Science of the Total Environment 578 (2017) 383–391

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Mediterranean countries' food consumption and sourcing patterns: An Ecological Footprint viewpoint

Alessandro Galli [a,*], Katsunori Iha [a], Martin Halle [a], Hamid El Bilali [b], Nicole Grunewald [a], Derek Eaton [a], Roberto Capone [b], Philipp Debs [b], Francesco Bottalico [b]

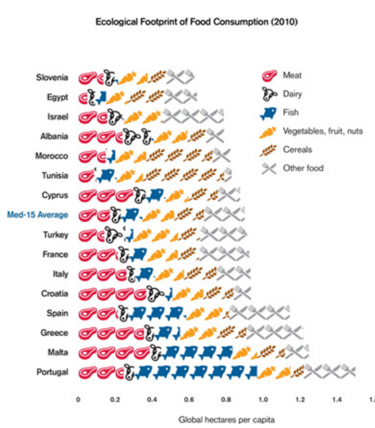
[a] *Global Footprint Network, 18 Avenue Louis-Casai, 1219 Geneva, Switzerland*

[b] *International Centre for Advanced Mediterranean Agronomic Studies in Bari (CIHEAM-Bari), Via Ceglie 9, 70010 Valenzano, Bari, Italy*

HIGHLIGHTS

- Ecological Footprint accounting is applied to Mediterranean countries' food sector.
- Food consumption and sourcing profiles for Mediterranean countries are investigated.
- Dietary patters are among the key drivers of the region's ecological deficit.
- France is the sole biocapacity self-sufficient country in terms of food provision.
- Calorie-adequate diets and changes in dietary patterns could reduce the Footprint.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 12 September 2016
Received in revised form 24 October 2016
Accepted 25 October 2016
Available online 9 November 2016

Editor: D. Barcelo

Keywords:
Mediterranean diet
Footprint
Food security
Food trade
Food consumption

ABSTRACT

Securing food for growing populations while minimizing environmental externalities is becoming a key topic in the current sustainability debate. This is particularly true in the Mediterranean region, which is characterized by scarce natural resources and increasing climate-related impacts.

This paper focuses on the pressure Mediterranean people place on the Earth ecosystems because of their food consumption and sourcing patterns and then explores ways in which such pressure can be reduced. To do so, it uses an Ecological-Footprint-Extended Multi-Regional Input-Output (EF-MRIO) approach applied to 15 Mediterranean countries. Results indicate that food consumption is a substantial driver of the region's ecological deficit, whereby demand for renewable resources and ecosystems services outpaces the capacity of its ecosystems to provide them. Portugal, Malta and Greece are found to have the highest per capita food Footprints (1.50, 1.25 and 1.22 global hectares (gha), respectively), while Slovenia, Egypt and Israel have the lowest (0.63, 0.64 and 0.79 gha, respectively). With the exception of France, all Mediterranean countries rely on the biocapacity of foreign countries to satisfy their residents' demand for food.

By analyzing the effect of shifting to a calorie-adequate diet or changing dietary patterns, we finally point out that the region's Ecological Footprint – and therefore its ecological deficit – could be reduced by 8% to 10%.

* Corresponding author.
E-mail address: alessandro@footprintnetwork.org (A. Galli).

http://dx.doi.org/10.1016/j.scitotenv.2016.10.191

1. Introduction

Humanity is facing deeply interlinked economic, social and environmental crises that stem, in large part, from current unsustainable patterns of consumption and production (Clay, 2011). Humanity is now consuming more resources than ever, both per person and in absolute terms (e.g., Galli et al., 2014; Steffen et al., 2015). Therefore, for achieving global sustainable development, fundamental changes in the way societies consume and produce are indispensable (UNEP, 2012a, 2012b).

By 2050 the world's population will reach 9.7 billion, 32% higher than today (UN-DESA, 2015). Urbanization will continue at an accelerated pace, and about 66% of the world's population will be urban (compared to 54% today) (UN-DESA, 2014). To feed this larger, urbanized and richer population, Alexandratos and Bruinsma (2012) projected that a 60% increase in agricultural production is needed to provide an adequate food supply from 2006 to 2050. According to Davis et al. (2016), the environmental burden from the food sector will likely grow in this same period, despite societal improvements in agricultural production efficiencies.

The provision of food is one of the vital services that nature provides to humanity (Fischler, 1988; Nordström et al., 2013). Nonetheless, the exploitation of nature to meet humanity's demand for food is among the major causes of environmental degradation (Foley et al., 2011; Gephart et al., 2016; Pinstrup-Andersen and Pandya-Lorch, 1998). The food we choose, its production and distribution chains, and the way in which we eat have multifaceted effects on our environment, society and economy (DeFries et al., 2004; Foley et al., 2005; Vitousek et al., 1997). This places food at the heart of the sustainability debate (Ehrlich et al., 1993). Moreover, the way in which humans acquire food, through agriculture and food systems, is one of the largest contributors to biodiversity loss, greenhouse gas emissions, and agrochemical pollution of ecosystems (MEA, 2005; IPCC, 2013; IAASTD, 2009).

Environmental degradation in the Mediterranean has reached a level that requires immediate action (UNEP, 2010). With urbanization and rising incomes, typical dietary patterns are shifting towards consumption patterns based on animal products, requiring more water, land and energy (Pimentel and Pimentel, 2003; Gerbens-Leenes and Nonhebel, 2005; Lundqvist et al., 2008) and increasing greenhouse gas emissions (Carlsson-Kanyama and Gonzalez, 2009). A growing body of research is showing that changes in our food production and distribution systems and in our dietary choices can however achieve substantial reductions in food-related GHG emissions (Marlow et al., 2009; Garnett, 2011; Macdiarmid et al., 2012; Vieux et al., 2012).

The aims of this paper are thus to: i) provide a benchmark assessment of the pressure Mediterranean residents place on ecosystems within and outside their region due to their current food production, trade and final consumption patterns; and ii) identify changes in dietary choices that could lower such pressure and ease access to food resources – through both domestic production and trade – in the long run.

2. Methodology and data sources

Three main datasets and their associated methodologies are used in this analysis:

- Food supply data from FAO Food Balance Sheets (FAO, 2015a);
- Ecological Footprint data drawn from Global Footprint Network's National Footprint Accounts (NFAs) 2014 Edition, covering nearly 160 countries, for the year 2010 (GFN, 2014);
- Version 8 of the Global Trade Analysis Project (GTAP) Multi-Regional Input-Output (MRIO) model, which consists of 57 sectors – 12 of which are agricultural – and refers to 129 countries and regions for the year 2007 (GTAP, 2014; Narayanan et al., 2012).

2.1. Food supply

Countries' food supply data is used here to assess the quantity of each food commodity available for utilization within a given country during the course of a year. This data is drawn from the FAOSTAT database (FAO, 2015a) and refers to the supply concept defined by FAO and used in compiling national food balance sheets (FAO, 2001):

$$S_{d,u} = P_i + I_i - E_i + CS_i \quad (3)$$

where $S_{d,u}$ is the total food supply for domestic utilization, P_i is the amount of each food product i domestically produced,[1] I_i and E_i are the amount of each food product i imported and exported, respectively, and CS_i is the annual change in stocks (decrease or increase) of each food product i considered in the FAO food balance sheet.

On the utilization side, a distinction should be made between the quantities exported, fed to livestock, used for seed, processed for food and non-food uses, lost during storage and transportation, and the quantities provided as food supplies available for human consumption at the retail level. Distinction between food supply available for human consumption and real food consumption is not easily computed by the FAO food balance sheets and food consumption surveys would likely provide a more complete picture (FAO, 2001). We assume, however, that food supply data from the FAO food balance sheets provide a good first approximation of countries' apparent food consumption.

Food supply data is expressed in terms of quantity (kg yr^{-1} or g day^{-1}) and, through the use of appropriate food composition factors for all primary and processed products, in terms of caloric value/energy (kcal day^{-1}). By dividing food supply data by population data, per capita figures expressed in kcal cap^{-1} day^{-1}, are obtained (FAO, 2001).

2.2. Ecological Footprint analysis

The Ecological Footprint (Wackernagel et al., 1999) is a biomass-based resource accounting tool tracking key resource provisioning and one critical regulating ecosystem service (i.e., climate stabilization through carbon sequestration) that humans consume (aggregated into a metric called *Ecological Footprint*) and comparing it with the biosphere's supply of such provisioning and regulating services (aggregated into a metric called *biocapacity*) (Galli et al., 2014). Both metrics are expressed in hectare-equivalent units, or global hectares (gha), which represent productivity-weighted hectares (Galli, 2015). Full details on the calculation of the two metrics as well as their limitations can be found in Borucke et al. (2013).

Adopting a consumer-based approach, a country's Ecological Footprint is calculated by tracking the ecological assets (i.e. crop-, grazing-, forest-, fish-, built-up and carbon-uptake land) appropriated by national production activities and then adding the ecological assets embedded in imported goods and subtracting those embedded in exported goods (Galli et al., 2014). While country-level Ecological Footprint analyses are usually performed via a process-based approach relying on physical trade flows data (Borucke et al., 2013), the detailed tracking of countries' food consumption and sourcing profiles performed in this paper requires that the traditional Footprint method (Borucke et al., 2013; Wackernagel and Rees, 1996) be extended by means of the GTAP 8 Multi-Regional Input-Output (MRIO) model.

While a global model is used to run the analysis, results are provided for just 15 Mediterranean countries (Albania, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Malta, Morocco, Portugal, Slovenia, Spain, Tunisia, and Turkey). The decision to focus on the Mediterranean region

[1] For primary commodities, production relates to the total domestic production whether inside or outside the agricultural sector (i.e. including non-commercial production and production in kitchen gardens). Production is reported at the farm level for primary crops (i.e. excluding pre-harvest and harvesting losses for crops) and livestock items and in terms of live weight for primary fish items. Production of processed commodities relates to the total output of the commodity at the manufacture level.

is motivated by the scope of the grant supporting this research; the country selection was determined by the following criteria: A) countries with populations greater than 1 million inhabitants directly bordering the Mediterranean Sea and/or characterized by biomes typical of the Mediterranean region, and B) availability's of country's MRIO and Ecological Footprint data.

The traditional Footprint methodology (as described in Borucke et al., 2013) is first used to calculate the Ecological Footprint of all national production activities (EF_P). Secondly, to estimate the overall national Ecological Footprint of consumption by means of the EF-MRIO model, six environmental extension tables are required, which initially allocate the Ecological Footprint of production (EF_P) for crop-, grazing-, forest-, built-up and carbon-uptake land as well fishing grounds to each of the 57 producing economic sectors identified by GTAP 8. The EF_P for cropland is allocated to GTAP sectors 1 to 8; the EF_P for grazing land is allocated to GTAP sectors 9 to 12; the EF_P for forest land is allocated to sector 13 and that of fishing grounds to sector 14; the EF_P for carbon-uptake land is allocated to each one of the 57 sectors on the basis of each sector's share of the total emissions as provided by the energy-environmental extension already present in GTAP; the EF_P of built-up land is assigned to each one of the 57 sector depending on the sector's value added to the country's GDP. See Appendix A for the full list of GTAP 8 sectors.

Following Weinzettel et al. (2011) and Ewing et al. (2012), the national Ecological Footprint of consumption (EF_C) is thus derived according to Eq. (1):

$$EF_C = F(I-A)^{-1} y_N \tag{1}$$

where F is the environmental extension matrix (direct EF_P of sectors normalized per unit of sector output, which is expressed in gha $\$^{-1}$) derived from the above *EF_P-to-sector* allocation; y_N is the country total final demand for goods, expressed in \$; I is the identity matrix (a matrix of zeros for 57 columns and rows with diagonal consisting of one's) and A is the technical coefficients matrix (representing the Leontief inverse), which reflects the monetary exchange between each sector to produce one currency unit worth of output from a specific sector of the economy. Eq. (1) thus accounts for all indirect/upstream resource requirements from final consumption and also allows determining the Footprint embedded in multilateral trade exchanges (i.e., the natural resources and ecological services required to produce commodities and services, and exchange them on the international market).

As the EF-MRIO model calculates the resource requirements of each sector in the economy - including both food-related and food-unrelated sectors (see Appendix A) - household resource requirements are then calculated by analyzing the composition of household final demand for goods and services by COICOP[2] consumption categories such as food, transport and the like. 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 (Wiedmann et al., 2006). We refer to the household resource requirements by consumption category as Consumption Land-Use Matrix (CLUM), which displays the biomass requirements by land type for each consumption category. We then refer to the Ecological Footprint of household's food consumption (i.e., the resource provisioning and the regulatory services demanded to provide households with the food they consume) as food Footprint or ${}_fEF_C$.

The ${}_fEF_C$ of any country thus include a) direct demands such as the cropland Footprint needed to produce wheat, the grazing land needed to produce meat, the fishing ground needed to produce fish; and b) indirect demands such as the carbon Footprint from CO_2 released during food production/cultivation (e.g., emissions from fertilizer and pesticide production, farm vehicle CO_2 emissions, emissions from electricity-operated machineries used in harvesting, processing, etc.) and trade, as well as the built-up land Footprint occupied by food industries.

Given the impossibility to distinguish between resources available for food production vs. resources available for other uses (e.g., fibers, etc.) in calculating a country's biocapacity, ${}_fEF_C$ is compared in this study with the Ecological Footprint of food producing sectors (${}_fEF_P$) to get a macro-level insight on each country's food sourcing profile (i.e., the percentage of ${}_fEF_C$ provided by local ecosystems within each nation vs. the amount imported from ecosystems in foreign countries). ${}_fEF_P$ is calculated as the sum of the EF_P of each land type allocated to GTAP sectors 1 to 12 and 14.

2.3. Calculating Footprint intensities and Footprint reduction potentials

The Footprint intensity of each country's dietary consumption pattern (i.e., its food Footprint intensity) is also used for cross-country comparisons and for assessing Footprint reduction potentials: it is calculated by dividing the country's household ${}_fEF_C$ by its food supply (see Section 2.1) and expressed in gha kcal^{-1}. Moreover, an approach similar to Davis et al. (2014) is used to account for diets' moderation. However, while Davis et al. (2014) considered a calories-adequate diet of 3000 kcal cap^{-1} day^{-1} with 20% calories from animal origin, we opted for using the FAO-recommended benchmark of 2500 kcal cap^{-1} day^{-1}, and assumed unvaried compositions of countries' diets. This assumption was implemented to keep the effect of an overall reduction in calories separate from that of a change in food Footprint intensity resulting from a change in diet composition (see Section 3). This reduction could also be achieved in part through reductions in food losses and waste. Resource efficiency was then considered in terms of national food Footprint intensities (expressed in gha demanded per kcal produced), taking the highest actual efficiency observed in the region (that of Egypt) as a benchmark.

3. Results

Food accounts for a large part of the Mediterranean region's overall Ecological Footprint. In the 15 countries analyzed, food and non-alcoholic beverages account for an average 0.9 gha per person, which represents 28% of the regional Ecological Footprint (approximately 3.2 gha per person). Food, therefore, constitutes the largest sector of demand ahead of transportation, whose share accounts for 22% (see Fig. 1).

Behind this regional average, there are important differences in the ${}_fEF_C$ of individual Mediterranean countries (see Fig. 1): Portugal has by far the largest per capita ${}_fEF_C$ in the region at 1.5 gha, followed by Malta (1.2 gha) and Greece (1.2 gha). Egypt and Slovenia, in contrast, have per capita ${}_fEF_C$ levels that are just over half that of Portugal with 0.64 gha and 0.63 gha, respectively. Countries in the region also exhibit considerable variability in the share of ${}_fEF_C$ in their total Ecological Footprints. While in Slovenia ${}_fEF_C$ represents only 14% of total Ecological Footprint, it represents about 45% of the total in Albania and Tunisia and up to 56% in Morocco. Accordingly, food represents the largest share of the Ecological Footprint for 9 out of the 15 countries considered in the region.

Mediterranean countries also vary considerably in terms of their food supply (see Fig. 2A). Most countries in the region have a daily food supply that is 20% to 40% higher than the average[3] FAO-

[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 Nations Statistics Division for use in Expenditures Classification, National Accounts, Household Budget Survey and the Consumer Price Index.

[3] Per capita minimum daily energy requirements depend on many factors such as age, gender, weight, height and physical activity. For adult persons (over 18), values vary from 2000 (sedentary) to 3200 (active) kcal cap^{-1} day^{-1} for males, and from 1600 (sedentary) to 2400 (active) kcal cap^{-1} day^{-1} for females (FAO, 2008). Due to the lack of data to derive country-specific values, the FAO-determined value of 2,500 kcal cap^{-1} day^{-1} is used in this study as a regional average benchmark.

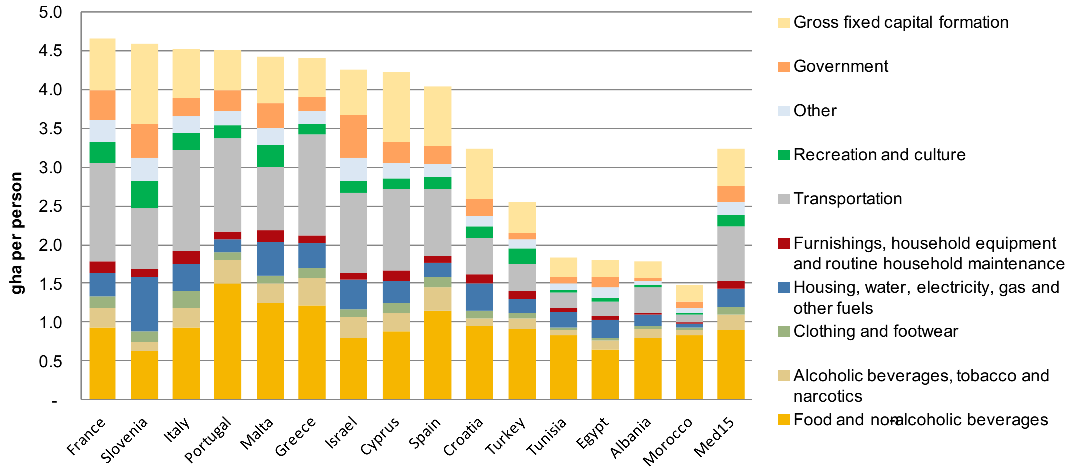


Fig. 1. Ecological Footprint of consumption for 15 Mediterranean countries, by main COICOP categories, in 2010. Categories with a low contribution to national Ecological Footprint values, such as "Health", "Communication", "Education", "Restaurants and hotels", and "Miscellaneous good and services", have been here grouped under the category "Other".

determined minimum daily dietary energy requirement benchmark of 2500 kcal cap^{-1} day^{-1} (FAO et al., 1985; see also Pimentel and Pimentel, 2003). Cyprus is the only exception, with a food supply only 6% above the benchmark. Moreover, comparison of countries' food Footprint intensities reveals a considerable spread, with the lowest value found in Egypt (4.98E-07 gha $kcal^{-1}$) and the highest in Portugal (1.17E-06 gha $kcal^{-1}$) (see Fig. 2B).

Protein-intensive diets are found in countries such as Portugal and Malta, which have the highest food Footprint intensity (see Fig. 2B). The reasons for Portugal's high value are fourfold: 1) overall high food consumption (people in Portugal consume up to 3518 kcal cap^{-1} day^{-1}, approximately 41% more than the FAO-recommended daily dietary energy requirement), 2) high proportion of products from the fish sector within the daily diet (contributing to 44% of the Portuguese food Footprint in 2010), 3) decreasing national fish landings (Baeta et al., 2009) balanced by increased imports (see FAO, Fisheries and Aquaculture Department, 2016) of fish commodities (contributing to an increase in the trade-embedded carbon Footprint) and 4) consumers' preference to eating high trophic level fishes such as the Atlantic cod and tuna (especially skipjack tuna), which place a high demand on the planet's marine primary production (Grunewald et al., 2015; Pauly and Christensen, 2002). Egypt's low intensity is due to its low-protein, cereals- and vegetables-rich diet as well as the high productivity of its crops, which reduce its dependence on imported food and thus also on the carbon associated with trade (see Fig. 3).

At the regional level, ${}_{f}EF_{P}$ and ${}_{f}EF_{C}$ are nearly in balance (see Fig. 4), meaning that food production in the region requires as many renewable natural resources and ecosystem services as those associated with Mediterranean residents' food consumption. However, a considerable variation among countries exists. France and Spain are the only two countries with a ${}_{f}EF_{C}$ lower than their ${}_{f}EF_{P}$ by 46% and 22%, respectively. Turkey's ${}_{f}EF_{P}$ and ${}_{f}EF_{C}$ are nearly in balance. All other countries in the region have a ${}_{f}EF_{C}$ higher than their ${}_{f}EF_{P}$. In some cases the imbalance is particularly acute indicating a noticeable reliance on food resources from the outside: the ${}_{f}EF_{P}$ is only 13% and 24% of the ${}_{f}EF_{C}$ in Malta and Israel, respectively.

The simple comparison of the Ecological Footprints of food production and consumption can be further disaggregated to better understand the food production and sourcing profiles of individual countries, making a distinction between production for domestic food consumption, production for domestic non-food consumption, and

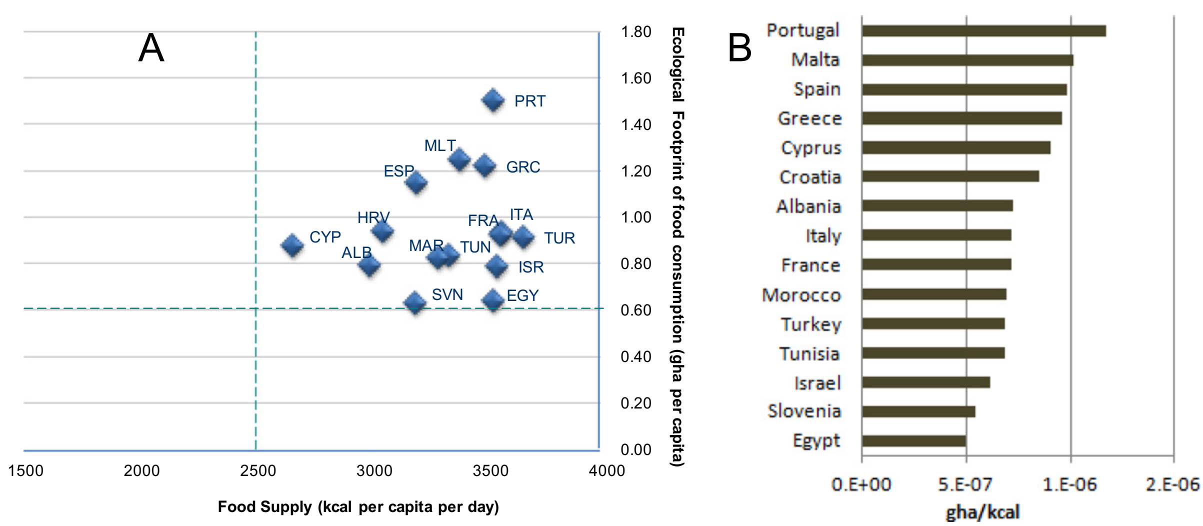


Fig. 2. Per capita Ecological Footprint of food consumption vs. daily calories supply (A) and household food Footprint intensity (B) of 15 Mediterranean countries. The dotted vertical and horizontal lines in figure A indicate a minimum intake of 2500 cal per capita per day – the current minimum average caloric supply required for less than 5% undernourishment across all countries – and the food Footprint of Costa Rica (0.60 gha per capita) – the most efficient food Footprint globally observed (source: Iha and Kiyono, 2012). See Appendix B for full list of country codes.

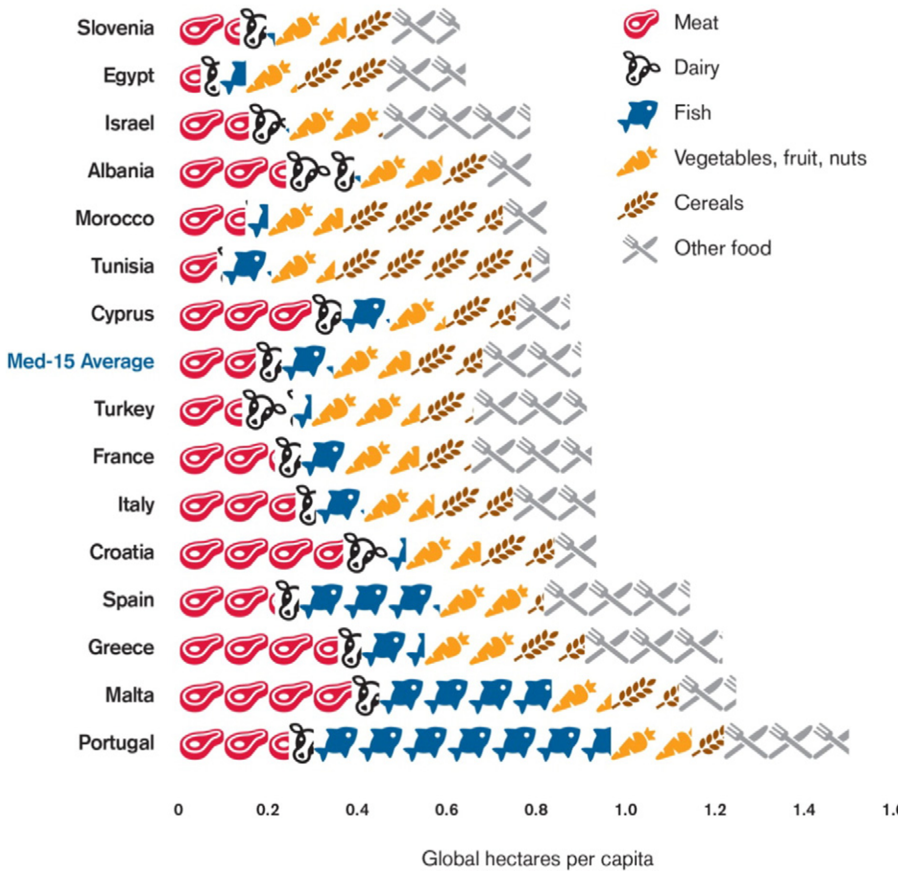


Fig. 3. Per capita Ecological Footprint of food consumption ($_{f}EF_{C}$) broken down by product type based on data for 2010.

production for exports. Similarly, total food consumption can be broken down between domestic sources and imports.

Looking at the $_{f}$EF embedded in traded products, we observe that although some countries are net exporters of certain food categories, all the countries in the analysis – except France – rely on net imports of food biocapacity to satisfy the food consumption needs of their residents (Fig. 5). This highlights the role of ecosystems located in other countries in meeting the food needs of populations in Mediterranean countries.

Cereals represent the largest share of net $_{f}$EF trade in all 15 countries of the region (see Fig. 5). On a per capita basis, external food-related biocapacity dependency is particularly high in small countries such as Cyprus, Israel and Malta as well as in Portugal (Fig. 5A). High per capita import dependency in small countries is consistent with findings from previous studies (e.g., Weinzettel et al., 2013) while Portugal's high value is due to a high calories supply coupled with a low per capita biocapacity (Galli et al., 2015).

At the country level, Italy is the largest net importer of $_{f}$EF for the consumption of all food types (Fig. 5B), primarily importing from France (*wheat* and *bovine cattle*, *sheep and goats*, *horses*), China (*bovine cattle*, *sheep* and *goats*, *horses* and *vegetables*, *fruit*, *nuts*) and Brazil (*bovine cattle*, *sheep and goats*, *horses* and *cereal grains*). Conversely, France exports mainly cereal-related $_{f}$EF (i.e., *wheat*, *cereal grains* and *oil seeds*) to Italy, Germany and Spain and imports $_{f}$EF embodied in

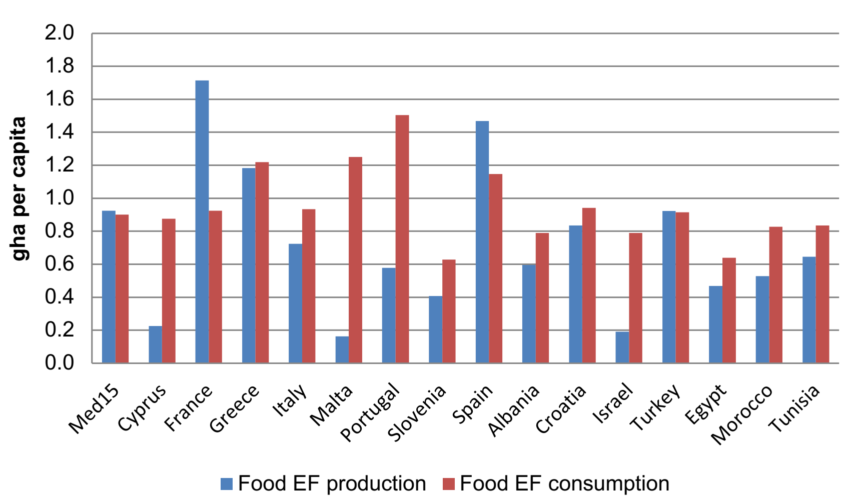


Fig 4. Per capita $_{f}EF_{C}$ and $_{f}EF_{P}$ for 15 selected Mediterranean countries and the region (Med15) average. Results are expressed in global hectares (gha).

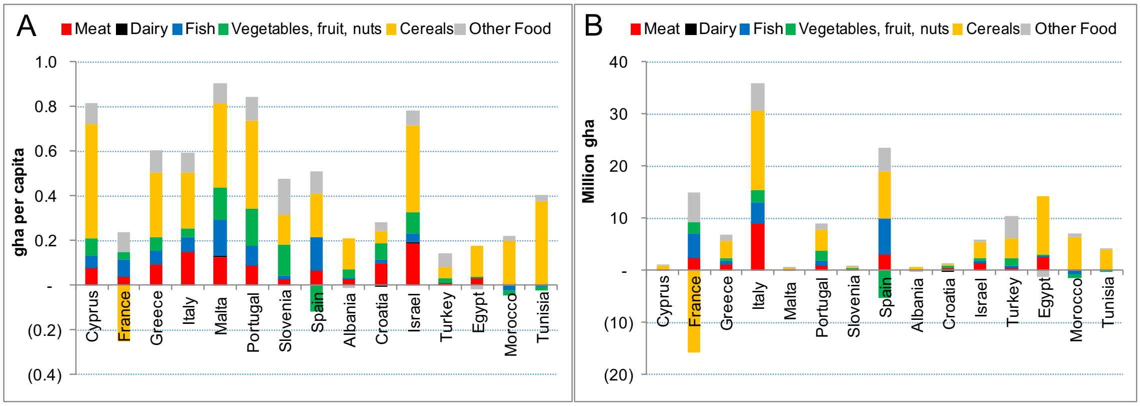


Fig. 5. $_f$EF embedded in net trade, by type of food, for 15 selected Mediterranean countries and the region average (Med15), in 2010. Results are expressed in global hectares (gha) in both per capita (A) and total (B) terms. Positive values in the y-axis indicate net import while negative values indicate net export flows.

fishing (from Norway, USA and China), *bovine cattle*, *sheep and goats* (from China, Brazil and New Zealand) and *vegetables*, *fruit*, *nuts* (from Spain, China and Madagascar). Spain exports $_f$EF embedded in *vegetables*, *fruits*, *nuts* (to France, Germany and UK), while it imports embedded $_f$EF mostly in *cereal grains* (from Brazil, France and Argentina) and in *fishing* (from South Africa, Norway and Morocco) (see the Supplementary Online Material for detailed results on the Footprint embedded in trade flows by product and trade partner).

Finally, Fig. 6A shows the reduction in $_f$EF$_C$ that countries could experience should they shift to a calories-adequate diet of 2500 kcal cap^{-1}day^{-1} (assuming no change in the dietary composition); Fig. 6B shows reductions in $_f$EF$_C$ that countries could experience if they were to keep the same current amount of food energy supply but shift the composition of diets to the least Footprint intensive one (see also Fig. 2B).

Countries such as Italy, France, Turkey, Tunisia and Morocco, would achieve the same level of $_f$EF$_C$ reduction irrespective of the action taken (calories adequate shift or shift to less Footprint intensive diets). Slovenia, Egypt and Israel would obtain the higher saving by shifting to a calories adequate diet as they possess the three lowest dietary Footprint intensities. All other countries would benefit more (in terms of $_f$EF$_C$ reduction) by keeping their current kcal level but shifting the composition of their diets towards increasing the consumption of cereals as well as unprocessed fruits and vegetables, while limiting the intake of protein, fat, sugar and salt (thereby lowering their food Footprint intensity).

4. Discussions & conclusions

The Mediterranean region is in a situation of severe ecological deficit, consuming around 40% more renewable natural resources and ecosystem services than it provides (Galli et al., 2015). The analysis presented in this paper reveals that household food consumption accounts for 28% of the Mediterranean region's Ecological Footprint. In the majority of the analyzed countries, food consumption is the largest of the COICOP categories considered (see Fig. 1), while in France, Slovenia, Italy, Greece, Israel and Cyprus it represents the second highest share of the Ecological Footprint after transportation.

Food consumption is therefore a key area to consider when searching for means to reduce the environmental impacts of consumption in the region. Addressing these impacts entails dealing with increasing resource use efficiency and productivity (through sustainable intensification of food production), reducing food losses and waste (FLW), and moderating diets (especially the demand for meat and animal products) (Davis et al., 2016; Lacirignola et al., 2014), as several studies have demonstrated that solely increasing agricultural productivity might not be sufficient to reduce the environmental pressure of humanity's growing food demand (e.g., Davis and D'Odorico, 2015; Davis et al., 2016; Jalava et al., 2014; Tilman and Clark, 2014) and that commodities' consumption rate tends to increase when production efficiency increases (e.g., Jevons, 1866). As such, we explored the potential of three of the above strategies for Ecological Footprint reductions, which can be seen as elements of a sustainable consumption and production (SCP) program: reducing calorie intake through moderating diets, reducing FLW, and increasing resource use efficiency via changes in diets' composition. Reductions in both caloric intake and food waste decrease the food Ecological Footprint. It is important in this regard to recognize that a substantial portion of the food Footprint represents waste or discarded food in the supply chain or by households. The FAO estimates that approximately one-third of food supply is lost or wasted (FAO, 2012, 2013a, 2013b; Kummu et al., 2012). Thus a reduction in calorie consumption can entail both a moderation of diets and a decrease in waste by efficiency improvements in supply change as well as behavior change by households.

Overall, our analysis of the food-related Footprint saving options found that by shifting to a calories adequate diet of 2500 kcal cap^{-1}day^{-1}, the $_f$EF$_C$ of the Mediterranean region (considered here as the weighted-average of 15 countries analyzed) could potentially be reduced by 28%. This would lead to an overall reduction of 7.7% in the Ecological Footprint of the region. Conversely, should all countries adopt the least Footprint intensive diet, the food Footprint of the Mediterranean region could be reduced by 30% and the region's overall Footprint by 8.3%. Should each country implement the best strategy to reduce its respective food Footprint, the region's overall Ecological Footprint would be reduced by 10%.

Such a reduction could improve the region's food security in aggregate by lowering the environmental externalities associated with the consumption of food: other things being equal, diets that require less biocapacity imply less demand for agricultural land whose scarcity and degradation (Zdruli et al., 2007; Zdruli, 2012) is a key issue for the region's future food security, alongside water scarcity and biodiversity loss (CIHEAM and FAO, 2015; Lacirignola et al., 2014; Rastoin and Cheriet, 2010; UNEP, 2012c).

Implementing the three strategies investigated in this study would only address some of the multiple threats to future food security in the region. A fuller treatment would, in addition to the issue of moderating or otherwise changing diets, consider agricultural intensification and increasing resource use and sustainability. Additionally, the current issue of food and nutrition security in the Mediterranean region goes far beyond the issue of how many calories are consumed, as many in the region still lack vitamins and other micronutrients and many countries in the eastern and southern Mediterranean still have precarious food situations or are just overcoming food insecurity (Padilla et al., 2005; FAO, 2015b). National food security may not be sufficient to ensure food security at the individual level but arguably can improve food availability at the household and individual levels.

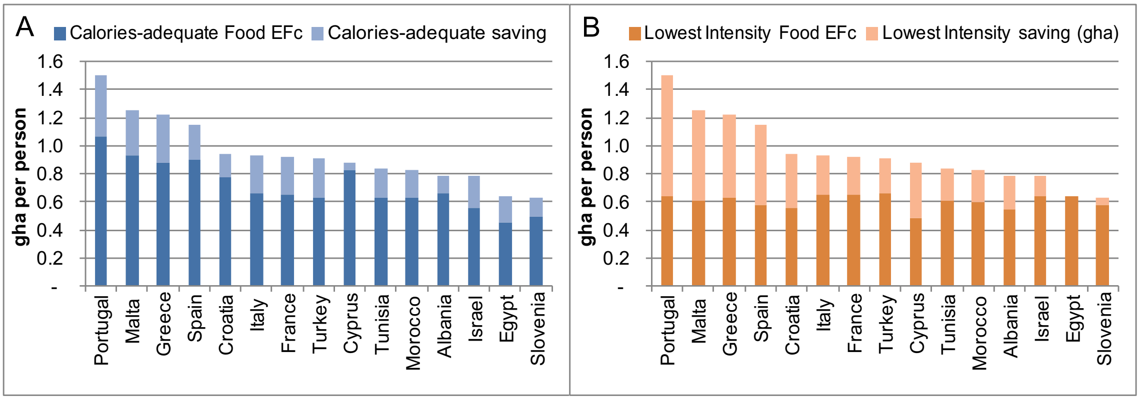


Fig. 6. Per capita $_{F}EF_{C}$ of 15 Mediterranean countries and Footprint saving due to shifting to a calories-adequate diet (A) or adopting the region's lowest Footprint intensive diet (B), in 2010. In each figure, the height of the bar indicates the current per capita value, light colors indicate the Footprint saving associated with dietary or efficiency changes and the darker colors indicate the resulting (after-saving) Footprint value.

Moreover, we acknowledge that pressure on the region's land resources also depends on food trade policies. For instance, food self-sufficiency might expose countries to domestic food supply disruption: countries with extreme self-sufficiency policies (e.g., import barriers, exports bans, and a complete reliance on domestic production), could be hit by supply disruption harder than countries with diversified food sourcing profiles. Conversely, dependence on imports can expose countries to external shocks such as those arising from production shocks affecting key commodity exporters and the policy responses that may follow (e.g. the grain export bans announced by several countries during the 2007–08 food price crisis).

Leaving a more comprehensive analysis of these trade-related issues to future work, the comparative analysis of Mediterranean countries' food consumption and food sourcing profiles provided in this paper identifies specific behavioral policy interventions and estimates their potential to support more sustainable consumption and production patterns. According to Leach et al. (2016), product-specific food Footprint values could also be used in the development of environmental impact food labels; these labels could support producers who provide sustainable products as well as trigger sustainable behavioral choices in consumers.

Although applied here to just 15 Mediterranean countries, our approach could be easily extended to approximately 130 world countries for which Ecological Footprint and MRIO data exist.

Acknowledgements

We would like to acknowledge MAVA Foundation pour la Nature (Grant No. 13/09) for its support to Global Footprint Network's Mediterranean-MENA Program. We also wish to thank Michel Gressot and Nicoletta Patrizi and the three anonymous reviewers for their useful comments and suggestions on a preliminary version of this article, as well as David Lin, Jon Martindill, Laurel Hanscom, and Michael Borucke for their work on the National Footprint Accounts.

Appendix A. GTAP 8 Data Base sectors

GTAP sector number	GTAP sector CODE	Sector description	GTAP sector number	GTAP sector CODE	Sector description
1	PDR	Paddy rice	30	LUM	Wood products
2	WHT	Wheat	31	PPP	Paper products, publishing
3	GRO	Cereal grains nec	32	P_C	Petroleum, coal products
4	V_F	Vegetables, fruit, nuts	33	CRP	Chemical, rubber, plastic products
5	OSD	Oil seeds	34	NMM	Mineral products nec
6	C_B	Sugar cane, sugar beet	35	I_S	Ferrous metals
7	PFB	Plant-based fibers	36	NFM	Metals nec
8	OCR	Crops nec	37	FMP	Metal products
9	CTL	Bovine cattle, sheep and goats, horses	38	MVH	Motor vehicles and parts
10	OAP	Animal products nec	39	OTN	Transport equipment nec
11	RMK	Raw milk	40	ELE	Electronic equipment
12	WOL	Wool, silk-worm cocoons	41	OME	Machinery and equipment nec
13	FRS	Forestry	42	OMF	Manufactures nec
14	FSH	Fishing	43	ELY	Electricity
15	COA	Coal	44	GDT	Gas manufacture, distribution
16	OIL	Oil	45	WTR	Water
17	GAS	Gas	46	CNS	Construction
18	OMN	Minerals nec	47	TRD	Trade
19	CMT	Bovine meat products	48	OTP	Transport nec
20	OMT	Meat products nec	49	WTP	Water transport
21	VOL	Vegetable oils and fats	50	ATP	Air transport
22	MIL	Dairy products	51	CMN	Communication
23	PCR	Processed rice	52	OFI	Financial services nec
24	SGR	Sugar	53	ISR	Insurance
25	OFD	Food products nec	54	OBS	Business services nec
26	B_T	Beverages and tobacco products	55	ROS	Recreational and other services
27	TEX	Textiles	56	OSG	Public Administration, Defense, Education, Health
28	WAP	Wearing apparel	57	DWE	Dwellings
29	LEA	Leather products			

Appendix B. GTAP 8 Data Base countries and regions

GTAP Country CODE	Country NAME	GTAP Country CODE	Country NAME	GTAP Country CODE	Country NAME
ALB	Albania	IDN	Indonesia	ROU	Romania
ARE	United Arab Emirates	IND	India	RUS	Russian Federation
ARG	Argentina	IRL	Ireland	SAU	Saudi Arabia
ARM	Armenia	IRN	Iran, Islamic Republic of	SEN	Senegal
AUS	Australia	ISR	Israel	SGP	Singapore
AUT	Austria	ITA	Italy	SLV	El Salvador
AZE	Azerbaijan	JPN	Japan	SVK	Slovakia
BEL	Belgium	KAZ	Kazakhstan	SVN	Slovenia
BGD	Bangladesh	KEN	Kenya	SWE	Sweden
BGR	Bulgaria	KGZ	Kyrgyzstan	THA	Thailand
BHR	Bahrain	KHM	Cambodia	TUN	Tunisia
BLR	Belarus	KOR	Korea, Republic of	TUR	Turkey
BOL	Bolivia, Plurinational Republic of	KWT	Kuwait	TWN	Taiwan
BRA	Brazil	LAO	Lao People's Democratic Republic	TZA	Tanzania, United Republic of
BWA	Botswana	LKA	Sri Lanka	UGA	Uganda
CAN	Canada	LTU	Lithuania	UKR	Ukraine
CHE	Switzerland	LUX	Luxembourg	URY	Uruguay
CHL	Chile	LVA	Latvia	USA	United States of America
CHN	China	MAR	Morocco	VEN	Venezuela
CIV	Cote d'Ivoire	MDG	Madagascar	VNM	Viet Nam
CMR	Cameroon	MEX	Mexico	XAC	South Central Africa
COL	Colombia	MLT	Malta	XCA	Rest of Central America
CRI	Costa Rica	MNG	Mongolia	XCB	Caribbean
CYP	Cyprus	MOZ	Mozambique	XCF	Central Africa
CZE	Czech Republic	MUS	Mauritius	XEA	Rest of East Asia
DEU	Germany	MWI	Malawi	XEC	Rest of Eastern Africa
DNK	Denmark	MYS	Malaysia	XEE	Rest of Eastern Europe
ECU	Ecuador	NAM	Namibia	XEF	Rest of EFTA
EGY	Egypt	NGA	Nigeria	XER	Rest of Europe
ESP	Spain	NIC	Nicaragua	XNA	Rest of North America
EST	Estonia	NLD	Netherlands	XNF	Rest of North Africa
ETH	Ethiopia	NOR	Norway	XOC	Rest of Oceania
FIN	Finland	NPL	Nepal	XSA	Rest of South Asia
FRA	France	NZL	New Zealand	XSC	Rest of South African Customs Union
GBR	United Kingdom	OMN	Oman	XSE	Rest of Southeast Asia
GEO	Georgia	PAK	Pakistan	XSM	Rest of South America
GHA	Ghana	PAN	Panama	XSU	Former Soviet Union
GRC	Greece	PER	Peru	XTW	Rest of the World
GTM	Guatemala	PHL	Philippines	XWF	Rest of Western Africa
HKG	Hong Kong	POL	Poland	XWS	Rest of Western Asia
HND	Honduras	PRT	Portugal	ZAF	South Africa
HRV	Croatia	PRY	Paraguay	ZMB	Zambia
HUN	Hungary	QAT	Qatar	ZWE	Zimbabwe

Appendix C. Supplementary data

Supplementary data to this article can be found online at http://dx.doi:10.1016/j.scitotenv.2016.10.191.

References

Alexandratos, N., Bruinsma, J., 2012. World Agriculture Towards 2030/2050: The 2012 Revision (ESA Working Paper 12-03). Food and Agriculture Organization of the United Nations, Rome, Italy.

Baeta, F., Costa, M.J., Cabral, H., 2009. Changes in the trophic level of Portuguese landings and fish market price variation in the last decades. Fish. Res. 97, 216–222.

Borucke, M., Moore, D., Cranston, G., Gracey, K., Iha, K., Larson, J., Lazarus, E., Morales, J.C., Wackernagel, M., Galli, A., 2013. Accounting for demand and supply of the biosphere's regenerative capacity: the national footprint accounts' underlying methodology and framework. Ecol. Indic. 24, 518–533.

Carlsson-Kanyama, A., Gonzalez, A., 2009. Potential contributions of food consumption patterns to climate change. Am. J. Clin. Nutr. 89 (5), 1704S–1709S.

CIHEAM, FAO, 2015. Mediterranean food consumption patterns: diet, environment, society, economy and health. A White Paper of Priority 5 of Feeding Knowledge Program, Expo Milan 2015. CIHEAM-IAMB, Bari & FAO, Rome http://www.fao.org/3/a-i4358e.pdf.

Clay, J., 2011. Freeze the footprint of food. Nature 475, 287–289.

Davis, K.F., D'Odorico, P., 2015. Livestock intensification and the influence of dietary change: a calorie-based assessment of competition for crop production. Sci. Total Environ. 538, 817–823.

Davis, K.F., D'Odorico, P., Rulli, M.C., 2014. Moderating diets to feed the future. Earth's Future. 2, pp. 559–565.

Davis, K.F., Gephart, J.A., Emery, K.A., Leach, A.M., Galloway, J.N., D'Odorico, P., 2016. Meeting future food demand with current agricultural resources. Glob. Environ. Chang. 39, 125–132.

DeFries, R.S., Foley, J.A., Asner, G.P., 2004. Land-use choices: balancing human needs and ecosystem function. Front. Ecol. Environ. 2 (5), 249–257.

Ehrlich, P.R., Ehrlich, A.H., Daily, G.C., 1993. Food security, population and environment. Popul. Dev. Rev. 19 (1), 1–32.

Ewing, B.R., et al., 2012. Integrating ecological and water footprint accounting in a multi-regional input–output framework. Ecol. Indic. 23, 1–8.

FAO, 2001. Food Balance Sheets: A Handbook. Economic and Social Development Department; Food and Agriculture Organization of the United Nations (FAO), Rome Available online at. ftp://ftp.fao.org/docrep/fao/011/x9892e/x9892e00.pdf.

FAO, 2008. Updating the Minimum Dietary Energy Requirements. Available online at. http://www.fao.org/fileadmin/templates/ess/documents/food_security_statistics/metadata/undernourishment_methodology.pdf.

FAO, 2012. Towards the Future We Want: End Hunger and Make the Transition to Sustainable Agricultural and Food Systems. Food and Agriculture Organization (FAO), Rome Available online at. http://www.fao.org/docrep/015/an894e/an894e00.pdf .

FAO, 2013a. SAVE FOOD: Global Initiative on Food Losses and Waste Reduction. Key Findings. Available online at. http://www.fao.org/save-food/key-findings/en .

FAO, 2013b. Food wastage footprint: impacts on natural resources. Available at. http://www.fao.org/docrep/018/i3347e/i3347e.pdf.

FAO, 2015a. FAOSTAT: Food Blance. Available at:. http://faostat3.fao.org/browse/FB/*/E.

FAO, 2015b. Regional Overview of Food Insecurity - Near East and North Africa: Strengthening Regional Collaboration to Build Resilience for Food Security and Nutrition. FAO, Cairo.

FAO, Fisheries and Aquaculture Department, 2016. Fishery Commodities and Trade Statistics. Available on-line at. http://www.fao.org/fishery/statistics/global-commodities-production/en.

FAO, WHO, UNU, 1985. Protein and Energy Requirements. Food and Agriculture Organization, World Health Organization, United Nations University, Rome.

Fischler, C., 1988. Food, self and identity. Soc. Sci. Inf. 19:937–953. 10.1177/053901848001900603.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., et al., 2005. Global consequences of land use. Science 309, 570–574.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., et al., 2011. Solutions for a cultivated planet. Nature 478, 337–342.

Galli, A., 2015. On the rationale and policy usefulness of Ecological Footprint accounting: the case of Morocco. Environ. Sci. Pol. 48, 210–224.

Galli, A., Wackernagel, M., Iha, K., Lazarus, E., 2014. Ecological Footprint: implications for biodiversity. Biol. Conserv. 173, 121–132.

Galli, A., Halle, M., Grunewald, N., 2015. Physical limits to resource access and utilization and their economic implications in Mediterranean economies. Environ. Sci. Pol. 51, 125–136.

Garnett, T., 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy 36, s23–s32.

Gephart, J.A., Davis, K.F., Emery, K.A., Leach, A.M., Galloway, J.N., Pace, M.L., 2016. The environmental cost of subsistence: optimizing diets to minimize footprints. Sci. Total Environ. 553, 120–127.

Gerbens-Leenes, W., Nonhebel, S., 2005. Food and land use. the influence of consumption patterns on the use of agricultural resources. Appetite 45, 24–31.

Global Footprint Network (GFN), 2014. National Footprint Accounts. 2014 ed. Available at. http://www.footprintnetwork.org.

Grunewald, N., et al., 2015. The Ecological Footprint of Mediterranean Diets. 32. CIHEAM Watch Letter, pp. 10–16.

GTAP, 2014. Global Trade Analysis Project (GTAP). https://www.gtap.agecon.purdue.edu/default.asp.

Iha, K., Kiyono, H., 2012. Japan Ecological Footprint Report 2012. WWF Japan, Global Footprint Network (GFN).

IPCC, 2013. Fifth Assessment Report: Climate Change 2013. Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press.

Jalava, M., Kummu, M., Porkka, M., Siebert, S., Varis, O., 2014. Diet change - a solution to reduce water use? Environ. Res. Lett. 9, 091003.

Jevons, W.S., 1866. VII. The Coal Question, second ed. Macmillan and Company, London .

Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., Ward, P.J., 2012. Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Sci. Total Environ. 438, 477–489.

Lacirignola, C., Capone, R., Debs, P., El Bilali, H., Bottalico, F., 2014. Natural resources - food nexus: food-related environmental footprints in the Mediterranean countries. Front. Nutr. 1:1–16. 10.3389/fnut.2014.00023.

Leach, A.M., Emery, K.A., Gephart, J., Davis, K.F., Willem Erisman, J., Leip, A., Pace, M.L., D'Odorico, P., Carr, J., Cattell Noll, L., Castner, E., Galloway, J.N., 2016. Environmental impact food labels combining carbon, nitrogen, and water footprints. Food Policy 61, 213–223.

Lundqvist, J., de Fraiture, C., Molden, D., 2008. Saving water: from field to fork. SIWI Policy Brief. Stockholm International Water Institute, Stockholm, Sweden Available at:. http://www.siwi.org/documents/Resources/Policy_Briefs/PB_From_Filed_to_Fork_2008.pdf.

Macdiarmid, J.I., Kyle, J., Horgan, G.W., Loe, J., Fyfe, C., Johnstone, A., McNeil, G., 2012. Sustainable diets for the future: can we contribute to reducing greenhouse gas emissions by eating a healthy diet? Am. J. Clin. Nutr. 10.3945/ajcn.112.038729

Marlow, J.H., Hayes, W.K., Soret, S., Carter, R.L., Schwab, R.E., Sabate', J., 2009. Diet and the environment: does what you eat matter? Am. J. Clin. Nutr. 89 (suppl), 1699s-703.

MEA (Millennium Ecosystem Assessment), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC Available at:. http://www.millenniumassessment.org/documents/document.356.aspx.pdf.

Narayanan, G., Angel Aguiar, B., McDougall, R., 2012. Global Trade, Assistance, and Production: The GTAP 8 Data Base. Center for Global Trade Analysis, Purdue University.

Nordström, K., Coff, C., Jönsson, H., Nordenfelt, L., Görman, U., 2013. Food and health: individual, cultural, or scientific matters? Genes Nutr. 8 (4), 357–363.

Padilla, M., Ahmed, Z.S., Wassef, H.H., 2005. In the Mediterranean region: overall food security in quantitative terms but qualitative insecurity. CIHEAM Analytic Note No 4 – June 2005 http://portail2.reseau-concept.net/Upload/ciheam/fichiers/ANP4.pdf.

Pauly, D., Christensen, V., 2002. Primary production required to sustain global fisheries. Nature 374, 255–257.

Pimentel, D., Pimentel, M., 2003. Sustainability of meat-based and plant-based diets and the environment. Am. J. Clin. Nutr. 78 (3), 660S–663S.

Pinstrup-Andersen, P., Pandya-Lorch, R., 1998. Food security and sustainable use of natural resources: a 2020 vision. Ecol. Econ. 26, 1–10.

Rastoin, J.L., Cheriet, F., 2010. Food security in the Mediterranean: a major geostrategic issue. IPEMED No 6. Institut de Prospective Economique du Monde Méditerranéen (IPEMED) http://www.ipemed.coop/adminIpemed/media/fich_article/1316526334_LesnotesIPEMED_6B_FoodSecurity_ENG.pdf.

Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., Ludwig, C., 2015. The trajectory of the Anthropocene: the great acceleration. The Anthropocene Review 2, 81–98.

Tilman, D., Clark, M., 2014. Global diets link environmental sustainability and human health. Nature 515, 518–522.

UN-DESA, 2014. World Urbanization Prospects: The 2014 Revision, Highlights. (ST/ESA/SER.A/352). United Nations - Department of Economic and Social Affairs (UN-DESA), Population Division, New York.

UN-DESA, 2015. World Population Prospects: The 2015 Revision, Key Findings and Advance Tables. Working Paper No. ESA/P/WP.241. United Nations - Department of Economic and Social Affairs (UN-DESA), Population Division, New York.

UNEP, 2010. HERE and NOW - Education for Sustainable Consumption: Recommendations and GuidelinesA publication from the United Nations Environment Programme (UNEP) and the Marrakech Task Force on Education for Sustainable Consumption.

UNEP, 2012a. Global Outlook on Sustainable Consumption and Production Policies: Taking Action TogetherUnited Nations Environment Programme (UNEP), Nairobi.

UNEP, 2012b. The critical role of global food consumption patterns in achieving sustainable food systems and food for allA UNEP Discussion Paper. UNEP, Paris Available at:. http://fletcher.tufts.edu/CIERP/~/media/Fletcher/Microsites/CIERP/Publications/2012/UNEPGlobalFoodConsumption.pdf.

UNEP, 2012c. Avoiding future famines: strengthening the ecological foundation of food security through sustainable food systems. A UNEP Synthesis Report Available at:. http://www.unep.org/publications/ebooks/avoidingfamines/portals/19/Avoiding_Future_Famines.pdf.

Vieux, F., Darmon, N., Touazi, D., Soler, L.G., 2012. Greenhouse gas emissions of self-selected individual diets in France: changing the diet structure or consuming less? Ecol. Econ. 75, 91–101.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of earth's ecosystems. Science 277, 494–499.

Wackernagel, M., Rees, W.E., 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. New Society Publishers, Gabriola Island, Canada.

M.Wackernagel, M., L.Onisto, L., P.Bello, P., A.Callejas Linares, A., I.S.Lopez Falfan, I.S., J.Mendez Garcıa, J., A.I.Suarez Guerrero, A.I., M.G.Suarez Guerrero, M.G., 1999. Natural capital accounting with the Ecological Footprint conceptEcol. Econ. 29 (3), 375–390.

Weinzettel, J., Steen-Olsen, K., Galli, A., Cranston, G., Ercin, E., Hawkins, T., Wiedmann, T., Hertwich, E., 2011. Footprint Family Technical Report: Integration Into MRIO Model. One Planet Economy Network, London Available on-line at. http://www.oneplaneteconomynetwork.org/resources/programme-documents/OPEN_EU_WP2_EC_Deliverable_Technical_Document.pdf.

Weinzettel, J., Hertwich, E.G., Peters, G.P., Steen-Olsen, S., Galli, A., 2013. Affluence drives the global displacement of land use. Glob. Environ. Chang. 23, 433–438.

Wiedmann, T., Minx, J., Barrett, J., Wackernagel, M., 2006. Allocating Ecological Footprints to final consumption categories with input–output analysis. Ecol. Econ. 56 (1), 28–48.

Zdruli, P., 2012. Land resources of the Mediterranean: status, pressures, trends and impacts on regional future development. Land Degradation & Development. Wiley 10.1002/ldr.2150.

Zdruli, P., Lacirignola, C., Lamaddalena, N., Trisorio Liuzzi, G., 2007. The EU-funded MEDCOASTLAND thematic network and its findings in combating land degradation in the Mediterranean region. In: Sivakumar, M.V.K., Ndiang'ui, N. (Eds.), Climate and Land Degradation. Springer, Berlin, Heidelberg, New York.