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The Ecological Footprint of Mediterranean cities: Awareness creation and policy implications

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ABSTRACT

The Ecological Footprint is an accounting tool that has been used by resource managers and widely communicated to the public over the last 20 years. The National Footprint Accounts (NFA) are a system of national-level Ecological Footprint accounts that can be geographically scaled to derive Footprint values for major consumption categories at the household level for a given region, province, city or urban agglomeration. A number of city Footprint assessments have been undertaken during the last two decades. However, these studies have used different approaches, rendering comparability challenging. Here we present a top-down approach to consistently track the Ecological Footprint of 19 coastal cities in the Mediterranean region. Valletta, Athens, and Genoa are the cities with the highest per capita Ecological Footprint, ranging between 5.3 and 4.8 gha per person; Tirana, Alexandria and Antalya have the lowest Ecological Footprint, ranging between 2.1 and 2.7 gha per capita. Most cities' Footprints exceed that of their countries with the exception of Thessaloniki, Tel Aviv, Venice, Palermo and Naples. This analysis provides a macro-level indication of the overall resource demands by cities, their drivers and leverage point. The main Footprint drivers are food consumption, transportation and consumption of manufactured goods. Differences among cities' Ecological Footprint values are most likely driven by socio-economic factors, such as disposable income, infrastructure, and cultural habits. City level Footprint findings can be used to help design sustainability policies and positively reinforce collective public achievements so far.

1. Introduction

Decision makers currently face the challenge of navigating through a wealth of disparate information. As sustainability is primarily a trans-disciplinary issue, no single metric exists that is able to independently and solely address the full complexity of sustainability (Galli et al., 2012). Nonetheless, quantitatively assessing and monitoring individual sustainability dimensions (e.g., the environmental pillar) is feasible. This requires a systemic approach, capable of analyzing multiple human pressures through a consistent lens. With known limitations (e.g., Galli et al., 2016; Kitzes et al., 2009), Ecological Footprint Accounting (EFA) has been used as a first approximation of the overall human pressure on Earth's ecosystems (Galli 2015a; Lin et al., 2015; Wackernagel et al., 2014).

The Ecological Footprint (EF) is a biomass-based resource accounting tool, which aims to track human demand for, and nature's supply of, key resource provisioning and one critical regulating ecosystem service (Wackernagel et al., 1996; Galli et al., 2014). The main contribution of this accounting tool is in providing a benchmark to compare the demand humans place on the ecosystems and in its applicability at scales ranging from single products to the world as a whole (Kitzes et al., 2009). This in turn allows users to understand resource demand at local scales while gaining insights on how it relates back to the global sustainability challenge.

The most complete, robust, and consistent applications of the Ecological Footprint so far are national-scale assessments, which are known as National Footprint Accounts (NFAs) (Kitzes et al., 2009). NFAs are annually provided by Global Footprint Network for approximately 160 countries, as well as global totals, for a period of approximately 5 decades. The first systematic attempt at their calculation was performed in 1997 by Wackernagel and colleagues

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(Wackernagel et al., 1997) but only in 2003 Global Footprint Network initiated its National Footprint Accounts (NFAs) program.

Besides providing information on natural capital and ecosystem accounting (Lin et al., 2015; Wackernagel et al., 2014), these national-level accounts can be geographically scaled to derive the EF for major consumption categories at the household level for a given region, province, city or urban agglomeration. The regionally scaled EF has been particularly popular in countries such as Switzerland, Germany, USA, Canada and UK (e.g., Collins et al., 2015; Collins and Flynn, 2015; von Stokar et al., 2006. See also Bastianoni et al., 2013; Galli, 2015b, and Vale and Vale, 2013, for overviews of national Ecological Footprint applications).

The world population is foreseen to reach 9 billion by 2050, 67% of which is expected to live in urban areas (up from 46% in 2015) (FAOSTAT, 2016); at the same time, per capita income is also predicted to increase (FAO, 2009). Urbanization's direct impact results from obvious changes in land use (Angel et al., 2005), but indirect and interlinked impacts exist as well. For instance, climate change and urbanization are ultimately linked as suggested by the unprecedented role cities took at the 2015 Climate COP in Paris. The International Energy Agency (IEA) estimates that 71% of energy-related global greenhouse gases can be assigned to cities (Hoornweg et al., 2011), and this proportion is expected to reach 76% by 2030. These rapid changes imply an increase in resource consumption so that it is expected that food production will increase by 70% between 2005 and 2050 (FAO, 2009), and become more energy demanding due to the intensification of agricultural practices (Bi et al., 2011). Urbanization will also have indirect effects resulting from changes in consumption caused by increasing affluence (Myers and Kent, 2003).

By contrast, cities offer economic opportunities (e.g., employment) as they generate 80% of the world GDP (World Bank, 2015). Further, urban areas offer genuine occasions that influence many sectors simultaneously, known as sustainability multipliers (Wackernagel et al., 2006). For example, taxes imposed on vehicles, on a mileage basis, create direct and indirect benefits at different scales: they reduce congestion, improve air quality, and promote public health, reduce fossil fuel use, and create more employment in public transit. Urban areas also offer opportunities for an economy of scale due to the proximity of the many diverse activities (Moore et al., 2013; Rees, 1997). On the other side, the protection of resident's future well-being requires paying more attention to cities, because they depend on ecosystem services to sustain life, health, security, good social relation, and other important aspects of human well-being (Escobedo et al., 2011; Groenewegen et al., 2006; Cummins and Jackson 2001; Nowak et al., 1998). The loss of ecosystems and their services, also within cities, is likely to cause serious impact on several scales (Gómez-Baggethun and Barton, 2013). For instance, the increasing pressure to produce more food is a critical issue, mainly through the loss of bio-productive land because of urbanization and the impacts of climate change (Godfray and Charles, 2011).

While urbanization is among the major challenges of the next decades, sustainable planning and resource management in cities also represent an opportunity to favor a global sustainability transition (Pearson, 2013). As such, creating effective polices requires meaningful urban metrics based on a quantitative understanding of cities (Bettencourt et al., 2010).

The Mediterranean region has been facing an ecological deficit since the 1960s (Galli et al., 2015) and has witnessed an increased urbanization, especially in coastal areas where more than half of the Mediterranean population lives. The objective of this paper is thus to demonstrate that a top-down EF city analysis can effectively analyze, in a consistent and comparable manner, the resource demand of cities located across the Mediterranean (see Fig. 1), and shed light on these cities' contribution to the regional ecological deficit. A review of existing city-level Ecological Footprint applications is first provided in Section 2; Section 3 then lists the cities analyzed in this study and describes the top-down Footprint methodology used. Results are then presented (Section 4) and their policy implications discussed (Section 5) in light of policies currently in place in these cities. Section 6 provides the study's final conclusions.

2. Review of existing city's Ecological Footprint assessments

Under the adage "think globally, act locally", city level sustainability analyses have proliferated over the past decades (see Table 1). Several city networks have emerged, primarily focusing on efficient and renewable energy carriers (for post carbon cities) as well as climate resilience, recycling and resource management, and sustainable mobility. While the objectives and long term vision of these networks are clear, proper benchmarking and monitoring tools are yet to be identified. In an attempt to provide such tools, a number of city Footprint assessments have been performed since the late '1990s (see for instance Bastianoni et al., 2013; Collins and Flynn, 2015; Galli, 2015b) contributing to the spreading of this indicator. Such assessments had been primarily motivated by local administrators' and planners' interest in understanding the link between local consumption and global

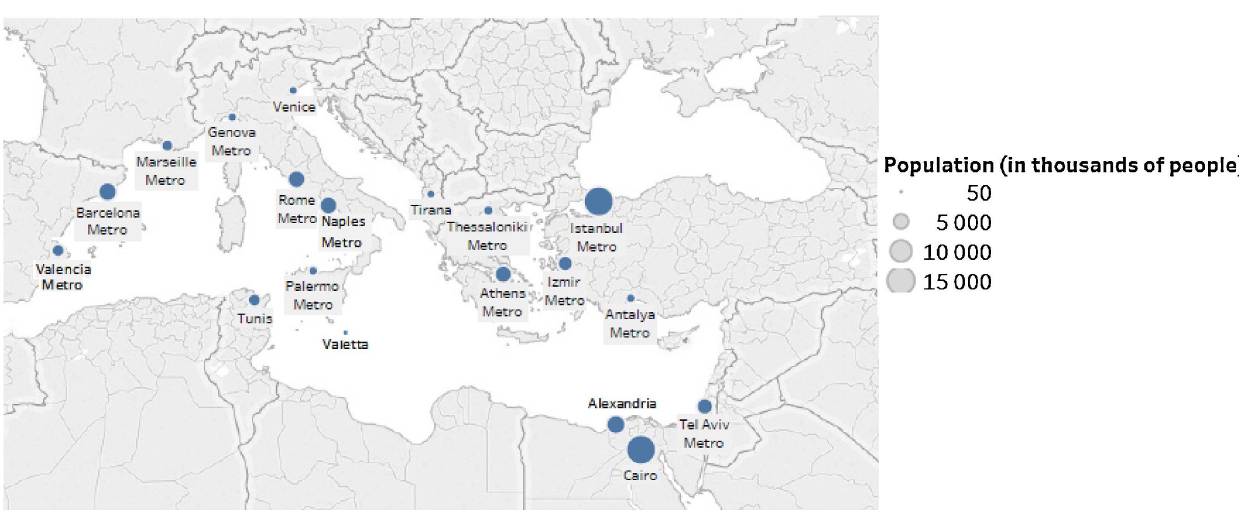

Fig. 1. Geographic location and total population of the Mediterranean cities analyzed in this study (2015 data).

Table 1
Overview of the main city level Ecological Footprint applications conducted as of today. Year means the year the EF value refers to.

Country	City	Methodology	Year	City Footprint value (gha)	Reference
Australia	Sydney	Top-down	2001	5.92 (ha)	(Lenzen, 2008)
Brazil	Curitiba	Top-down	2009	2.6	(Global Footprint Network, 2010)
Canada	Calgary	Top-down	2001	9.86	(Wilson and Anielski, 2005)
	Calgary	Bottom-up	2007	9.5–9.9	(Global Footprint Network, 2007)
	Edmonton	Top-down	2001	9.45	(Wilson and Anielski, 2005)
	Edmonton	Top-down	2008	8.56	(Anielski, 2010)
	Québec City	Top-down	2001	6.89	(Wilson and Anielski, 2005)
	Toronto	Top-down	2001	7.36	(Wilson and Anielski, 2005)
	Vancouver	Bottom-up	2006	4.7	(Moore et al., 2013)
	Vancouver	Top-down	2001	7.71	(Wilson and Anielski, 2005)
Chile	Santiago de Chile	Top-Down	1998	2.6	(Wackernagel, 1998)
China	Chongqing	Top-down	2009	2.2	(WWF, 2012)
	Hong Kong	Top-down	2008	4.3	(Global Footprint Network and WWF, 2013)
	Shanghai	Top-down	2009	3.8	(WWF, 2012)
	Shenyang	Bottom-up	2009	1.8	(Geng et al., 2014)
	Tianjin	Top-down	2009	2.7	(WWF, 2012)
Ecuador	Quito	Top-down	2006	2.4	(Moore and Stechbart, 2010)
Iran	Isfahan	Bottom-up	2007	1.22	(Shayesteh et al., 2015)
	Tehran	Bottom-up	2005	3.79	(Tavallai and Sasanpour, 2009)
Israel	Beer-Sheva	Bottom-up	2007	3.98	(Zeev et al., 2014)
	Ra'anana	Bottom-up	2002	4.0	(Kissinger and Haim, 2008)
Italy	Piacenza	Bottom-up	2002	3.79	(Scotti et al., 2009)
	Siena (and its Province)	Bottom-up	1999	5.80	(Bagliani et al., 2008)
Japan	Kawasaki	Bottom-up	2009	5.1	(Geng et al., 2014)
Norway	Oslo	Bottom-up	2000	7.76	(Aall and Norland, 2002)
Philippines	Manila	Top-down	2009	1.82	(Global Footprint Network and Laguna Lake Development Authority, 2013)
Spain	Barcelona	Bottom-up	1996	3.23	(Relea and Prat, 1998)
United Kingdom	Birmingham	Top-down	2007	5.22	(Calcott and Bull, 2007)
	Bradford		2007	5.21	
	Bristol		2007	5.22	
	Cardiff		2007	5.20	
	Cardiff	Top-down	2001	5.5	(Collins et al., 2006)
	Edinburgh	Top-down	2007	5.76	(Calcott and Bull, 2007)
	Glasgow	Top-down	2007	5.21	
	Greater Nottingham	Bottom-up	2003	5.27	(Birch et al., 2005)
	Liverpool	Top-down	2007	5.25	(Calcott and Bull, 2007)
	London		2007	5.48	
	Manchester		2007	5.36	
	Newport		2007	5.01	
	Nottingham		2007	5.26	
	Plymouth		2007	5.01	
	Winchester		2007	6.52	
	York	Bottom-up	2000	6.98	(Barrett et al., 2002)
USA	San Francisco	Top-down	2007	7.1	(Moore, 2011)

Note: Footprint results for the cities of Barcelona, Ra'anana and York are expressed in hectares rather than global hectares. The study of Siena also includes the Footprint of the other 35 municipalities belonging to the Provincial administration.

environmental impact (Collins and Flynn, 2015). However, these studies have used different approaches, surveys and methods, rendering comparability among studies challenging.

Usually EF applications fit within two main approaches: Top-Down (compound) or Bottom-Up (component) (Moore et al., 2013; Wilson and Grant, 2009). The top-down approach uses national data – including production, import and export data – to calculate a nation's Footprint, which is then broken down by consumption categories via monetary multi-regional input-output (MRIO) tables (Ewing et al., 2012; see also Section 3.2) or actual materials and energy flows (process based) and subsequently scaled to the city level by means of household expenditure survey data. This approach could allow comparing the EF of many diverse cities across countries, but – prior to this study – it has only been used for single-city assessments such as in Calgary, Manila, San Francisco and Quito (see Table 1). Conversely, the bottom-up approach avoids calculating the National Footprint value and directly uses city-level data – either local monetary input-output tables or physical flows of materials and energy – to calculate the city Footprint value. This latter method has been applied in cities like Cardiff, Kawasaki, Shenyang, Vancouver and York (Table 1); it allows better representing the local situation and it is easily understood and accepted by local authorities (Moore et al., 2013). However, this bottom-up approach is resource and data intensive, often requires longer execution time due to data unavailability, and does not easily allow comparing cities across different countries due to different data sources and assumptions within the calculation.

3. Materials and method

3.1. Study area and source of data

The Mediterranean region is considered here to cover countries of Southern Europe, Middle East and North Africa that directly border the Mediterranean Sea. Dense interactions between all corners and early integration among Mediterranean civilizations contributed to the region's great landscape, cultural diversity and attractiveness. About 220 million tourists visit the region every year and, alongside the Mediterranean residents, they put the Mediterranean's ecological assets under high pressure, thus contributing to resource overexploitation: overfishing, intensive agriculture, forest degradation, and water shortage (WWF, 2015). From a Footprint viewpoint, the region has been characterized by

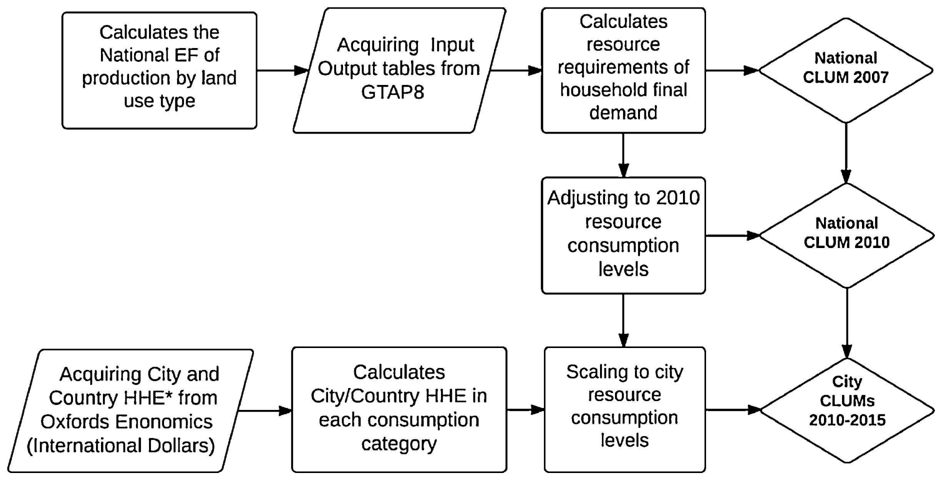

Fig. 2. Top-down (MRIO-based) Ecological Footprint approach – Calculation Steps.

an ecological deficit since 1961 (Galli et al., 2015). During the period 1961–2010, per capita biocapacity decreased by 21%, while the Ecological Footprint of an average Mediterranean resident increased by 54%. During this period, the regional population has also increased (+102%) causing an overall increase in the total regional Footprint by approximately 211%. As a result, the region depends on external biocapacity to meets 30% of his demand for biomass-based resources (Galli et al., 2015).

The research presented in this paper sets out to assess the Ecological Footprint of major Mediterranean coastal cities, as more than half of the regional population lives on the coasts. However, availability and quality of the three datasets used in the calculation (see below) limited the selection to the 19 coastal cities for which reliable data was available: Alexandria, Antalya, Athens, Barcelona, Cairo, Genoa, Istanbul, Izmir, Marseille, Naples, Palermo, Rome, Tel Aviv, Thessaloniki, Tirana, Tunis, Valencia, Valletta, and Venice (Fig. 1).

Data used in our analysis are National Footprint Accounts (NFA) 2014 edition (Global Footprint Network, 2014), Input-Output tables from the GTAP 8 MRIO model (GTAP, 2014), and annual household expenditure (HHE), for the years 2010–2015. HHE data is obtained from Oxford Economics (2015), which is published in international dollars (Purchasing Power Parities,[1] US$ PPP) and it is classified by Classification of Individual Consumption According to Purpose (COICOP)[2] category. As HHE data in US$ at PPP for the city of Venice was not available, expenditure data expressed in Euro was used for this city and adjusted according to the price differences between this city and Italy. Price data were drawn from Numbeo (2015).

3.2. Method

Ecological Footprint Accounting tracks demand for biologically productive land and water areas to produce the natural resources and ecological services that humans consume, and it compares this demand with the biosphere supply of such resources and services (Borucke et al., 2013). Both demand and supply for productive areas are expressed in hectare-equivalent units (or global hectares – gha), which represent hectares with world average biological productivity (Galli, 2015a). In order to estimate each city's Ecological Footprint, a multi-step process – which starts by calculating the Footprint of the hosting country – was used, as summarized in Fig. 2.

To calculate a country's Ecological Footprint of consumption, National Footprint Accounts (Borucke et al., 2013) were used to calculate the Ecological Footprint of production activities within that country. The Ecological Footprint embedded in trade flows as well as the indirect resource requirements throughout the supply chain were calculated by means of Multi-Regional Input-Output (MRIO) modeling (Ewing et al., 2012; Weinzettel et al., 2014) and used to derive the national Ecological Footprint of consumption. We used Input-Output tables from GTAP 8, which consist of 57 sectors and cover 129 countries and regions, for the year 2007 (Narayanan et al., 2012)

To estimate the national Ecological Footprint of consumption by means of such Ecological-Footprint-Extended Multi-Regional Input-Output analysis (EF-MRIO), six environmental extension tables are required, which initially allocate the Ecological Footprint of production for crop-, grazing-, forest-, built-up and carbon-uptake land as well fishing grounds to each of the 57 economic sectors identified by GTAP. Except for carbon-uptake- and built-up land, the Ecological Footprint of production is used to allocate the resource demand of each economic sector. For the carbon-uptake land, the CO_2 sector intensity data from the energy-environmental extension of GTAP is applied. Built-up land is assigned to each sector depending on that sector's share of value added to a country's GDP (further details on the EF-MRIO analysis can be found in Galli et al., 2017 and Weinzettel et al., 2014).

The key equation for calculating a country's Ecological Footprint of consumption through MRIO analysis is:

$$EF_N = F\,(I\text{-}A)^{-1}\,y_N \quad (1)$$

where EF_N is a country's Ecological Footprint embodied in total national final demand for biomass products y_N; F is the environmental extension matrix derived from the Ecological Footprint of production; I is the identity matrix and A is the technical coefficients matrix, which reflects the monetary exchange between each sector in order to produce one currency unit worth of output from a specific sector of the economy. Together $(I\text{-}A)^{-1}$ represents the Leontief inverse, which gives the total output from each sector for one unit of final demand from a specific sector.

[1] The US$ PPP is defined as the number of "dollars that are needed to buy a dollar's worth of goods in the country as compared to the United States" (World Bank).

[2] COICOP stands for Classification Of Individual Consumption According to Purpose and is the internationally agreed classification system for reporting household consumption expenditures. It is published by the United Nation Statistics Division for use in Expenditures Classification, National Accounts, Household Budget Survey and the Consumer Price Index.

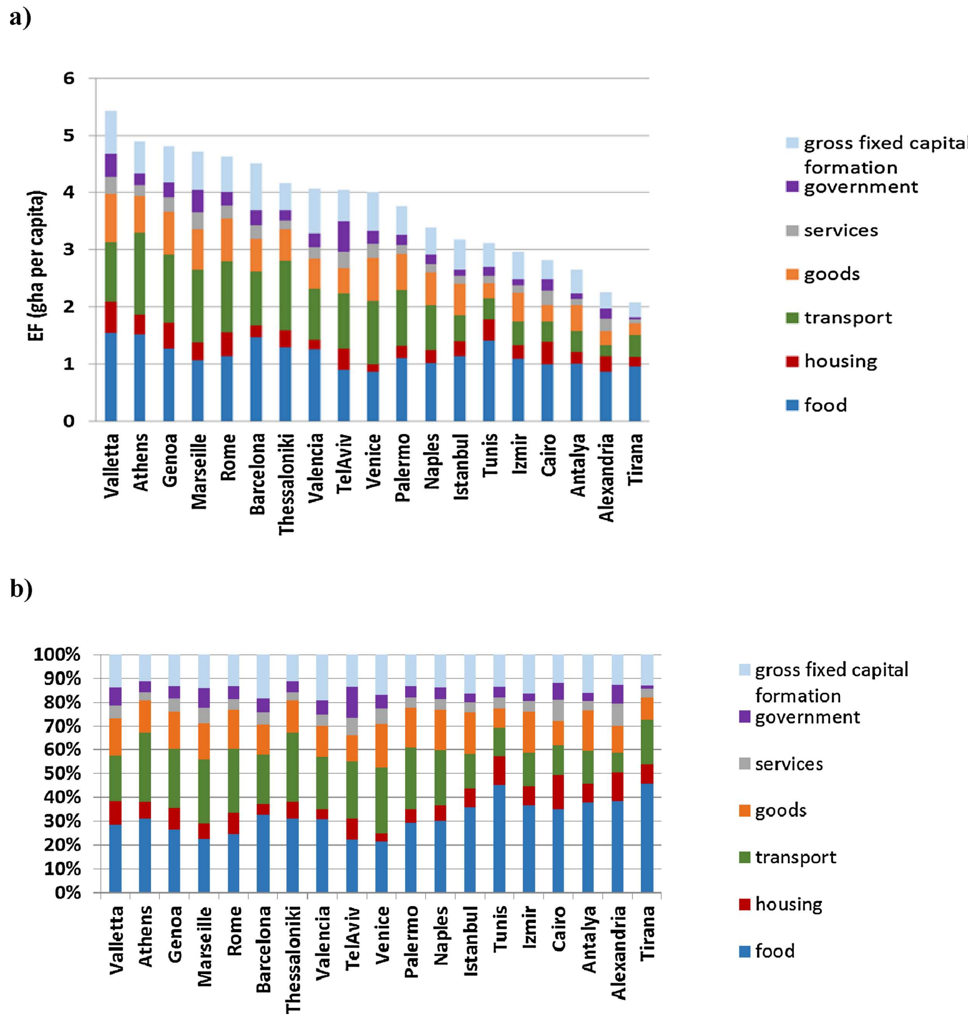

Fig. 3. a) Rank of per capita EF of cities by consumpton category in 2015; b): Percentage contribution of each category of consumption to the total Footprint.

Therewith equation 1 accounts for all indirect/upstream resource requirements from final consumption (Weinzettel et al., 2011, 2014) and the EF-MRIO model provides the resource requirements of each sector in the national economy.

Subsequently, national household resource requirements are calculated by analyzing the composition of household final demand for goods and services by COICOP consumption categories, such as food or transport. To allocate Footprint values to final consumption categories we follow the methodology proposed by Wiedmann et al. (2006). Different goods and services are produced with varying inputs from the different economic sectors in the economy. The household demand matrix (concordance table) assigns to each consumption category the respective amount of resource requirements by sector and allows for policy analysis together with household expenditure data (Biesiot and Noorman, 1999; Wiedmann et al., 2006). We refer to the household's resource requirements by land type for each consumption category as Consumption Land-Use Matrix (CLUM).

As GTAP 8 provides input-output data for the year 2007, each national CLUM represents the average national household resource demand in the year 2007. Such CLUM is then adjusted to represent resource consumption requirements in the year 2010 by means of Ecological Footprint of consumption data drawn from the National Footprint Accounts. We assume that the structure of the economy (e.g., the energy intensity of produced goods) and share of income spent on housing or food does not drastically change over a 3-year period (between 2007 and 2010).

The ratio between city-level and national-level per capita household expenditures (HHE) drawn from Oxford Economics (2015) was then used as a scaling factor to derive the household's Ecological Footprint of consumption of each city from the Ecological Footprint of consumption of the corresponding hosting country (Wiedmann et al., 2006). To get comparable expenditures, differences in price level among cities and countries were accounted for by using household expenditure data expressed in international dollars at Purchasing Power Parities (PPP).[3] A detailed description of the methodology used by Oxford Economics in compiling household data can be found in (Oxford Economics, 2014). Time series HHE data was used to calculate cities' CLUMs for the period 2010–2015. The Ecological Footprint of government consumption was scaled by the ratio of total expenditures in the country and total expenditures in the city, while the gross fixed capital formation (GFCF) was scaled by comparing cities' and countries' expenditures for household furnishings, equipment and maintenance.

[3] Oxford Economics uses data from the International Monetary Fund to convert consumer spending data in each country and currency to PPP equivalents (Oxford Economics, 2014). For Venice, the city expenditure data was adjusted by means of consumer price index (CPI) data for this city and its hosting country (i.e., Italy).

3.3. Strengths and weaknesses of the method

Strengths and weaknesses of national-level EF-MRIO analyses have been extensively discussed in the academic literature (see for instance Kitzes, 2013; Weinzettel et al., 2014) and thus addressing them is beyond the scope of this paper. However, a few of such strengths and weaknesses deserve to be highlighted as they likely affect city level Footprint applications. On the weaknesses side, EF-MRIO analyses suffer from the potential low resolution of input-output tables and the homogeneity assumption, because of which 1$ of products purchased by a final consumers from a sector such as *Bovine cattle, sheep and goats, horses*[4] is considered to have the identical embodied environmental impact irrespective of the fact that what is being purchased is a sheep or a goat product. As pointed out by Kitzes (2013), the extent of this weakness depends on the resolution (i.e., the number of sectors) of the MRIO model used (see Hertwich and Peters, 2010; Owen et al., 2014; Wiedmann, 2009, for a comparison of the most commonly used MRIO models and their resolution). Moreover, the accuracy of cross-national city analysis is likely to be limited by disparities in the collection and standardization of raw input-output data in the different nations.

However, EF-MRIO analyses 1) are useful in allowing for a rapid evaluation of the upstream environmental impacts associated with downstream economic consumption, and 2) allow comparability across cities, which would otherwise be impossible to obtain through bottom-up urban-metabolism-based approaches. As such, future research aiming at developing international urban Ecological Footprint standards should be directed, in our opinion, towards a hybridization of MRIO and urban metabolism approaches. Only a few case studies exist, to our knowledge, in which both methods have been used to assess the Footprint of the same city or sub-national authority (e.g., Global Footprint Network and University of Sydney, 2005) revealing a tendency of the MRIO-based approach to provide lower Footprint values than the urban metabolism one.

4. Results

Here we first present the results of the Footprint analysis for the 19 cities (section 4.1) and then investigate the factors affecting these values (see Section 4.2).

4.1. Ecological Footprint analysis

The Footprint of each city is first presented for the year 2015 (sections 4.1.1 and 4.1.2) and then for the period 2010–2015 (section 4.1.3). The comparison between each city and its hosting country is also analyzed (sections 4.1.4 and 4.1.5).

4.1.1. Ecological Footprint by consumption categories (in 2015)

Per capita Ecological Footprint (EF) varies among cities, even within the same country. Looking at the year 2015, Valetta, Athens, Genoa, Marseille, Roma and Barcelona are the cities with the highest per capita Ecological Footprint, ranging from 4.52 for Barcelona to 5.43 for Valletta. Conversely, Tirana, Alexandria, Antalya, Cairo, Izmir and Tunis have the lowest Ecological Footprint, ranging from 2.08 for Tirana to 3.12 for Tunis (see Fig. 3a). Cities located in Europe tend to have a higher EF than cities located in North Africa and cities with higher income levels show higher EFs due to heavier demand for resources (Wackernagel et al., 2013).

The largest Footprint category is food and its share tends to increase in cities with low EF values. Food contributes, on average, to approximately 40% of the total EF for the bottom five cities while it contributes to only about 27% for the top five cities (see Fig. 3b). The share of food in the total EF of Tunis and Tirana is nearly 46%.

The second largest category is personal transportation: it includes the use of private vehicles and public transport and represents on average about 14% of the total EF in cities with lower EF values and nearly 25% in cities with the largest Footprint. The share of transportation in the total EF of Athens and Thessaloniki is nearly 30%.

The third largest EF category is the consumption of goods, which includes clothing, furniture, electronics and books among others, ranging between 12% and 15% for cities with smaller and larger EF, respectively. However, in Cairo, housing (including rent, air conditioning, heating, and water) represents the second largest Footprint category, while it represents the third largest Footprint category in Tunis. Housing represents 10% for the cities with lower EF, while it is nearly 8% in cities with higher EF values. Services (including medical services, education and eating out) are also rather similar, approximately 5% for both the bottom and top five cities by overall EF ranking.

Apart from the resource demands by households, resources are also demanded by industries in the form of gross fixed capital formation; this represents resources required by companies for investments and contributes on average to 14% of the total city's EF. The public sector also places a demand on resources, which is associated with government activities and is about 4% in the bottom five and 6% in the top five cities.

4.1.2. Ecological Footprint by land use types (in 2015)

Cities' EF values by land-use type show that the largest component is the carbon Footprint. This component accounts for more than half of Tel Aviv's EF, and for nearly half the EF of Rome, Palermo, Genoa, Naples, Athens and Valletta. However, noticeable variability can be found in this Footprint component, with per capita carbon Footprint values ranging from 0.73 gha in Tirana, to 2.77 gha in Valletta. To a large extent, the carbon Footprint represents the energy intensity of goods and services consumed. Wealthier households consume more energy intensive goods and have better access to transportation, which drives their carbon Footprint. The cropland Footprint is the second largest single component and its value within cities' overall Footprint has a narrower range, from approximately 0.8 gha per person in Valletta and Tel Aviv to nearly 1.3 gha in Barcelona (see Fig. 4). The overall demand for cropland is similar between the cities since resource demands from cropland are the least income sensitive. Food is a basic need and also households with lower incomes have to buy food: in these cities, a higher share of their overall resource demands is dedicated to cropland compared to wealthier households, where the carbon Footprint is the biggest component in demand.

4.1.3. Cities Ecological Footprint over time (2010–2015)

EF values through time were found stable for most cities (Fig. 5). Barcelona's Footprint over the period 2010–2015 was almost constant, with an average of 4.5 gha per capita. Valetta showed the most noticeable increase over time, from 5.32 to 5.43 (+2%). Athens, Naples and Valencia also had increasing trends. Conversely, Rome, Palermo, Istanbul, Antalya, Tirana and Thessaloniki had a slight decrease. An open question remains: Are these decreases the result of dedicated policy implementations or merely a reflection of reduced economic activity? Most major Mediterranean cities are committing themselves to transitioning to a "green economy" that encourages sustainable consumption and production: for instance

[4] See Galli et al., 2017 for a full list of the sectors considered in the GTAP8 model.

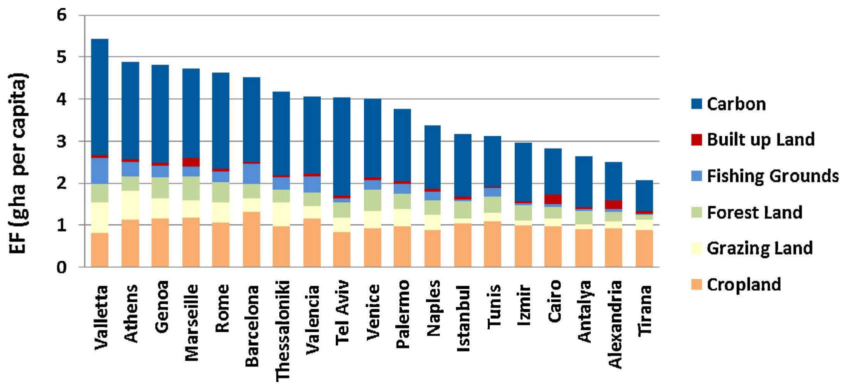

Fig. 4. Mediterranean Cities' EF values by land-use types, in 2015.

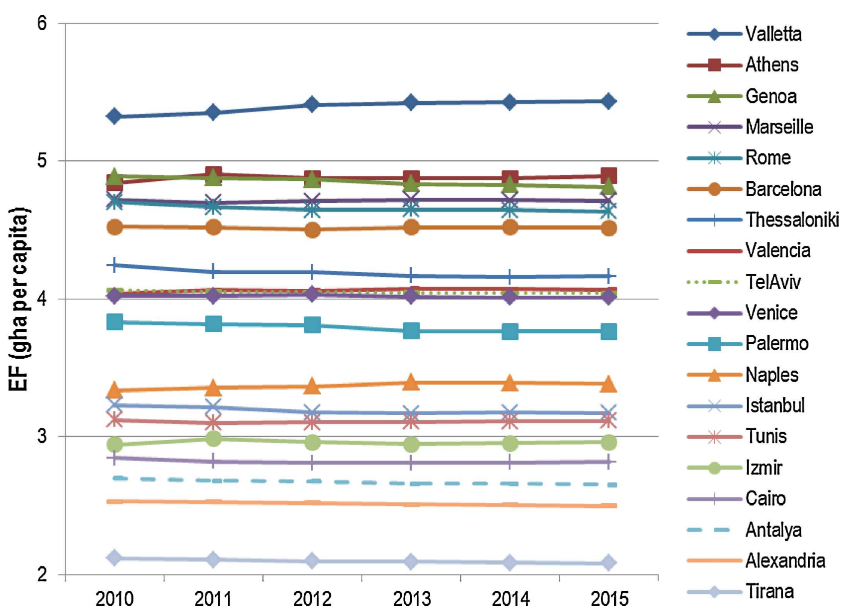

Fig. 5. Ecological Footprint of cities over the period 2010–2015.

the Med Cities Network and the CAT-MED[5] platform promote awareness of urban sustainable development including strategies for citizen's sustainable consumption.

4.1.4. Deviation between the city and the country Footprints

Most cities were found to have a per capita EF higher than that of their hosting country, except for Thessaloniki, Tel Aviv, Venice, Palermo and Naples (Fig. 6): the EF of Tunis is higher than that of Tunisia by 1.29 gha per capita (+70%); Istanbul's per capita EF is 0.67 gha higher than that of Turkey (+26%); Valetta's EF is 0.89 gha per capita higher (+20%) than the average of Malta. The money spent (HHE) has a direct impact on the resources being consumed (EF). Thus, most cities boost consumption levels as urban citizens tend to consume more than the country average.

These large deviations are possibly due to tourism differences. However, in the current Footprint methodology, it is not possible to differentiate residential consumption from tourist consumption[6] (Kitzes et al., 2009).

On the other end, the southern Italian cities of Naples and Palermo have EF values substantially smaller than the average Italian Footprint, which could be due to their worse-off economic situation or idiosyncrasies, e.g., black market, a form of revenue generation and consumer spending that evades statistics. Also, resources utilization is better optimized in Tel Aviv and Thessaloniki as consumption and spending are higher at national level. Household expenditure data of the city and the country has a greater deviation trend (Fig. 6) than EF values.

4.1.5. Total city Footprints

When the population factor is taken into account, the Mediterranean city with the highest total Ecological Footprint is Istanbul, followed by Cairo, Barcelona and Rome. Moreover, in comparing cities' EF with that of the hosting country, Tel Aviv metropolitan area was found to account for 43% of Israel's entire

[5] See for more information the web sites of this projects http://www.medcities.org/fr/ – http://www.catmed.eu/index.php?idioma=fr – http://www.agroenvironmed.eu/.

[6] According to Kitzes et al. (2009), tourism is considered an export sector of the economy and it is not allocated to the home country of tourists due to the lack of an international data about tourist travels.

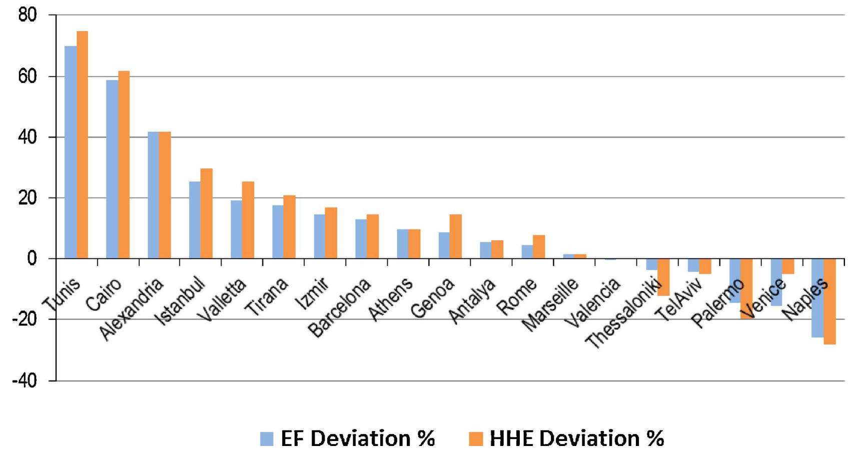

Fig. 6. Deviation of city EF from country EF considering only the household consumption categories (for 2010). Note: year 2010 is investigated here as this is the latest year for which both city and country level EF results are available.

Table 2
Percentage contribution of each city's EF to its hosting country's EF (for 2010). Population data provided by Oxford Economics.

Country	Income level	City	Population	Country EF tot	City EF tot	City EF/Country EF
–		–	[1000 people]	[gha]	[gha]	[%]
Albania	Upper-middle-income	Tirana	729	5,736,353	1,543,962	27%
Egypt	Lower-middle-income	Alexandria	4630	145,494,646	11,729,404	8%
		Cairo	12,835		36,547,850	25%
France	High-income	Marseille	1643	292,284,405	7,757,256	3%
Greece	High-income	Athens	4020	50,136,069	19,460,961	39%
		Thessaloniki	1155		4,903,016	10%
Israel	High-income	Tel Aviv	3311	31,603,685	13,452,595	43%
Italy	High-income	Genoa	905	273,849,582	4,423,274	2%
		Naples	4400		14,689,601	5%
		Palermo	960		3,677,824	1%
		Rome	4173		19,621,650	7%
		Venice	844		3,393,771	1%
Malta	High-income	Valletta	80	1,847,470	427,361	23%
Spain	High-income	Barcelona	4721	186,406,675	21,362,451	11%
		Valencia	1852		7,477,595	4%
Tunisia	Upper-middle-income	Tunis	1916	19,198,435	5,983,579	31%
Turkey	Upper-middle-income	Antalya	897	186,183,201	2,420,393	1%
		Istanbul	13,017		42,071,596	23%
		Izmir	2813		8,275,354	4%

Ecological Footprint, Athens metropolitan area for 39% of Greece's, and Tunis for 31% of Tunisia's. At the opposite end, Marseille accounts for only about 3% of France's Ecological Footprint and Antalya for just 1% of Turkey's (see Table 2). This result is mostly driven by the urbanization structure of a country. In countries with few megacities the resource consumption will concentrate there and will impact the countries resource consumption the most. In countries with a more evenly spread level of urbanization the resource consumption will be less concentrated and localized policies will likely have smaller effects.

4.2. Factors influencing the Ecological Footprint

The EF for each consumption category increases with income, but the shape of this relationship is different from one category to another. The EF of housing, personal transportation, and services show a higher degree of correlation with expenditures than the other consumption categories. Two noticeable insights are shown in Fig. 7 and Table 3.

First, spending for food is strongly linked to the Ecological Footprint. Regression analysis shows that a 1% increase in food

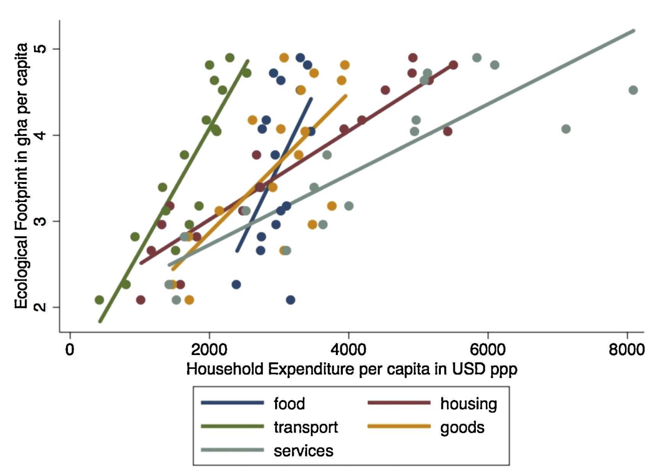

Fig. 7. Each point represents one observation and the line represents the relationship between the specific expense and the Ecological Footprint. Valetta was removed from the analysis since it represents an outlier.

Table 3
Ordinary Least Squares Regression, all variables are in logs and the sample size is 17 observations. Valetta was removed from the analysis since it represents an outlier.

variable	coefficient	robust std. err.	t-value	significant at	r-squared
food	1.40	0.47	2.96	1%	0.25
housing	0.42	0.05	8.74	1%	0.86
goods	0.64	0.12	5.33	1%	0.53
services	0.46	0.06	8.25	1%	0.81
transport	0.52	0.07	7.36	1%	0.76

expenditure is followed by a 1.4% increase in the Ecological Footprint (see coefficients in Table 3). This result is partially due to food making up for the biggest part of the resource requirements for households as it represents a basic need. Second, all other consumption categories show elasticity below 1% (see coefficients Table 3). This implies, for instance, that an increase in expenses on services by 1% is followed by an increase in the EF by 0.46%. Expenses on services, transport and housing are higher in wealthier households and are not a basic need. Therefore they are less EF intensive (coefficient below 1) but they explain most of the increase in the EF (see high values of r-squared Table 3). Food expenses are rather static and higher income typically results in an increase in food quality, but not quantity (see observations for food in Fig. 7). Poorer households may increase meat consumption by switching carbohydrate intensive foods with protein intensive foods. Wealthier households may only increase quality as the budget for food increases.

Fig. 7 also shows that most households spent between 2000 and 4000 dollars (at purchasing power parity) per year per person on food but some cause an EF of 2 gha and others resource requirements of almost 5 gha. Although focusing on the national level, a recent study by Galli et al. (2017) has shown that shifting to calories-adequate diets or changes in consumers' dietary preferences (towards less meat and more cereals and vegetables) could allow a 8%-10% reduction in the ecological deficit of the Mediterranean region. Nevertheless intervening in dietary habits is difficult as it is also culturally driven.

Transport expenses show a medium elasticity (transport is not a basic need), an increase in 1% is followed by a rise in EF by 0.52% and they also explain a large part of the change in EF (see coefficient and r-squared in Table 3). Different to food, the Footprint intensity of transport expenses depends strongly on public services and therewith policies. A good functioning public transport network can help to reduce resource requirements (mostly carbon Footprint) for transport services as it enables households to depend less on private cars. As households get wealthier, the number of cars usually goes up dramatically, which explains the steep slope of the regression line for transport in Fig. 7.

Expenses on housing and services are showing the smallest impact on the EF in this analysis with coefficients of 0.42 and 0.46 (see Table 3). An increase in expenses by 1% has the smallest impact on the EF as it is usually due to increased consumption in luxury services, not necessarily associated with a higher EF intensity. Services such as education, insurance or medical assistance can vary largely in cost and EF intensity, which is also clear when looking at the spread of observations in Fig. 7. Especially in the case of housing, the government can intervene by implementing policies to improve energy efficiency of housing.

5. Discussion & policy implication

The increasing concentration of people in cities represents both opportunities and challenges in the future (Moavenzadeh et al., 2002) due to the concentration of power and influence. In our study, 13 out of the 19 analyzed cities have a per capita Ecological Footprint larger than their hosting country, which suggests that the resource requirements in urban areas are generally higher than in rural areas. Some disparities can be found in cities in the same country: for instance, a resident in Naples and Palermo has a lower EF than an average Italian. This can be related to differences in income between northern and southern Italian cities – Rome's GDP is twice as high as Naples and Palermo (CityMetric staff, 2016). Some studies also reveal that Naples and Palermo have respectively the least living space per inhabitant, and are the worst cities in terms of unemployment compared to Genoa and Rome (Scaramella, 2003). Generally, increasing urban density leads to reduced consumption (Mindali et al., 2004).

Cities located in high-income countries (e.g., in OECD countries), have higher per capita EFs than cities in low-income countries. High-income countries have imposed increasing pressure on the natural environment as measured by the EF, alongside economic growth, accumulated wealth, and improved welfare (Niccolucci et al., 2007). Cities with higher per capita income enable more producers and consumers access to technologies than cities in developing countries. This implies a more intensive use of state-of-the-art technology and makes production more efficient, but on the other hand may also generate a rebound effect triggered by increasing productivity and declining prices (Giampietro and Mayumi, 2000). Per capita Footprints further increase with affluence due to a higher consumption of imported goods (Weinzettel et al., 2013), Interestingly, most cities have developed local policies especially promoting sustainable transport and energy efficiency in buildings (see Table S1).

These findings reveal the existence of a double dynamic taking place in cities. On one hand, cities concentrate investment, offer more access to eco-efficient (e.g., energy-saving) modes of consumption (largely, because of institutional density and economies of scale) (Kates and Parris, 2003), thus contributing to smaller per capita Footprints, all other things being equal. On the other hand, cities also function as a "social elevator", enabling residents to upgrade their lifestyle, and therefore increase their consumption level. Better understanding of the trade-off between these two dynamics is a major piece of the puzzle towards managing the dynamic interaction between nature and society and maintaining a long term balance between human development needs and the planet's environmental limits (Bettencourt et al., 2007). Identifying high leverage solutions that can reduce the global urban Footprint while sustainably meeting human needs for development must become a priority (Khan and Borgstrom-Hansson, 2016).

6. Conclusion

The top-down (MRIO-based) Ecological Footprint approach presented in this paper allowed consistently comparing the resources requirements of 19 cities in the Mediterranean region. Overall, we found that cities belonging to high income countries have greater EFs than those in low- and middle-income countries; the main Footprint drivers were food expenses and therewith cropland requirements for cities with low EF values, and transportation expenses resulting in a higher carbon Footprint, in cities with higher EF values.

Our study is based on a sample of 19 cities; as such further empirical research with far larger city samples would be needed in order to connect the early findings from this study to more comprehensive socio-economic analyses. Another methodological challenge is the integration of tourism as a driver of cities' Ecological Footprint. As expenditure data in relation to tourism is often not tracked in household expenditure surveys (Kitzes et al., 2009), this may be put to good use in a future study to identify the contribution of the tourism sector to cities' Ecological Footprint. Finally, the present method for calculating cities' EF based on the national 2010 CLUM calls for further improvements: once the national CLUM is available for the years 2010–2015, the calculation can be repeated and expanded to include a larger sample of countries.

The analysis presented in this paper – once improved as highlighted above and suggested in section 3.3–could serve as the basis for the development of a world-wide consistent system of Sub-National Ecological Footprint Accounts. This system could constitute a tool for initial benchmarking of cities' resource demand and identification of the drivers behind such demand; it could then help identifying hotspots and leverage points for planners and administrators wanting to mitigate such demand.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2016.12.013.

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