continued)

| FOOD GROUPS AND SUB-GROUPS |                        | CONSUMED WEIGHT                                                                                                                                                                                                                    |                               |                        | PRODUCT ORIGIN                                                          |                                        | EMISSION FACTORS               |                                                                                                                                                                                                                                                                                           |
|----------------------------|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|------------------------|-------------------------------------------------------------------------|----------------------------------------|--------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                            |                        | HOUSEHOLDS' FOOD CONSUMPTION (a)                                                                                                                                                                                                   | ORGANIC PRODUCTS (b, c)       | BULK PRODUCT (a, c, d) | NATIONAL OR INTERNATIONAL (e)                                           | SPANISH REGIONS (f, g, h)              | FARM AND PRE-FARM (i, j, k, l) | INTERNATIONAL IMPORTS (m)                                                                                                                                                                                                                                                                 |
| FISH AND SEAFOOD           | meals; Processed meat. |                                                                                                                                                                                                                                    |                               |                        |                                                                         |                                        |                                |                                                                                                                                                                                                                                                                                           |
|                            | Chicken meat           | Fresh chicken meat; Chicken offal; Frozen chicken meat; Frozen meat.                                                                                                                                                               |                               |                        | Poultry Meat                                                            | Poultry meat (carcass weight)          | Poultry meat                   |                                                                                                                                                                                                                                                                                           |
|                            | Other meat             | Rabbit meat; Other fresh meat; Other frozen meat; Other offal.                                                                                                                                                                     |                               |                        | Meat (other)                                                            | Horse and rabbit meat (carcass weight) | Rabbit                         |                                                                                                                                                                                                                                                                                           |
|                            | Fish and octopus       | Fresh fish; Fresh squid/octopus; Frozen fish; Anchovies; Sardine; Smoked salmon; Smoked trout; Tuna; Mackerel; Processed octopus; Processed squid; Other preserved fish; Other smoked fish; Frozen fish meals; Prepared fish meals | Fish and seafood              | Bulk fish              | Freshwater Fish; Demersal Fish; Pelagic Fish; Marine Fish; Cephalopods. | Fisheries and aquaculture              | Fish (all species)             | Division 034: Fish, fresh (live or dead), chilled or frozen. Division 035: Fish, dried, salted or in brine; smoked fish; flours, meals and pellets of fish, fit for human consumption.                                                                                                    |
|                            | Seafood                | Fresh clams/cockles; Fresh mussels; Prawns/langoustines; Preserved cockles; Preserved mussels; Preserved clams; Other molluscs/ other seafood.                                                                                     |                               |                        | Crustaceans; Molluscs.                                                  |                                        | Prawns, shrimps                | Division 036: Crustaceans, molluscs and aquatic invertebrates, fresh, chilled, frozen, dried, salted or in brine; crustaceans, in shell, chilled, frozen, dried, salted, in brine, or other; flours, meals and pellets of crustaceans or of aquatic invertebrates, for human consumption. |
| DAIRY                      | Cow milk               | Liquid milk (subtracted goat milk). Full cream evaporated milk. Powder milk. Evaporated milk.                                                                                                                                      | Milk and other dairy products | Un-packaged milk       | Cream, Milk - Excluding Butter                                          | Cow milk                               | Cow milk                       | Division 022: Milk and cream and milk products other than butter or cheese.                                                                                                                                                                                                               |
|                            | Dairy desserts         | Chocolate cream, cream desserts, crema catalana, ice creams, cakes and prepared flans                                                                                                                                              |                               |                        |                                                                         |                                        |                                |                                                                                                                                                                                                                                                                                           |
|                            | Other dairy products   | Dairy preparations, milkshakes and fermented milk (other), cream, curd, custards, other dairy products.                                                                                                                            |                               |                        |                                                                         |                                        |                                |                                                                                                                                                                                                                                                                                           |
|                            | Sheep or goat milk     | Goat milk.                                                                                                                                                                                                                         |                               |                        |                                                                         |                                        | Sheep + goat milk              |                                                                                                                                                                                                                                                                                           |
|                            | Cow yogurt             | Yogurt; Yogurt with bifidus; Yogurt shake.                                                                                                                                                                                         |                               |                        |                                                                         |                                        | Cow milk                       |                                                                                                                                                                                                                                                                                           |
|                            | Cow cheese             | Fresh cheese; Processed cheese; Soft cheese; Semi-cured cheese; Cured cheese; Dutch cheese; Emmenthal and gruyere cheese; Blue cheese; Other cheese.                                                                               |                               |                        |                                                                         |                                        |                                | Division 024: cheese and curd.                                                                                                                                                                                                                                                            |
|                            | Sheep or goat cheese   | Sheep cheese; Goat cheese.                                                                                                                                                                                                         |                               |                        |                                                                         |                                        | Sheep + goat milk              |                                                                                                                                                                                                                                                                                           |

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Table A. 1 (continued)

| FOOD GROUPS AND SUB-GROUPS |                                       | CONSUMED WEIGHT                                                                                                                                                                                   |                                |                                                  | PRODUCT ORIGIN                                                                                        |                                                                                                                                                                                                                                                                                                            | EMISSION FACTORS                              |                                                                                                                                                                                                                                                                    |
|----------------------------|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|--------------------------------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                            |                                       | HOUSEHOLDS' FOOD CONSUMPTION (a)                                                                                                                                                                  | ORGANIC PRODUCTS (b, c)        | BULK PRODUCT (a, c, d)                           | NATIONAL OR INTERNATIONAL (e)                                                                         | SPANISH REGIONS (f, g, h)                                                                                                                                                                                                                                                                                  | FARM AND PRE-FARM (i, j, k, l)                | INTERNATIONAL IMPORTS (m)                                                                                                                                                                                                                                          |
|                            | Butter                                | Butter.                                                                                                                                                                                           |                                |                                                  | Butter                                                                                                |                                                                                                                                                                                                                                                                                                            | Cow milk                                      | Division 023: Butter and other fats and oils derived from milk.                                                                                                                                                                                                    |
| PULSES                     | Dry pulses                            | Dry pulses.                                                                                                                                                                                       | Vegetables and legumes         | Bulk dry products (legumes, cereals, dry fruits) | Beans; Pulses; Peas.                                                                                  | Beans; Chickpea; Fava bean; Fava bean, green, without pod; Lentils; Pea; Pea, green, without pod; Other legumes.                                                                                                                                                                                           | Rainfed legumes                               | Division 054: Vegetables, fresh, chilled, frozen or simply preserved (including dried leguminous vegetables); roots, tubers and other edible vegetable products, n.e.s., fresh or dried.                                                                           |
|                            | Dry pulses                            | Dry pulses                                                                                                                                                                                        |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
| CEREAL BASED PRODUCTS      | Bread                                 | Bread                                                                                                                                                                                             | Cereals and cereal derivatives | Bulk bread, pastries, cookies and pasta.         | Wheat and products; Rye and products.                                                                 | Rye and wheat                                                                                                                                                                                                                                                                                              | Rainfed cereals                               | Division 041: Wheat (including spelt) and meslin, unmilled. Division: 048 Cereal preparations and preparations of flour or starch of fruits or vegetables.                                                                                                         |
|                            | Flour                                 | Flours and semolina                                                                                                                                                                               |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Pasta                                 | Pasta                                                                                                                                                                                             |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Bases and pastry                      | Pizza bases and puff pastry                                                                                                                                                                       |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Cereal-based refrigerated             | Frozen pasta meals; Prepared pizza.                                                                                                                                                               |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Cookies                               | Pastries, cookies, cereals                                                                                                                                                                        |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
| VEGETABLES                 | Preserved pasta meals                 | Prepared pasta; Other prepared pasta meals;                                                                                                                                                       | Vegetables and legumes         | Bulk dry products (legumes, cereals, dry fruits) | Rice (Milled Equivalent)                                                                              | Rice                                                                                                                                                                                                                                                                                                       | Rice                                          | Division 042: Rice.                                                                                                                                                                                                                                                |
|                            | Dry rice                              | Long grain rice; regular rice; Other kinds of rice                                                                                                                                                |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Pre-cooked rice                       | Parboiled rice;                                                                                                                                                                                   |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Rice meals                            | Preserved rice meals; Frozen rice meals; Other prepared rice meals                                                                                                                                |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Fresh potatoes                        | Fresh potatoes                                                                                                                                                                                    |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Fresh vegetables                      | Fresh vegetables (other than potatoes).                                                                                                                                                           |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
| VEGETABLES                 | Fresh potatoes                        | Fresh potatoes                                                                                                                                                                                    | Vegetables and legumes         | Bulk vegetables; Bulk salad.                     | Potatoes and products; Yams; Sweet potatoes; Roots; Tomatoes and products; Onions; Vegetables (other) | Artichoke; Asparagus; Aubergine; Beet; Borage; Cabbage, broccoli; Carrot; Cauliflower; Celery; Chard; Chicory; Cucumber; Cultivar for pickled cucumber, gherkins; Endive; Garlic; Leek; Lettuce; Onion; Potato; Radish; Other roots; Spinach; Squash/pumpkin; Tomato; Turnip; Zucchini; Vegetables, other. | Open air vegetables and greenhouse vegetables | Division 054: Vegetables, fresh, chilled, frozen or simply preserved (including dried leguminous vegetables); roots, tubers and other edible vegetable products, n.e.s., fresh or dried. Division 056: Vegetables, roots and tubers, prepared or preserved, n.e.s. |
|                            | Fresh vegetables                      | Fresh vegetables (other than potatoes).                                                                                                                                                           |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Frozen potatoes                       | Frozen potatoes;                                                                                                                                                                                  |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Frozen vegetables and vegetable meals | Frozen vegetables (other than potatoes); Frozen vegetable meals.                                                                                                                                  |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Preserved or prepared vegetables      | Processed potatoes; Preserved artichokes, asparagus, green beans, mushrooms, peas, peppers, sweetcorn and tomatoes; Preserved vegetable stew; Prepared vegetable meals; Prepared soups and reams; |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |
|                            | Preserved or prepared vegetables      | Processed potatoes; Preserved artichokes, asparagus, green beans, mushrooms, peas, peppers, sweetcorn and tomatoes; Preserved vegetable stew; Prepared vegetable meals; Prepared soups and reams; |                                |                                                  |                                                                                                       |                                                                                                                                                                                                                                                                                                            |                                               |                                                                                                                                                                                                                                                                    |

(continued on next page)

Table A. 1 (continued)

| FOOD GROUPS AND SUB-GROUPS |                         | CONSUMED WEIGHT                                                                                                                  |                                   |                                                  | PRODUCT ORIGIN                                                                                                                                                                                       |                                                                                                    | EMISSION FACTORS               |                                                                                 |
|----------------------------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|--------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|--------------------------------|---------------------------------------------------------------------------------|
|                            |                         | HOUSEHOLDS' FOOD CONSUMPTION (a)                                                                                                 | ORGANIC PRODUCTS (b, c)           | BULK PRODUCT (a, c, d)                           | NATIONAL OR INTERNATIONAL (e)                                                                                                                                                                        | SPANISH REGIONS (f, g, h)                                                                          | FARM AND PRE-FARM (i, j, k, l) | INTERNATIONAL IMPORTS (m)                                                       |
| FRUITS                     | Citrus                  | Other preserved vegetables.<br>Oranges; Mandarins; Lemons.                                                                       | Fruit, dry fruits and derivatives | Bulk vegetables                                  | Oranges; Lemons; Grapefruit and products; Citrus (other).                                                                                                                                            | Orange; mandarin; lemon; citrus other.                                                             | Citrus                         | Division 057: Fruit and nuts (not including oil nuts), fresh or dried.          |
|                            | Tropical fruits         | Banana; Avocado; Pineapple.                                                                                                      |                                   |                                                  | Coconuts - Incl Copra; Bananas; Plantains; Pineapples and products.                                                                                                                                  | Avocado; Bananas; Plantains.                                                                       | Subtropical fruits             |                                                                                 |
|                            | Other fruit (fresh)     | Apples; Apricots; Cherries; Grapes; Kiwi; Melon; Nectarines; Peaches; Pears; Plums; Strawberries; Watermelon; Other fresh fruit. |                                   |                                                  | Apples and products; Grapes and products (excl wine); Fruits (other).                                                                                                                                | Apple; Apricot; Cherry; Figs; Fruits; Melon; Peach; Pear; Plum; Strawberry; Watermelon; Grapevine. | Fruits                         |                                                                                 |
|                            | Other fruit (processed) | Preserved fruit; Frozen fruit.                                                                                                   |                                   |                                                  | Oranges; Lemons; Grapefruit and products; Citrus (other); Coconuts - Incl Copra; Bananas; Plantains; Pineapples and products; Apples and products; Fruits (other); Grapes and products (excl. wine). |                                                                                                    |                                | Division 058: Fruit, preserve, and fruit preparations (excluding fruit juices). |
| DRY FRUITS                 | Dry fruits              | Dry fruits.                                                                                                                      |                                   | Bulk dry products (legumes, cereals, dry fruits) | Nuts and products; Groundnuts (Shelled Eq); Sunflower seed.                                                                                                                                          | Almonds; chestnuts; hazelnuts; Pistachios; sunflower seeds; walnuts.                               | Treenuts                       | Division 057: Fruit and nuts (not including oil nuts), fresh or dried.          |
| OLIVE PRODUCTS             | Olive oil               | Olive oil.                                                                                                                       | Olive oil                         | Olive oil, self-supply                           | Olive Oil                                                                                                                                                                                            | Olive                                                                                              | Olive                          | Division 421.4 Olive oil and other oil obtained from olives.                    |
|                            | Olives                  | Olives.                                                                                                                          |                                   | Olives, other than packaged                      | Olives (including preserved)                                                                                                                                                                         |                                                                                                    |                                |                                                                                 |

Table A. 2

Weight conversion factors for food products derived from milk and olives.

| FOOD PRODUCT               | DRY MATTER/OIL CONTENT (%) | SOURCE                               | CONVERSION FACTOR |
|----------------------------|----------------------------|--------------------------------------|-------------------|
| Milk                       | 0.13                       | <a href="#">Byron et al. (1974)</a>  | –                 |
| Yogurt                     | 0.16                       | <a href="#">Byron et al. (1974)</a>  | 1.25              |
| Cheese                     | 0.50                       | <a href="#">Byron et al. (1974)</a>  | 3.95              |
| Butter                     | 0.82                       | <a href="#">Byron et al. (1974)</a>  | 6.41              |
| Full cream evaporated milk | 0.31                       | <a href="#">Hess (2003)</a>          | 2.42              |
| Powder milk                | 0.96                       | <a href="#">Spreer (1998)</a>        | 7.50              |
| Evaporated milk            | 0.31                       | <a href="#">Hess (2003)</a>          | 2.42              |
| Olives                     | 0.25                       | <a href="#">CSR Servicios (2018)</a> | 0.25              |
| Olive oil                  | 1.00                       | <a href="#">CSR Servicios (2018)</a> | 4.00              |

**Table A. 3**

Emission factors used for the estimation of carbon footprint at different stages of the food chain. Sources for emission factors from the literature: (a) [Aguilera et al. \(2015a\)](#); (b) [Aguilera et al. \(2015b\)](#); (c) [Weiss and Leip \(2012\)](#); (d) [Clune et al. \(2017\)](#); (e) [Poore and Nemecek \(2018\)](#). Sources for the estimation of calculated emission factors: (f) [Pérez Neira et al. \(2014\)](#); (g) [DataComex \(2019\)](#); (h) [MAPA \(2019a\)](#); (i) [MAPA \(2019b\)](#); (j) [MAPA \(2019c\)](#); (k) [Ministerio de Fomento \(2006\)](#); (l) [DEFRA, 2008](#); (m) [Pérez et al. \(2018\)](#); (n) [Pérez et al. \(2017a\)](#); (o) [Pérez et al. \(2017b\)](#). Units: g CO<sub>2</sub>e/kg bone free meat or produce (agricultural production, processing, packaging, commercial transport, retail and waste management) and g CO<sub>2</sub>e/km (home transport).

| PRODUCT GROUP AND SUB-GROUP |                                                                                                                                             | Agricultural production          |                                             |                             | Processing<br>(d, e) | Packaging<br>(e) | Commercial transport           |                                    | Retail<br>(e) | Home transport                 |                               | Waste management                 |                            |
|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|---------------------------------------------|-----------------------------|----------------------|------------------|--------------------------------|------------------------------------|---------------|--------------------------------|-------------------------------|----------------------------------|----------------------------|
|                             |                                                                                                                                             | Conventional,<br>Spain (a, b, c) | Conventional,<br>International (c,<br>d, e) | Organic,<br>Spain (a,<br>b) |                      |                  | International<br>origin (f, g) | National<br>origin (f,<br>h, i, j) |               | Private<br>transport<br>(k, l) | Public<br>transport<br>(k, l) | Waste<br>generation<br>(m, n, o) | Waste<br>composting<br>(m) |
| EGGS                        | Fresh eggs                                                                                                                                  | 3260                             | 2890                                        | –                           | 0                    | 180              | 296.04                         | 67.86                              | 40            |                                |                               |                                  |                            |
|                             | Egg products                                                                                                                                | 3260                             | 2890                                        | –                           | 784                  | 210              | 296.04                         | 67.86                              | 270           |                                |                               |                                  |                            |
| MEAT                        | Cow meat                                                                                                                                    | 30,380                           | 22,180                                      | –                           | 2240                 | 410              | 479.91                         | 81.53                              | 270           |                                |                               |                                  |                            |
|                             | Goat or sheep meat                                                                                                                          | 23,240                           | 20,340                                      | –                           | 1420                 | 410              | 479.91                         | 73.91                              | 270           |                                |                               |                                  |                            |
|                             | Pig meat                                                                                                                                    | 8280                             | 7530                                        | –                           | 480                  | 410              | 479.91                         | 94.39                              | 270           |                                |                               |                                  |                            |
|                             | Chicken meat                                                                                                                                | 6010                             | 4930                                        | –                           | 788                  | 410              | 479.91                         | 91.66                              | 270           |                                |                               |                                  |                            |
|                             | Other meat                                                                                                                                  | –                                | 4700                                        | –                           | 660                  | 410              | 479.91                         | 91.27                              | 270           |                                |                               |                                  |                            |
| FISH, SEA-<br>FOOD          | Fish and octopus                                                                                                                            | –                                | 4410                                        | –                           | 138                  | 410              | 1448.04                        | 263.71                             | 270           |                                |                               |                                  |                            |
|                             | Seafood                                                                                                                                     | –                                | 14,850                                      | –                           | 138                  | 410              | 1593.25                        | 263.71                             | 270           |                                |                               |                                  |                            |
| DAIRY                       | Cow milk                                                                                                                                    | 1340                             | 1350                                        | –                           | 84                   | 100              | 364.93                         | 99.37                              | 40            |                                |                               |                                  |                            |
|                             | Cow cheese                                                                                                                                  | 5234                             | 5273                                        | –                           | 765                  | 180              | 370.40                         | 99.37                              | 270           |                                |                               |                                  |                            |
|                             | Cow yogurt                                                                                                                                  | 1675                             | 1688                                        | –                           | 84                   | 100              | 364.93                         | 99.37                              | 270           |                                |                               |                                  |                            |
|                             | Butter                                                                                                                                      | 8584                             | 8648                                        | –                           | 765                  | 90               | 298.96                         | 99.37                              | 270           |                                |                               |                                  |                            |
|                             | Sheep or goat milk                                                                                                                          | 3990                             | 2860                                        | –                           | 84                   | 100              | 364.93                         | 99.37                              | 40            |                                |                               |                                  |                            |
|                             | Sheep or goat cheese                                                                                                                        | 15,586                           | 11,172                                      | –                           | 765                  | 180              | 370.40                         | 99.37                              | 270           |                                |                               |                                  |                            |
|                             | Dairy desserts: chocolate                                                                                                                   | 1675                             | 1688                                        | –                           | 765                  | 180              | 364.93                         | 99.37                              | 270           |                                |                               |                                  |                            |
|                             | cream, cream desserts,<br>crema catalana, ice<br>creams, cakes and<br>prepared flans                                                        |                                  |                                             |                             |                      |                  |                                |                                    |               |                                |                               |                                  |                            |
|                             | Other dairy products:<br>dairy preparations,<br>milkshakes and<br>fermented milk (other),<br>cream, curd, custards,<br>other dairy products | 1340                             | 1350                                        | –                           | 84                   | 100              | 364.93                         | 99.37                              | 270           |                                |                               |                                  |                            |

(continued on next page)

Table A. 3 (continued)

| PRODUCT GROUP AND SUB-GROUP |                                        | Agricultural production          |                                             |                             | Processing<br>(d, e) | Packaging<br>(e) | Commercial transport           |                                    | Retail<br>(e) | Home transport                 |                               | Waste management                 |                            |
|-----------------------------|----------------------------------------|----------------------------------|---------------------------------------------|-----------------------------|----------------------|------------------|--------------------------------|------------------------------------|---------------|--------------------------------|-------------------------------|----------------------------------|----------------------------|
|                             |                                        | Conventional,<br>Spain (a, b, c) | Conventional,<br>International (c,<br>d, e) | Organic,<br>Spain (a,<br>b) |                      |                  | International<br>origin (f, g) | National<br>origin (f,<br>h, i, j) |               | Private<br>transport<br>(k, l) | Public<br>transport<br>(k, l) | Waste<br>generation<br>(m, n, o) | Waste<br>composting<br>(m) |
| PULSES                      | Dry pulses                             | 233                              | 660                                         | 195                         | 0                    | 90               | 508.50                         | 57.43                              | 40            |                                |                               |                                  |                            |
|                             | Preserved pulses                       | 233                              | 660                                         | 195                         | 70                   | 360              | 508.50                         | 57.43                              | 40            |                                |                               |                                  |                            |
| CEREAL                      | Bread                                  | 315                              | 530                                         | 183                         | 208                  | 84               | 603.27                         | 50.35                              | 40            |                                |                               |                                  |                            |
| BASED                       | Flour                                  | 315                              | 530                                         | 183                         | 208                  | 90               | 603.27                         | 50.35                              | 40            |                                |                               |                                  |                            |
| PRODUCTS                    | Dry rice                               | 1660                             | 2660                                        | 2644                        | 59                   | 90               | 615.11                         | 74.18                              | 40            |                                |                               |                                  |                            |
|                             | Preserved or parboiled rice            | 1660                             | 2660                                        | 2644                        | 784                  | 210              | 615.11                         | 74.18                              | 40            |                                |                               |                                  |                            |
|                             | Frozen or prepared rice meals          | 1660                             | 2660                                        | 2644                        | 784                  | 210              | 615.11                         | 74.18                              | 270           |                                |                               |                                  |                            |
|                             | Pasta                                  | 315                              | 530                                         | 183                         | 208                  | 90               | 603.27                         | 50.35                              | 40            |                                |                               |                                  |                            |
|                             | Pizza and puff pastry                  | 315                              | 530                                         | 183                         | 208                  | 180              | 603.27                         | 50.35                              | 270           |                                |                               |                                  |                            |
|                             | Prepared pizza and frozen pasta meals  | 315                              | 530                                         | 183                         | 784                  | 210              | 603.27                         | 50.35                              | 270           |                                |                               |                                  |                            |
| VEGETABLES                  | Fresh potatoes                         | 230.5                            | 470                                         | 166.5                       | 0                    | 45               | 640.82                         | 92.78                              | 40            |                                |                               |                                  |                            |
|                             | Fresh vegetables (other than potatoes) | 230.5                            | 470                                         | 166.5                       | 0                    | 45               | 640.82                         | 92.78                              | 17            |                                |                               |                                  |                            |
|                             | Frozen potatoes                        | 230.5                            | 470                                         | 166.5                       | 70                   | 210              | 640.82                         | 92.78                              | 270           |                                |                               |                                  |                            |
|                             | vegetables and vegetable meals         |                                  |                                             |                             |                      |                  |                                |                                    |               |                                |                               |                                  |                            |
|                             | Preserved or prepared vegetables       | 230.5                            | 470                                         | 166.5                       | 70                   | 210              | 429.59                         | 92.78                              | 40            |                                |                               |                                  |                            |
| FRUITS                      | Citrus                                 | 147                              | 350                                         | 83                          | 0                    | 45               | 1356.98                        | 90.89                              | 17            |                                |                               |                                  |                            |
|                             | Tropical fruits                        | 301                              | 680                                         | 113                         | 0                    | 45               | 1356.98                        | 216.76                             | 17            |                                |                               |                                  |                            |
|                             | Other fruits (fresh)                   | 118                              | 340                                         | 94                          | 0                    | 45               | 1356.98                        | 90.99                              | 17            |                                |                               |                                  |                            |
|                             | Other fruits (processed)               | 118                              | 340                                         | 94                          | 70                   | 210              | 958.69                         | 90.99                              | 17            |                                |                               |                                  |                            |
| DRY FRUITS                  | Dry fruits                             | 972                              | 1420                                        | 955                         | 442                  | 90               | 1082.75                        | 58.40                              | 40            |                                |                               |                                  |                            |
| OLIVE                       | Olive oil                              | 1296                             | 3193                                        | −40                         | 1397                 | 790              | 31.35                          | 62.04                              | 40            |                                |                               |                                  |                            |
| PRODUCTS                    | Olives                                 | 324                              | 798                                         | −10                         | 70                   | 210              | 31.35                          | 62.04                              | 40            |                                |                               |                                  |                            |
| GENERIC                     |                                        |                                  |                                             |                             |                      |                  |                                |                                    |               | 130.00                         | 64.75                         | 118.84                           | −26.00                     |

(\*) Spanish emission factors for pre-and in farm vegetable crops have been calculated assuming that 68% of production corresponds to open-air systems and 32% to greenhouses (Aguilera et al., 2015a).

(\*\*) Emission factors in farm and pre-farm stage have been adapted for the different dairy and olive products based on dry matter and olive content.

**Table A. 4**Origin of imported food in Madrid. Sources: [DataComex \(2019\)](#).

| FOOD GROUPS               | Europe | Africa | America | Asia  | Oceania |
|---------------------------|--------|--------|---------|-------|---------|
| Meat                      | 96.8%  | 0.0%   | 2.4%    | 0.3%  | 0.4%    |
| Eggs and dairy            | 99.9%  | 0%     | 0.0%    | 0.0%  | 0.0%    |
| Fish and seafood          | 30.7%  | 6.6%   | 49.2%   | 13.5% | 0.1%    |
| Cereals                   | 76.2%  | 0.0%   | 23.5%   | 0.3%  | 0.0%    |
| Fruit, legumes and pulses | 57.6%  | 13.7%  | 25.7%   | 2.5%  | 0.1%    |

**Table A. 5**

Average speeds for bike, foot and train

| TRANSPORTATION MODE | Average speed (km/h) | Source                                 |
|---------------------|----------------------|----------------------------------------|
| Bike                | 13.5                 | <a href="#">Ciclismo Urbano (2019)</a> |
| Foot                | 5.3                  | <a href="#">Caminar Más (2019)</a>     |
| Train               | 120                  | <a href="#">Renfe (2019)</a>           |

**Table A. 6**

Survey results. The answers to question one show the number of respondents that declared belonging to each urban garden. Urban gardens with no survey respondents have been removed from the list. In the subsequent blocks, the answers show the average value given to the question using the slide control and the corresponding rate of change with respect to the baseline.

| SEGMENTATION QUESTION                               | ANSWERS |              |
|-----------------------------------------------------|---------|--------------|
| 1. Which garden do you belong to? (*)               |         |              |
| None                                                | 155     |              |
| Adelfas (Retiro)                                    | 4       |              |
| Alegría de la Huerta (Barajas)                      | 2       |              |
| Cantarranas (Moncloa - Aravaca)                     | 1       |              |
| El Campo de la cebada (Centro)                      | 1       |              |
| El Huerto de la Bego (Fuencarral - El Pardo)        | 1       |              |
| El Huerto de La Elipa (Ciudad Lineal)               | 1       |              |
| El Huertuco (San Blas)                              | 5       |              |
| El Tablao de la compostura (Fuencarral - El Pardo)  | 4       |              |
| Esta es una plaza (Centro)                          | 6       |              |
| Huerto Agrofonos (Moncloa - Aravaca)                | 2       |              |
| Huerto Carabanchel Alto (Carabanchel)               | 1       |              |
| Huerto de Batán (Latina)                            | 1       |              |
| Huerto Dehesa (Moncloa - Aravaca)                   | 2       |              |
| Huerto del CIN Montecarmelo (Fuencarral - El Pardo) | 1       |              |
| Huerto del Retiro (Retiro)                          | 11      |              |
| Huerto de Lucero (Latina)                           | 2       |              |
| Huerto La Salamandra (Moratalaz)                    | 3       |              |
| Huerto Pinar (Carabanchel)                          | 1       |              |
| Huerto Villa Rosa (Hortaleza)                       | 1       |              |
| Kybele (Moncloa - Aravaca)                          | 1       |              |
| La Huerta de Tetuán (Tetuán)                        | 1       |              |
| La Regüerta (Tetuán)                                | 1       |              |
| La Sanchita (Arganzuela)                            | 1       |              |
| Solar de Antonio Grilo (Centro)                     | 1       |              |
| Another one (not in the list)                       | 35      |              |
| MOBILITY BEHAVIOUR                                  | ANSWERS | HABIT CHANGE |
| 2. Now you use BICYCLE:                             |         |              |
| Urban gardeners                                     | 52,06   | +4.21%       |
| Control                                             | 45,23   | −9.55%       |
| 3. Now you use CAR OR MOTORBIKE:                    |         |              |
| Urban gardeners                                     | 47,54   | −4.93%       |
| Control                                             | 51,18   | +2.36%       |
| 4. Now you use TRAIN/UNDERGROUND:                   |         |              |
| Urban gardeners                                     | 48,24   | −3.51%       |
| Control                                             | 60,21   | +20.41%      |
| 5. Now you use BUS:                                 |         |              |
| Urban gardeners                                     | 49,09   | −1.83%       |
| Control                                             | 60,55   | +21.11%      |
| 6. Now you use SHARED CAR:                          |         |              |
| Urban gardeners                                     | 44,41   | +11.17%      |
| Control                                             | 44,07   | −11.87%      |

(continued on next page)

Table A. 6 (continued)

| SEGMENTATION QUESTION                                                            | ANSWERS |              |
|----------------------------------------------------------------------------------|---------|--------------|
| <i>DIETARY CHANGE</i>                                                            | ANSWERS | HABIT CHANGE |
| 7. Now you eat COW MEAT:                                                         |         |              |
| Urban gardeners                                                                  | 38,96   | −22.08%      |
| Control                                                                          | 41,75   | −16.50%      |
| 8. Now you eat POULTRY MEAT:                                                     |         |              |
| Urban gardeners                                                                  | 44,18   | −11.65%      |
| Control                                                                          | 53,08   | +6.17%       |
| 9. Now you eat PIG MEAT:                                                         |         |              |
| Urban gardeners                                                                  | 36,90   | −26.20%      |
| Control                                                                          | 43,81   | −12.39%      |
| 10. Now you eat FISH:                                                            |         |              |
| Urban gardeners                                                                  | 46,33   | −7.35%       |
| Control                                                                          | 57,39   | +14.77%      |
| 11. Now you eat DAIRY:                                                           |         |              |
| Urban gardeners                                                                  | 48,53   | −2.95%       |
| Control                                                                          | 49,28   | −1.43%       |
| 12. Now you eat FRUIT, VEGETABLE and PULSES:                                     |         |              |
| Urban gardeners                                                                  | 70,54   | +41.08%      |
| Control                                                                          | 66,29   | +32.58%      |
| 13. Now you consume BAKERY y BOTTLED DRINKS:                                     |         |              |
| Urban gardeners                                                                  | 35,03   | −29.95%      |
| Control                                                                          | 31,64   | −36.72%      |
| CONSUMPTION OF ORGANIC, BULK AND LOCAL PRODUCTS                                  | ANSWERS | HABIT CHANGE |
| 14. Now you consume ORGANIC PRODUCTS:                                            |         |              |
| Urban gardeners                                                                  | 68,63   | +37.25%      |
| Control                                                                          | 50,71   | +1.42%       |
| 15. Now you consume local products from MADRID REGION:                           |         |              |
| Urban gardeners                                                                  | 64,71   | +29.43%      |
| Control                                                                          | 53,43   | +6.86%       |
| 16. Now you consume local products from SPANISH ORIGIN:                          |         |              |
| Urban gardeners                                                                  | 64,48   | +28.95%      |
| Control                                                                          | 59,50   | +19.01%      |
| 17. Now you consume SEASONAL PRODUCTS:                                           |         |              |
| Urban gardeners                                                                  | 70,63   | +41.25%      |
| Control                                                                          | 60,35   | +20.70%      |
| 18. Now you consume BULK PRODUCTS:                                               |         |              |
| Urban gardeners                                                                  | 54,71   | 9.43%        |
| Control                                                                          | 51,92   | 3.85%        |
| <i>WASTE MANAGEMENT</i>                                                          | ANSWERS | HABIT CHANGE |
| 19. Now you compost your ORGANIC RESIDUES:                                       |         |              |
| Urban gardeners                                                                  | 70,35   | +40.69%      |
| Control                                                                          | 52,26   | +4.52%       |
| 20. The amount of waste you produce is now:                                      |         |              |
| Urban gardeners                                                                  | 42,83   | −14.35%      |
| Control                                                                          | 50,10   | +0.20%       |
| PRODUCTS FROM THE COMMUNITARIAN GARDEN                                           | ANSWERS | HABIT CHANGE |
| 22. How much vegetable from the urban garden do you consume on an average month? |         |              |
| Urban gardeners                                                                  | 4,23    | −            |

Table A. 7

Carbon footprint for the different food groups and food chain stages in 2012.

|                               | Farming | Proce-ssing | Packa-ging | Commercial transport | Retail | Sub-total | Home transport | Waste manage-ment | TOTAL  |
|-------------------------------|---------|-------------|------------|----------------------|--------|-----------|----------------|-------------------|--------|
| Eggs and dairy                | 226.1   | 17.8        | 13.8       | 28.6                 | 13.0   | 293.5     | 220.1          | 13.8              | 1543.4 |
| Meat                          | 615.2   | 49.6        | 11.7       | 7.4                  | 14.8   | 698.8     |                |                   |        |
| Fish and seafood              | 189.1   | 4.0         | 4.9        | 29.6                 | 7.8    | 235.4     |                |                   |        |
| Pulses                        | 1.3     | 0.1         | 0.5        | 0.8                  | 0.1    | 2.7       |                |                   |        |
| Cereals                       | 28.4    | 13.4        | 6.7        | 15.6                 | 3.1    | 67.2      |                |                   |        |
| Vegetables                    | 28.3    | 1.5         | 3.1        | 18.3                 | 4.0    | 55.2      |                |                   |        |
| Fruits                        | 22.3    | 0.1         | 1.3        | 39.1                 | 1.9    | 64.7      |                |                   |        |
| Dry fruits and olive products | 16.2    | 14.7        | 8.05       | 1.8                  | 0.6    | 41.3      |                |                   |        |
| TOTAL                         | 1126.9  | 101.1       | 50.1       | 135.42               | 45.1   | 1309.5    | 220.1          | 13.8              | 1692.3 |

**Table A. 8**

Potential change in food related carbon footprint in Madrid City associated to the participation in urban gardens.

|                                                                                 |           |
|---------------------------------------------------------------------------------|-----------|
| Madrid's population (INE, 2017)                                                 | 3,182,981 |
| UG annual GHG reduction (kgCO <sub>2</sub> e/per person)                        | 205.1     |
| Food change GHG mitigation potential in Madrid (kt CO <sub>2</sub> e/year)      | 652.9     |
| Madrid's total GHG emissions in 2016 (kt CO <sub>2</sub> e/year; F2I2 (2018))   | 10,706    |
| Madrid's Industry GHG emissions in 2016 (kt CO <sub>2</sub> e/year; F2I2, 2016) | 608       |

**Table A. 9**

Nitrogen footprint in 2012, and change in nitrogen footprint relative to 2012 (2012 → C 2017 and BL → UG, 2017) and relative to the participation in urban gardens (C → UG). The food group “other products” includes pulses, olive oil, olives and dry fruits. N footprints are calculated based on Leip et al., 2015.

| FOOD GROUPS      | N footprint (%; g N/yr/pc) | N footprint change (g N/yr/pc; %) |               |         |
|------------------|----------------------------|-----------------------------------|---------------|---------|
|                  | 2012                       | 2012 → UG 2017                    | 2012 → C 2017 | C → UG  |
| Cereals          | 7.0%                       | −112.1                            | −158.0        | +45.9   |
| Eggs and dairy   | 26.6%                      | −170.5                            | −82.9         | −87.6   |
| Fish and seafood | 0.5%                       | −6.4                              | +12.8         | −19.1   |
| Fruit            | 2.1%                       | +210.8                            | +167.2        | +43.6   |
| Meat             | 59.2%                      | −2931.4                           | −1434.7       | −1496.7 |
| Vegetables       | 2.1%                       | +206.3                            | +163.7        | +42.7   |
| Other products   | 2.6%                       | +67.4                             | +53.5         | +14.0   |
| TOTAL            | 24,192.1                   | −2735.9                           | −1278.5       | −1457.4 |
| % of change      | −                          | −11.3%                            | −5.3%         | −6.4%   |

**Table A. 10**

Comparison of the estimations in the change of GHGe for the period 2012–2017 using Spanish Panel on Household Consumption (2017 MAPA) (MAPA, 2020) and survey results for the control population (2017 C). These options are assessed using the following combinations of emission factors: Spanish–Various corresponds to the main analysis, based on the selection of emission factors closest to food consumption patterns in Madrid; Spanish–Clune to Spanish emission factors for farm-and pre-farm stages in nationally grown products and Clune et al. (2017) for the rest; Clune–Clune to Clune et al. (2017) factors for all; Spanish–Poore to Spanish emission factors for farm-and pre-farm stages in nationally grown products and Poore and Nemecek (2018) factors for the rest, and Poore–Poore to Poore and Nemecek (2018) factors for all.

|      | 2017 MAPA (kg CO <sub>2</sub> e/yr cap) | 2012→ 2017 MAPA | 2012→ 2017 C  |
|------|-----------------------------------------|-----------------|---------------|
| FCP  | 58.0 (3.4%)                             | 205.1 (12.1%)   | 147.1 (9.0%)  |
| SaC  | 54.8 (3.1%)                             | 203.8 (11.7%)   | 149.0 (8.8%)  |
| Cfa  | 19.7 (1.1%)                             | 141.8 (8.1%)    | 122.1 (7.0%)  |
| SaPN | 158.1 (7.1%)                            | 433.1 (19.3%)   | 275.0 (13.2%) |
| PNfa | 102.3 (3.2%)                            | 333.5 (10.5%)   | 231.2 (7.5%)  |

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