The positive climate impact of the Mediterranean diet and current divergence of Mediterranean countries towards less climate sustainable food consumption patterns

Simona Castaldi1, Katarzyna Dembska2, Marta Antonelli2,3, Tashina Petersson4, Maria Grazia Piccolo1 & Riccardo Valentini3,4,5

The Mediterranean diet (MD) is a world-renowned healthy dietary pattern. In the present study we analyse the climate sustainability of the MD and the greenhouse gas emissions (E_{GHG}) associated with current dietary patterns in Mediterranean and non-Mediterranean EU countries, focusing on the major deviations from the MD health and environmental targets in Mediterranean countries. The E_{GHG} associated with dietary patterns were calculated for seven Mediterranean countries (Cyprus, Croatia, Greece, Italy, Portugal, Spain and Malta, referred to as 7MED) and the other 21 countries in the EU 28 (referred to as 21OTHER), using 2017 as the reference year. A new harmonised compilation of 3449 carbon footprint values of food commodities, based on a standardised methodology to extract information and assign optimal footprint values and uncertainties to food items, was used to estimate E_{GHG} of food consumption. Our findings show that the E_{GHG} associated with the ideal MD pattern, 2.3 kg CO₂ equivalents (CO₂eq) capita⁻¹ d⁻¹, are in line with planetary GHG climate targets, though GHG emissions associated with food consumption in Mediterranean countries strongly diverged from the ideal MD. Both MED and 21OTHER countries were found to have comparable dietary associated E_{GHG} (4.46 and 4.03 kg CO₂eq capita⁻¹ d⁻¹ respectively), almost double that expected from a sustainable dietary pattern. The primary factor of dietary divergence in 7MED countries was found to be meat overconsumption, which contributed to 60% of the E_{GHG} daily excess (1.8 kg of CO₂eq capita⁻¹ d⁻¹).

In the present and future development of humankind, healthy food systems have an important role to play in both contributing to keeping greenhouse gas emissions (E_{GHG}) within planetary limits of sustainability and in improving health outcomes1,2. In terms of the former, feeding the global population currently accounts for 21–37% of total net anthropogenic E_{GHG}1. In terms of the latter, non-communicable diseases, such as diabetes, cardiovascular diseases, cancer and chronic respiratory diseases, are responsible for 41 million deaths each year, and one in five deaths are attributed to unhealthy diets globally3.

A dietary shift towards more sustainable food systems would be an effective measure to contribute to global E_{GHG} reduction targets1,2 and is a key element of the European Union’s new Farm to Fork strategy, a pivotal component of the European Green Deal’s ambition to decarbonise the continent by 2050. Tackling health and sustainable food consumption patterns is also key to improving the nutritional status and health of EU citizens4. In this respect, the Mediterranean diet (MD) could play an important role in EU climate targets, as it is recognized as a

1Department of Environmental, Biological and Pharmaceutical Science and Technology, University of Campania “Luigi Vanvitelli”, Via Vivaldi 43, 81100 Caserta, Italy. 2Barilla Center for Food & Nutrition Foundation, Via Madre Teresa di Calcutta, 3/a, Parma, Italy. 3Euro-Mediterranean Centre on Climate Change, Via Augusto Imperatore 16, 73100 Lecce, Italy. 4Department for Innovation in Biological, Agro-Food and Forestry Systems, University of Tuscia, Via Camillo de Lellis 4, 01100 Viterbo, Italy. 5Department of Ecology, Russian Timiryazev State Agrarian University, Timiryazevskaya st., 49, Moscow, Russia 127550. *email: simona.castaldi@unicampania.it
healthy dietary pattern\textsuperscript{5-8} that contributes to environmental\textsuperscript{7,8} social and cultural services\textsuperscript{10,11}. The MD\textsuperscript{10} is, in fact, rich in plant-based foods (cereals, fruits, vegetables, legumes, tree nuts, seeds and olives) with moderate-to-high consumption of fish and seafood, moderate consumption of eggs, poultry and dairy products (cheese, milk and yoghurt) and low consumption of red meat, with extra-virgin olive oil used as the principal source of added fat. The MD is still evolving, and there are many versions expressing the different food cultures of the Mediterranean region\textsuperscript{6}. In 2010, the MD was recognised by UNESCO\textsuperscript{12} as an intangible cultural heritage of humanity, raising its status to a model which should be fostered in the agricultural, political, cultural, economic and public health contexts of the Mediterranean area.

A recent global analysis of food-based dietary guidelines (FBDG)\textsuperscript{8} demonstrated that a core set of dietary guidance beneficial to health appears “nearly universally across countries” and in line with WHO global guidance; nonetheless, for many FBDGs, further improvements could be achieved towards greater health benefits\textsuperscript{5,8,9}. Furthermore, from an environmental perspective, it was found that the national-level reductions in environmental impacts achieved through the adoption of FBDGs were mostly moderate, and most FBDGs were not in line with global environmental targets, especially $E_{GHG}$ reduction targets\textsuperscript{7}.

The present study evaluates the adherence of the MD to global $E_{GHG}$ reduction targets and investigates the current food consumption patterns and associated $E_{GHG}$ in the EU, focusing on Mediterranean countries to evidence major deviations from MD health and environmental targets.

For this purpose, we calculated the average dietary consumption pattern, using 2017 as a reference year, for two groups of countries. The first group (7MED) includes the six European Mediterranean pioneer countries on which the first studies of the MD were based\textsuperscript{10}, Cyprus, Croatia, Greece, Italy, Portugal, Spain, plus Malta. The second group (21OTHER) includes the other 21 countries of the EU 28 in 2017. $E_{GHG}$ associated with the analysed dietary patterns were based on the carbon footprint (CF) concept\textsuperscript{13}, which uses a life cycle approach to incorporate $E_{GHG}$ from land management, industrial processes, transport and energy to cover all the possible $E_{GHG}$ associated with the functional unit of a food product. The current estimates of dietary consumption and associated $E_{GHG}$ are mainly based on the CF of fresh and minimally processed products and exclude beverages.

**Materials and methods**

**Carbon footprint values of food commodities.** The CF data, used in this study to estimate $E_{GHG}$ associated with food, were derived from a harmonised compilation of CF footprint values of food commodities, the Su-Edable LIFE (SEL) database, published by Petersson et al. 2021\textsuperscript{14,15}. The SEL database\textsuperscript{14} was created using a standardised methodology to extract information from published CF studies and to assign CF values and uncertainties to food items\textsuperscript{15}. The database contains 3349 CF values (with Eurocentric prevalence of 50–60%), extrapolated from 841 publications (1998–2019) and distributed in four main commodity groups: fresh or minimally processed (frozen, canned or dried) plant-based food commodities (978 CF data), plant-based industrially processed food (457 CF data), fresh or processed food commodities derived from terrestrial animals (1496 CF data) and food commodities from the ocean and freshwaters (263 CF data). Data from single studies, once harmonized to refer to the same system boundaries and functional unit, are further aggregated to represent the food items commonly found in the market definitions (apple, yogurt, potato, etc.). Each food item is categorised by typologies (a group of items with similar characteristics) and within some typology category, by sub-typologies (e.g. the typology “shellfish” includes the following sub-typologies: crustacean, bivalves and cephalopods). The CF database comprises a total of 85 food typologies, 11 food sub-typologies and 323 food items\textsuperscript{14,15}. A robust methodology of uncertainty attribution, based on three statistic indicators, is applied to define the statistically representative CF value of each food commodity (details of the statistical approach are fully explained in Petersson et al.\textsuperscript{15}).

**Daily per capita $E_{GHG}$ associated with food consumption of EU citizens.** We estimated the annual per capita $E_{GHG}$ associated with food consumption of EU citizens, differentiating 7MED and 21OTHER, using the following procedure.

Plant based food, meat and fish consumption data were extracted from the FAOSTAT food balance database\textsuperscript{16} by selecting the element “food” (code 5142), the reference year 2017, the 28 countries part of the European Union in 2017 and FAOSTAT items codes reported in Supplementary Table 1. As CF of fresh and hard or semi-hard cheese differ significantly (Supplementary Table 2), consumption data for these two food groups were calculated separately based on data reported in CLAL.it\textsuperscript{17} (Supplementary Table 3). Dairy consumption was calculated as production plus import minus export, assuming negligible storage of dairy products from the previous year. CLAL.it data of dairy production is based on EUROSTAT data from NewCronos (apro_mk_pobta and apro_mk_farm)\textsuperscript{18}, while import/export data reported by CLAL.it are derived from IHS/GTA data (see Supplementary Table 3).

The aforementioned food consumption data were aggregated into 20 food groups, considered as the most representative in the average dietary definitions: cereals, starchy tubers, vegetables, fruit, pulses, nuts and seeds, sweeteners, other vegetable oils, olive oil, butter, milk, cream, yogurt, cheese, beef, mutton and goat, pork, poultry, eggs, fish and shellfish.

The two country groups 7MED and 21OTHERS were analysed separately and, for each of them, the *annual weighted per capita* $E_{GHG}$ of each food group ($E_{FG}$) (kg CO$_2$eq capita$^{-1}$ yr$^{-1}$) was calculated with Eq. 1:

$$E_{FG} = \sum_{i=1}^{n} \left( \frac{item_{i}(g_{1,2})}{Population(g_{1,2})} \times CF_{i} \right)$$

(1)
### Table 1. Mediterranean dietary pattern scenarios used to define the MD reference diet in this study. Three patterns of MD differing for weekly frequency distribution of protein sources, within the recommended limits provided by the Mediterranean pyramid diet (MPD)\(^{10,19}\) and complying with nutritional indications\(^{20-24}\). Portions and weekly frequency have been calibrated for an average EU citizen energy requirement\(^{21}\), estimated by the EFSA Panel on Dietetic Products, Nutrition and Allergies\(^{21}\), which varies depending on individual characteristics (e.g. age, gender, lifestyle and degree of physical activity), cultural context, locally available foods and dietary customs\(^{20}\). To define the impacts of a reference MD dietary plan, specific recommendations are needed. Portions (g) and the intake frequency of food groups in each of the three scenarios were calibrated within the MD limits on the following bases: (a) the average energy requirement by an average EU citizen (about 2380 kcal capita\(^{-1}\) day\(^{-1}\)), estimated by the EFSA Panel on Dietetic Products, Nutrition and Allergies\(^{21}\), which specifically recommend serving size\(^{10,19}\), as the exact make-up of a diversified, balanced and healthy diet will vary depending on individual characteristics (e.g. age, gender, lifestyle and degree of physical activity), cultural context, locally available foods and dietary customs\(^{20}\). To define the impacts of a reference MD dietary plan, three different weekly dietary scenarios (Table 1) were created where the daily intake of plant-based food groups characteristic of the MD pattern and their weekly consumption frequency, we relied upon the comprehensive literature review of the MD by Davis et al.\(^{19}\) and on the MD pyramid guidelines\(^{10}\). The reference document report the minimum–maximum limits of food group consumption frequency over a week but do not mention the specific serving size\(^{10,19}\), as the exact make-up of a diversified, balanced and healthy diet will vary depending on individual characteristics (e.g. age, gender, lifestyle and degree of physical activity), cultural context, locally available foods and dietary customs\(^{20}\). To define the impacts of a reference MD dietary plan, three different weekly dietary scenarios (Table 1) were created where the daily intake of plant-based food groups (cereals, vegetables, fruit, etc.) was left constant in the three scenarios, while the consumption frequency of animal protein foods (poultry, red meat, fish, eggs, and dairy) was varied within the limits imposed by the MD guidelines. Portions (g) and the intake frequency of food groups in each of the three scenarios were calibrated within the MD limits on the following bases: (a) the average energy requirement by an average EU citizen (about 2380 kcal capita\(^{-1}\) day\(^{-1}\)), estimated by the EFSA Panel on Dietetic Products, Nutrition and Allergies\(^{21}\), which

| Food type               | Scenario 1 | Scenario 2 | Scenario 3 |
|-------------------------|------------|------------|------------|
|                         | Daily (g)  | Weekly freq | Daily (g)  |
|                         | portion    |            | portion    |
| Cereals                 | 300        | 7          | 300        |
| Legumes                 | 50         | 3          | 50         |
| Potatoes                | 500        | 2          | 500        |
| Vegetables              | 400        | 7          | 400        |
| Fruit                   | 300        | 7          | 300        |
| Nuts/seeds             | 30         | 7          | 30         |
| Red meat\(^f\)          | 100        | 1          | 100        |
| Poultry                 | 100        | 2          | 100        |
| Cheese                  | 83.3\(^c\) | 3          | 75\(^d\)   |
| Butter                  | 0          | 0          | 0          |
| Eggs                    | 100        | 2          | 100        |
| Vegetable oil\(^\infty\) | every meal | 40         | 40         |
| Fish                    | 150        | 3          | 150        |
| Sugar equiv.\(^{21}\)   | 20         | 7          | 20         |

where \(i\) represents the total kilograms of the \(i\)-th item belonging to the food group \(FG\) (including \(n\) items) consumed by all the citizens of either group in 2017; \(CF\) is the CF value (kg CO\(_2\)eq kg\(^{-1}\) product) attributed to the \(i\)-th item extracted from the SEL database\(^{14}\) (data used for calculations are reported in Supplementary Table 1). The daily per capita CO\(_2\)eq emissions (\(E_{\text{GHG}}\)) estimated for the average citizen of 7MED or 21OTHERS were calculated as the sum of the emissions of the 20 food groups divided by 365 (days in a year) with Eq. 2:

\[
\text{Daily per capita } E_{\text{GHG}} = \frac{\sum_i^n (E_{\text{FG}})_i}{365}
\]

### Daily per capita \(E_{\text{GHG}}\) associated with the Mediterranean diet. To determine which are the food groups characteristic of the MD pattern and their weekly consumption frequency, we relied upon the comprehensive literature review of the MD by Davis et al.\(^{19}\) and on the MD pyramid guidelines\(^{10}\). The reference document reports the minimum–maximum limits of food group consumption frequency over a week but do not specifically recommend serving size\(^{10,19}\), as the exact make-up of a diversified, balanced and healthy diet will vary depending on individual characteristics (e.g. age, gender, lifestyle and degree of physical activity), cultural context, locally available foods and dietary customs\(^{20}\). To define the impacts of a reference MD dietary plan, three different weekly dietary scenarios (Table 1) were created where the daily intake of plant-based food groups (cereals, vegetables, fruit, etc.) was left constant in the three scenarios, while the consumption frequency of animal protein foods (poultry, red meat, fish, eggs, and dairy) was varied within the limits imposed by the MD guidelines. Portions (g) and the intake frequency of food groups in each of the three scenarios were calibrated within the MD limits on the following bases: (a) the average energy requirement by an average EU citizen (about 2380 kcal capita\(^{-1}\) day\(^{-1}\)), estimated by the EFSA Panel on Dietetic Products, Nutrition and Allergies\(^{21}\), which
takes into account different age and sex groups and various levels of physical activity associated with sustainable lifestyles in healthy individuals; the energy requirements were distributed over three main meals, breakfast, lunch and dinner plus two snacks; (b) the content of the main nutritional elements and caloric values (kcal) of each food group\(^{(22,23)}\); (c) healthy diet standards set by the World Health Organization\(^{(20)}\) and by the Harvard T.H. Chan School of Public Health’s Healthy Eating Plate\(^{(24)}\). The WHO recommends a healthy diet to include fruit, vegetables, legumes, nuts and whole grains, at least 400 g of fruit and vegetables per day, less than 10% of total energy intake from free sugars, less than 30% of total energy intake from fats, minimal to no trans fats and less than 5 g of salt per day. The Healthy Eating Plate provides a guide on balanced meals and divides an ideal plate into four parts: half of the plate for vegetables and fruits, a quarter for whole grains and the last quarter for healthy proteins.

Next, food items used for the estimates of consumption data, were aggregated into 15 food groups (Table 1), based on MD Pyramid guidelines\(^{(10,25)}\) and a CF value (functional unit kg CO2eq kg\(^{-1}\) or l\(^{-1}\) food) was assigned to each food group in each dietary scenario (Table 1). For this specific task, the CF value attributed to each food group was estimated as a weighted CF value (weighted \(\text{CF}_{FG}\)) using the CF values extracted from the SEL database\(^{(11)}\). This approach avoids wrongly attributing equal environmental “weight” to items that only have a moderate level of consumption by EU citizens within a food group. The following Eq. (3) was used:

\[
\text{Weighted CF}_{FG} = \sum_{i=1}^{n} \left( \text{CF}_i \times \text{freq}_i \right)
\]

where \(\text{CF}_i\) is the CF value of the \(i\)-th food item of the food group \(FG\) (including \(n\) items); \(\text{freq}_i\) is the relative frequency of consumption of the \(i\)-th food item in the food group \(FG\) (food groups are reported in Table 1). For the specific case of the item “wheat”, which is in the food group “cereals”, an average CF value was calculated from bread, flour and pasta CFs extracted from the database by Petersson et al.\(^{(19)}\). For the specific case of the weighted \(\text{CF}_{FG}\) of the food group “cheese”, two items were considered separately; fresh cheese and semi-hard/hard cheese, due to their different caloric value and nutrient density and different CFs\(^{(14,15)}\) (Table 1).

To estimate the total \(E_{\text{CF}_{FG}}\) associated with each of the three scenarios of the MD (Table 1), the total weekly intake (g) of each food group was multiplied by its corresponding weighted \(\text{CF}_{FG}\); the total weekly emissions of each food group were then summed and then divided by 7 (days in a week) to express the result as average per capita daily emissions.

### Deviations of food consumption patterns from the Mediterranean diet in Mediterranean countries.

To estimate the deviation of the current daily consumption of 7MED from the ideal MD pattern, the weekly consumption rate of the average Mediterranean citizen (\(W_{\text{CF}_{FG}}\)) (grams capita\(^{-1}\) week\(^{-1}\)) was calculated for each food group reported in Table 1 with Eq. (4):

\[
W_{\text{CF}_{FG}} = \sum_{i=1}^{n} \frac{\text{item}_i}{\text{Population}} \times \frac{7}{365}
\]

where \(\text{item}_i\) represents the total kilograms of the \(i\)-th item, belonging to the food group \(FG\) (including \(n\) items), consumed by all 7MED citizens in 2017; \(\text{Population}\) is the total number of individuals in the 7MED countries in 2017.

For this specific analysis, to compare the dietary intake to the correct food consumption term “bone free meat”, the average bone free meat consumption of Mediterranean citizens was estimated using the FAOSTAT element “protein supply quantity” (code 674) (g protein per capita d\(^{-1}\)). Eq. 674 (g protein per capita d\(^{-1}\)) was used to estimate the average bone free meat consumption of bone free meat (\(C_{\text{BFM}}\)) (g capita\(^{-1}\) d\(^{-1}\)) in 7MED for each meat type (beef, mutton, pork and poultry), to avoid biases due to disproportional population size and meat consumption among the studied countries.

\[
C_{\text{BFM}} = \left[ \sum_{i=1}^{n} \left( \text{ITEM}_{P_{\text{BF}}}/\text{Prt}_{\text{BF}} \times \text{Population}_i \right) \right] / \sum_{i=1}^{n} \text{Population}_i
\]

where \(n\) represents the 7MED countries, \(\text{ITEM}_{P_{\text{BF}}}\) is the daily protein supply quantity for the specific meat type \(P\) in country \(i\); \(\text{Prt}_{\text{BF}}\) is the fraction of protein content of the meat, calculated considering different meat cuts\(^{(23)}\), with \(\text{Prt}_{\text{BF}}\) values of 0.21 for beef meat (anterior and posterior cuts), 0.21 for mutton, 0.19 for chicken (with skin), 0.17 pork (average of steak, sausages, ham); \(\text{Population}_i\) is the number of individuals present in the country \(i\). All data refers to the year 2017. The weekly consumption was estimated as \(C_{\text{BFM}}\) multiplied by 7 (days in a week).

The weekly food deviation of the 7MED from the ideal MD pattern was calculated for each of the 15 food groups as the difference between the amount of weekly food intake proposed by the MD (average value of the 3 scenarios of Table 1) and the calculated weekly consumption data (with 2017 as the reference year). The weekly deviation expressed in grams was multiplied by the weighted CF factors of each food group to derive total CO2eq emissions (Supplementary Table 4). The total CO2eq daily net excess was estimated by summing the CO2eq weekly deviations of the 15 groups divided by 7 (days in a week). For the meat category, the excess of each meat type (beef, mutton, pork and poultry) was calculated separately and multiplied by the respective CF value, and then the emissions were summed again to represent red meat (beef, mutton and pork) and poultry separately.

Kcal deviation per week (Supplementary Table 4) per food group was also derived by multiplying the weekly deviation in grams of the food group by its weighted kcal value. The latter was calculated from the kcal values of the single food items belonging to the group, with a similar approach to Eq. 3.
Annual per capita $E_{\text{GHG}}$ from meat consumption of EU citizens between 1961 and 2017. The $E_{\text{GHG}}$ associated with apparent meat consumption in the EU from 1961 to 2017 was estimated based on the element “food” (code 5142) in the FAOSTAT food balance database. To analyse the meat consumption in the 28 countries investigated in this study for a timeframe when EU 28 was not existing yet, we listed the countries present in the EU 28 in 2017 and then we analysed the trend of each country from 1961. Due to different political assets, Czechoslovakia data was considered from 1961 to 1992, and Belgium-Luxembourg data from 1961 to 1999. Croatia data is missing before 1991, which might have resulted in some bias between the data of meat consumption in 7MED before and after 1991. However, the estimate of emissions from meat consumption represents a weighted average and not the sum of total emissions, which means that any error would be considered only minor. To estimate the CO$_2$eq emissions for each meat type, we used an average CF value based on bone free meat and meat with bone CF data.

Results and discussion

To meet the 2050 global emission reduction target, the EAT-Lancet Commission has proposed a planetary health dietary pattern formulated to represent a boundary of 5 Gt of CO$_2$eq per year (uncertainty range of 4.7–5.4 Gt CO$_2$eq yr$^{-1}$) from food production, about half of the total GHG emissions (CO$_2$eq) expected in 2050 with the RCP2.6 scenario (2 °C temperature rise). The CFs values used in this study to estimate the MD $E_{\text{GHG}}$ were applied to the recommended average weekly per capita food consumption rates reported by Willet et al., obtaining a value of 2.49 kg CO$_2$eq capita$^{-1}$ d$^{-1}$, which we used as a reference value to assess the climate sustainability of the MD. We then assessed that adherence of an average citizen to the MD pattern, as reported in Table 1, would lead to a daily per capita $E_{\text{GHG}}$ of 2.31 ± 0.14 kg CO$_2$eq capita$^{-1}$ d$^{-1}$. This value is in agreement with the estimated $E_{\text{GHG}}$ impact of the EAT-Lancet dietary recommendations, corroborating the important role that the MD could play in contributing to the EU $E_{\text{GHG}}$ mitigation targets.

In contrast, our analysis of actual food consumption patterns in 7MED shows that Mediterranean citizens were far from this ideal dietary target emitting, on average, about 4.46 kg CO$_2$eq capita$^{-1}$ d$^{-1}$, which is almost double the expected daily $E_{\text{GHG}}$ from the ideal MD pattern. Moreover, average daily $E_{\text{GHG}}$ in 7MED was comparable to that of the other EU citizens (21OTHER), which is 4.03 kg CO$_2$eq capita$^{-1}$ d$^{-1}$ (Fig. 1). An in-depth analysis of $E_{\text{GHG}}$ associated with the dietary consumption patterns of the two groups (Fig. 1) shows that there are no major differences in terms of the highest-emitting food: beef meat, mutton meat and cheese. While $E_{\text{GHG}}$ from poultry consumption were comparable, the 7MED countries showed higher $E_{\text{GHG}}$ from pork and fish consumption. $E_{\text{GHG}}$ from added fat sources were comparable, as 21OTHER citizens consumed slightly more than twice the amount of butter (CF 8.48 kg CO$_2$eq kg$^{-1}$) used in Mediterranean countries, while 7MED citizens consumed 8 times more olive oil (CF of 3.26 kg CO$_2$eq kg$^{-1}$), which levelled off the difference. Both groups had a comparable use of seed oil. +7MED citizens tended to consume more plant-based food, which is one of the three pillars of the MD. Notably, the difference in $E_{\text{GHG}}$ between the two groups was relatively small (Fig. 1), as the CF magnitude of plant-based food is significantly lower than that of animal-based food.

To better comprehend the current patterns of food consumption and related GHG impacts in Mediterranean countries, we compared the ideal weekly MD plan with the real weekly food consumption pattern of Mediterranean EU citizens. Our results show a clear deviation of real dietary habits from the ideal MD pattern. The per capita dietary intake exceeded the energy and nutrient requirements of the reference MD diet, which was largely the result of increased intake of meat, mostly red meat, cheese, additional fats and carbohydrate-rich food (Fig. 2a, c). Food and calorie excess not only have major consequences on healthy perspective but also result in a considerable daily excess of $E_{\text{GHG}}$, equal to 1.8 kg of CO$_2$eq capita$^{-1}$ d$^{-1}$ (Fig. 2b). Whereas carbohydrate-rich food and additional fats significantly contributed to the calorie excess (Fig. 2c, Supplementary Table 4, 2 daily extra portions of grains, 1 extra portion of potatoes, 27 of sugars equivalents, 5 daily extra portions of oil and 37 extra grams of butter per week), the biggest contribution came from the ingestion of animal proteins (Fig. 2b, Supplementary Table 4, 2 portions of beef meat, 5 of pig meat, 1/2 of poultry meat, 2 of cheese per week). Overall, the animal protein excess was 70% of the estimated total $E_{\text{GHG}}$ excess of 1.8 kg of CO$_2$eq capita$^{-1}$ d$^{-1}$, with red meat alone representing 56%. A low intake of red meat has been associated with traditional Mediterranean diets and is considered one of the main reasons for Mediterranean people’s longevity. A low incidence of coronary heart disease and mortality was identified in the island of Crete, Greece, in the 1960s. This was associated with an average intake of red meat and poultry that combined was only 35 g capita$^{-1}$ d$^{-1}$.

We calculated that, in Mediterranean countries in the 1960s, the total apparent meat consumption (FAOSTAT definition which includes meat with bone for some categories of cuts and animals), was around 25 kg capita$^{-1}$ yr$^{-1}$, corresponding to 68 g capita$^{-1}$ d$^{-1}$, which is in agreement with the daily intake of edible meat cut estimated in Crete by Kromhout et al. In 2017 the total apparent meat consumption of Mediterranean citizens had reached 86 kg capita$^{-1}$ yr$^{-1}$ (around 235 g capita$^{-1}$ d$^{-1}$), more than three times the meat consumption estimated in 1960 (Supplementary Fig. 1). This increase has coincided with a dramatic increase in $E_{\text{GHG}}$ (Fig. 3). In the early 1990s, per capita $E_{\text{GHG}}$ from meat consumption in Mediterranean countries were already above the $E_{\text{GHG}}$ values estimated for the other EU countries, and only recently have the two groups started to converge, largely as a result of reduced beef consumption (Supplementary Fig. 1, Fig. 4).

It is important to note that the estimates of $E_{\text{GHG}}$ provided in this study are mainly based on an analysis of minimally processed food items and exclude highly processed food and beverages. While this allowed a direct comparison with the MD, which is traditionally based on fresh and locally produced food and excludes many common beverages, it might introduce some underestimation of the total food-related $E_{\text{GHG}}$ of EU citizens. In this respect, adherence to MD diet would be even more beneficial to climate targets than estimated, as fresh local and traditional food forms the base of Mediterranean food preparation. With an excess of 1.8 kg CO$_2$eq...
Figure 1. Annual per capita $E_{\text{GHG}}$ (kg CO$_2$ eq. capita$^{-1}$ yr$^{-1}$) associated with food consumption of EU citizens. $E_{\text{GHG}}$ of food groups refer to the weighted mean food consumption of Mediterranean citizen (7MED, grey bars) and other EU countries (21OTHER, black bars) in 2017.

Figure 2. Deviations of food consumption patterns of Mediterranean citizens (7MED) from the reference MD. Data are represented as total weekly deviation of each analysed food group to take into account a complete dietary plan with specific weekly frequency consumption of different food items. Differences are reported as (a) fresh food weight intake (g), (b) $E_{\text{GHG}}$ derived from C footprint of consumed food items, (c) calorie intake. Positive values indicate an extra weekly intake, negative sign a deficit weekly intake.
capita\(^{-1}\) d\(^{-1}\) applied to the population of the 7MED countries, the potential total savings from adhering to MD recommendations would be approximately 105 Mt CO\(_2\) eq y\(^{-1}\).

**Conclusions**

The results of this study support the positive role that the MD could have on EU climate mitigation targets if it were fully adopted by Mediterranean citizens. The analysis also shows that the nutritional transition experienced by Mediterranean countries, in particular over the last 30 years, has undermined this potential. A significant dietary shift to the dietary patterns of the Mediterranean tradition would bring significant environmental gains.
as well as increased health benefits related to non-communicable diseases, including a lower incidence of cancer, cognitive disease and cardiovascular diseases as well as for metabolic syndrome, obesity and type 2 diabetes.\(^2\)\(^3\)

As indicated by Willet et al., \(^2\) the absence of scientific targets for achieving healthy diets from sustainable food systems has been hindering large-scale and coordinated efforts to transform the global food system.\(^7\) The present analysis provides guidance to effectively implement actions and measures to support sustainable and healthy dietary shifts at the Mediterranean and EU levels.

Received: 28 May 2021; Accepted: 4 May 2022
Published online: 25 May 2022

References

1. IPCC, 2019: Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (eds. Shukla, P.R. et al.). https://www.ipcc.ch/srcdl/download (2019).

2. Willett, W. et al. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet* 393, 447–492 (2019).

3. Gakidou, E. et al. Global, regional, and national comparative risk assessment of 84 behavioral, environmental and occupational, and metabolic risks or clusters of risks 1990–2016: a systematic analysis for the global burden of disease study 2016. *Lancet* 390, 1345–1422 (2016).

4. Wilkins, E. et al. European Cardiovascular Disease Statistics 2017. European Heart Network, Brussels. Access online at: file:///C:/Users/simon/Dropbox/II%20Immo%20PC%20Desktop-3B4809B/Downloads/European%20cardiovascular%20disease%20statistics%202017.pdf (2017).

5. Trichopoulou, A. et al. Definitions and potential health benefits of the Mediterranean diet: views from experts around the world. *BMC Med.* 12, 112 (2014).

6. Dernini, S. & Berry, E. M. From a healthy diet to a sustainable dietary pattern. *Front. Nutr.* 2, 15 (2015).

7. Springmann, M. et al. The healthiness and sustainability of national and global food-based dietary guidelines: modelling study. *BMJ* 370, m2322 (2020).

8. Herforth, A. et al. A global review of food-based dietary guidelines. *Adv. Nutr.* 10, 590–605 (2019).

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

10. Bach-Faig, A. et al. Mediterranean diet pyramid today. Science and cultural updates. *Public Health Nutr.* 14(12A), 2274–2284 (2011).

11. Serra-Majem, L., Bach-Faig, A. & Raidó-Quintana, B. Nutritional and cultural aspects of the Mediterranean diet. *Int. J. Vitam. Nutr. Res.* 82, 157–162 (2012).

12. UNESCO Nomination file no. 00884 for Inscription in Baku, Azerbaijan in December 2013 and Nomination file no. 00394 for Inscription on the Representative List of the Intangible Cultural Heritage of Humanity approved in Nairobi, Kenya in November 2010 in http://www.unisob.na.it/ ateneo/c002_l.htm?vr=1.

13. ISO 14067:2018(en) Greenhouse gases—Carbon footprint of products—Requirements and guidelines for quantification (2018).

14. Petersson, T. et al. SUEATABLE_LIFE: a comprehensive database of carbon and water footprints of food commodities. Figshare https://doi.org/10.6084/m9.figshare.13271111 (2021).

15. Petersson, T. et al. A multilevel carbon and water footprint dataset of food commodities. *Sci. Data* 8, 127 (2021).

16. FAOSTAT food balance database http://www.fao.org/faostat/en/#data/FBS

17. CLALIT https://www.cland.it/en/index.php

18. Annual Production Series of Dairy products. Source: EUROSTAT NewCronos (apra_mk_pobta and apra_mk_farm) https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/eur-dairy-historical-production-stocks-series_en.pdf (Accessed on 20 September 2020).

19. Davis, C., Bryan, J., Hodgson, J. & Murphy, K. Definition of the Mediterranean diet: a literature review. *Nutrients* 7(11), 9139–9153 (2015).

20. WHO, FACT SHEET: Healthy diet, 2020. Available online: https://www.who.int/news-room/fact-sheets/detail/healthy-diet (Accessed on August 19, 2020).

21. EFSA. Panel on dietetic products, nutrition and allergies (NDA); Scientific opinion on dietary reference values for energy. *EFSA J.* 11(1), 3005. https://doi.org/10.2903/j.efsa.2013.3005 (2013).

22. LARN, The IV revision of DRV of nutrients and energy for Italian population. 2014, Italian Society of Human Nutrition (SINU), https://eng.sinu.it/larn/ (Accessed on November 20, 2020).

23. Consiglio per la ricerca in agricoltura e l’analisi dell’ economia agraria, 2019, Tabelle di Composizione degli Alimenti. Available online: https://www.crea.gov.it/italab-tabelle-di-composizione-degli-alimenti (Accessed on August 18, 2020).

24. “The Nutrition Source”, 2011, “the Harvard T.H. Chan School of Public Health”. Available online: https://www.hsph.harvard.edu/nutritionsource/healthy-eating-plate (Accessed on August 19, 2020).

25. Renzella, J. et al. What national and subnational interventions and policies based on Mediterranean and nordic diets are recommended or implemented in the WHO European region, and is there evidence of effectiveness in reducing noncommunicable diseases? Copenhagen: WHO Regional Office for Europe; 2018. (Health Evidence Network Synthesis Report, No. 58.) Available from: https://www.ncbi.nlm.nih.gov/books/NBK519076/ (2018).

26. Poore, J. & Nemecek, T. Reducing food’s environmental impacts through producers and consumers. *Science* 360, 987–992 (2018).

27. Kromhout, D. et al. Food consumption patterns in the 1960s in seven countries. *Am. J. Clin. Nutr.* 49, 889–894 (1989).

Acknowledgements

This work was supported by the LIFE program [grant number LIFE16 GIC/IT/000038].

Author contributions

S.C. Conceptualization, Data curation, Formal analysis, Methodology, Roles/Writing—original draft, Writing—review & editing; K.D. Conceptualization, Data curation, Formal analysis, Methodology, Roles/Writing—original draft, Writing—review & editing; M.A. Writing—review & editing; T.P. Data curation, Writing—review & editing; M.G.P. Data curation, Formal analysis; R.V. Writing—review & editing.
Competing interests
The authors declare no competing interests.

Additional information
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-022-12916-9.

Correspondence and requests for materials should be addressed to S.C.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

© The Author(s) 2022