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The greenhouse gas emissions from food consumption in Turkey: a regional analysis with developmental parameters†

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Due to the expected growth rate in world energy consumption in the near future, it is critical to estimate future energy consumption and associated environmental problems as precisely as possible. This study aims to describe total greenhouse gas emissions (GHGE) linked to different geographical diet profiles in Turkey, to map the environmental impacts that these generate. We used the last Address Based Population Registration System results to identify regions, populations, and some developmental parameters such as population density, the population growth rate, gross domestic product per capita, and socio-economic development scores, and the latest National Nutrition and Health Survey to determine the nutrient composition of Turkey's regional diets. The West Marmara diet had the highest GHGE levels, at 2983.79 g CO_2-eq. per person per day, followed by the Istanbul diet and South-eastern Anatolia diet (2941.73 g CO_2-eq. per person per day and 2935.08 g CO_2-eq. per person per day) whereas the Mediterranean diet had the lowest, at 2623.90 g CO_2-eq. per person per day. The contributions of beef and lamb to total diet weight (both were 0.98%) were lower than their contribution to total GHGE (21.65% and 21.04%). Our findings indicated that dietary changes could significantly help to reduce GHGE. Additionally, GHGE of diets might be associated with developmental parameters, but we did not find statistical differences. If the balance between natural resources and economic growth factors cannot be achieved in developing countries such as Turkey, which is a member of the United Nations, the environment will start to suffer and environmental sustainability will become a distant goal. Therefore, more studies are needed to confirm these results.

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Introduction

The world's population continues to grow, and it is estimated that the world population, which is 7.5 billion today, will reach 8.5 billion in 2030 and between 9.4 and 10.1 billion in 2050.[1] Energy plays a crucial role in various economic activities in a country such as transportation and freight, industrial manufacturing, heating and cooling, national defense, food production and more.[2] Parallel to the rapidly increasing population, the climate has begun to rapidly change globally due to gases being released into the atmosphere and the creation of a greenhouse effect as a result of increased use of fossil fuels such as oil, coal, and natural gas from energy sources, and the inability of these gases to be reabsorbed by the atmosphere.[3]

The world is under the threat of global warming, and greenhouse gas emissions (GHGE) have affected both the natural environment and humans. According to the last Intergovernmental Panel on Climate Change (IPCC) report (2013), the primary cause of global warming is human activities, 95% of which occurred since the middle of the twentieth century.[4]

Food systems play a key role in driving climate change including all processes in the production, aggregation, processing, distribution, consumption, and disposal of food products. Therefore, reduction of GHGE of food systems is required.[5–7] Among all these processes involved in food systems, food consumption is one of the most important as a climate change mitigation option. It is recommended that consumption of more plant-based, organic and regional-based diets is important for reducing GHGE.[8–10] In this line, IPCC estimates that dietary changes might decrease the total GHGE by 0.7–8 $GtCO_2$-eq. per year by 2050.[7]

The developmental processes for a country mainly depend on economic growth. Natural resources serve as inputs into the production or development process. If the relationship between natural resources and development processes cannot be avoided, damage to the environment is inevitable.[11] The prevalence of such problems is higher in developing countries such as Turkey, where economic growth and environmental sustainability are critically important. Also, the share of the Turkish industrial sector in gross domestic product was approximately 26% and thereby a key driver of the economic growth as in many

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other countries.[12] Some studies have focused on the relationship between economic growth and GHGE with their possible influencing factors such as population and energy consumption,[11,13–19] but there is no study about this subject in Turkey according to the last Turkish Greenhouse Gas Inventory Report (2021).[20]

Due to the expected growth rate in world energy consumption in the near future, it is critical to estimate future energy consumption and associated environmental problems as precisely as possible. Thus, the energy consumption structure can be correctly presented, the relationship between energy consumption and economic developmental parameters can be coordinated, and countermeasures can be determined against energy-related environmental problems (*e.g.* CO_2 emissions).[2] According to the last Turkish Greenhouse Gas Inventory Report (2021), total GHGE in 2019 decreased by 1.4% compared to 2018 emissions in Turkey, however, the total GHGE per individual is 6.4 tons of CO_2 equivalents (CO_2 eq.).[20] Given the dramatic changes and the region's growing influences globally on many levels, each region has different diets and economic growth factors. This study aims to describe total GHGE linked to different geographical diet profiles in Turkey, to map the environmental impacts that these generate. Additionally, the relationship between GHGE linked to geographical diets and developmental parameters such as population, population growth rate, gross domestic product per capita, and socio-economic development scores of a country was analyzed. The first hypothesis was GHGE linked to geographical diet profiles is different. The second hypothesis was there is a relationship between GHGE linked to different regions' diets and developmental parameters.

Methods

Economic growth data

We used the last Address Based Population Registration System (ABPRS) results to identify regions, populations, and some developmental parameters such as population density, population growth rate, gross domestic product per capita, and socio-economic development scores in each region.[21,22]

ABPRS is a modern database where the information about the population of people according to their place of residence is kept up-to-date and population movements can be monitored at any time.[23] In this study, we included all the regions from Turkey which are divided according to the nomenclature of territorial units for statistics (NUTS) due to these regions' use by the National Nutrition and Health Survey (NNHS).[24] NUTS is a geocoding system that originated in the 1970s in Europe. The main purpose of these regional units is to collect statistics on a regional basis, conduct socio-economic analyses, and create the framework of regional policies for society.[25]

According to the NUTS classification, we calculated the total population size, population density, population growth rate, gross domestic product per capita, and socio-economic development scores for each region (Table 1).

Food consumption data

Data on food consumption in Turkish households were obtained from the NNHS (2019) which was performed by the Turkish Ministry of Health. In this study, we used the last NNHS for analyzing the contributions of diets of each region to total GHGE. According to the NUTS regions, the total food consumption was obtained from individuals aged 15 and over.[24]

In the NNHS, trained dietitians collected food consumption data from individuals using 24 hour dietary recall and food frequency questionnaire methods.[24] Both methods were carried out in two independent times separated by two weeks (10–14 days), as recommended by the European Food Safety Authority and dietary intake was expressed in grams consumed per person per day.[26]

Additionally, the meat consumption is given only as the total amount of meat and meat products such as red meat, poultry, and fish and their products in the NNHS. It is well known that the GHGE values of varieties of meat and meat products are extremely different from each other (ESI Table 1†). Therefore, to calculate the mean contributions to GHGE, total meat and meat product consumption were divided into four categories by 1/2 red types of meat like beef, lamb and 1/4 poultry, and 1/4 fish. The reason for this separation was that Turkey's overall food consumption is given by red meat, poultry, fish, and their

Table 1 The population and some developmental parameters of the NUTS regions in Turkey

NUTS regions	Number of urban extents	Population size	Population density	Population growth rate	Gross domestic product per capita	Socio-economic development scores
Istanbul	1	15 462 452	2831	15 029 231	86 798	4.051
West Marmara	5	3 632 398	84	3 503 609	109 159	3.129
Ege	8	10 689 115	120	10 383 963	151 375	5.538
East Marmara	8	8 235 816	169	7 824 597	123 502	7.454
West Anatolia	3	8 168 261	109	7 871 847	112 544	3.563
Mediterranean	8	10 759 218	120	10 303 984	128 502	2.417
Middle Anatolia	8	4 088 228	45	3 977 447	75 773	−0.721
West Black Sea	10	4 638 622	63	4 574 182	105 414	−0.561
East Black Sea	6	2 677 584	105	2 633 417	35 109	−1.104
Northeast Anatolia	7	2 192 453	31	2 188 214	57 444	−6.349
Middle-east Anatolia	8	3 951 294	48	3 854 869	53 028	−7.923
South-eastern Anatolia	9	9 118 921	120	8 665 165	80 869	−9.583

products, but the food consumption of NUTS regions is given only by the main food groups. According to the data, consumption of red meats and products was higher than the others. Thus, we divided the total meat consumption: 1/2 red types of meat, 1/4 poultry, and fish.

Greenhouse gas emissions data

We used life-cycle assessments (LCA) for estimating the GHGE of foods and drinks.[27] LCA is a method to evaluate environmental loads related to all stages of a product's life (production, processing, packaging, transportation, storage, preparing, cooking, and wastage), in this case from farm to fork.[28] There is currently no data on GHGE values for foods produced in Turkey. As a result, for GHGE data, a literature review was conducted, and these data were used. The selection criteria for these studies were a large number of food analyses and the clarity of the system limit, from agricultural input manufacturing to the farm gate. As a result, emissions from after the retail phase (transportation, storing, cooking, and wasting) and emissions from land-use change were excluded from this study. Additionally, food wastage was not included in the present study due to the lack of data. The combined climate effect of all greenhouse gases is expressed as g CO_2 eq. per kg food product.[29]

The data from the NNHS has uncertainties in the composition of the diets. As shown in ESI Table 1,† the variables with uncertainties in this study are GHGE values.

A flowchart about the study is presented in Fig. 1.

Statistical analysis

The data were analyzed by using SPSS 24.0 (Statistical Package for the Social Sciences, Inc.; Chicago, Illinois, United States) and Microsoft Excel. Descriptive statistics (means and standard deviations and percentages of the population) were used for GHGE levels of food consumption of NUTS regions. In all NUTS regions, linear regression was used to assess the significance of changes in GHGE and developmental parameters (population, population density, population growth rate, gross domestic product per capita, and socio-economic development score). *P*-Values were evaluated at <0.05 significance level. Additionally, the energy and macronutrients from diets of NUTS regions were calculated using Nutrition Information System 8.2 (BeBIS 8.2, Willstaett, Germany; Turkish version).

Results

Among the GHGE levels of diets in NUTS regions, the diet from the West Marmara region had the highest GHGE levels with 2983.79 g CO_2-eq. per person per day, followed by the diet of Istanbul with 2941.73 g CO_2-eq. per person per day, and the diet of Southeastern Anatolia with 2935.08 g CO_2-eq. per person per day whereas the Mediterranean region diet had the lowest GHGE levels (2623.90 g CO_2-eq. per person per day). Additionally, the mean GHGE level of regions' diets was 2718.29 g CO_2-eq. per person per day (Table 2).

The contributions of beef and lamb to total diet weight (both were 0.98%) were lower than their contribution to total GHGE (21.65% and 21.04%). Additionally, bread, cereals, and bakery products were the third-highest food group that contributed to total GHGE with 13.4%, their contribution to total diet was 12.67% (Fig. 2).

The correlation analysis showed that the average GHGE levels linked to different geographical diets are not associated with population, population density, population growth rate, gross domestic product per capita, and socio-economic development scores ($p > 0.05$) (Table 3).

According to the linear regression analysis, no statistical differences were found between the average GHGE levels linked to different geographical diets and parameters such as population, population density, population growth rate, gross domestic product per capita, and socio-economic development scores ($p > 0.05$) (Table 4).

Discussion

Today, climate change impacts are a serious threat to the world.[30] Economic growth factors and food systems are the major contributors to the GHGE. Additionally, Turkey is a developing country with a rapidly increasing population and is facing a climate crisis like the rest of the world. Despite its

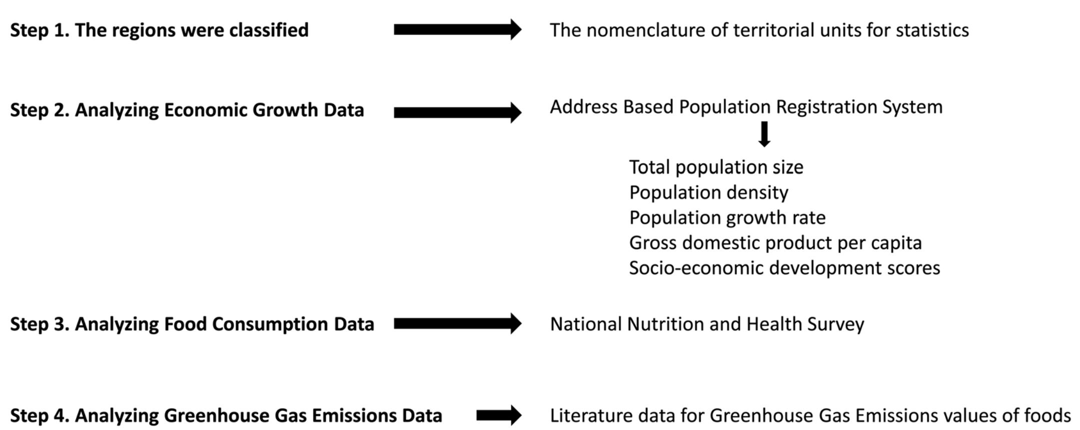

Fig. 1 Flowchart about the study.

Table 2 Daily GHGE, energy, and macronutrient values according to the diets of NUTS regions in Turkey[a]

Food type	Istanbul (*n*: 1811)	West Marmara (*n*: 673)	Ege (*n*: 2204)	East Marmara (*n*: 1315)	West Anatolia (*n*: 1143)	Mediterranean (*n*: 1734)	Middle Anatolia (*n*: 667)	West Black Sea (*n*: 828)	East Black Sea (*n*: 389)	Northeast Anatolia (*n*: 256)	Middle East Anatolia (*n*: 542)	South-eastern Anatolia (*n*: 891)	All regions (*n*: 12 453)
Dairy products	266.32	273.14	252.01	250.06	249.23	273.41	224.76	229.35	236.86	254.23	265.35	315.81	257.54
Beef	679.62	672.15	623.65	600.69	611.31	497.37	619.35	603.56	688.80	609.88	605.57	654.36	622.22
Lamb	660.67	653.42	606.27	583.95	594.27	483.51	602.08	586.74	669.60	592.88	588.69	636.12	604.87
Fish and seafoods	104.43	103.28	95.83	92.30	93.93	76.43	95.17	92.74	105.84	93.71	93.05	100.55	95.61
Poultry	97.56	96.49	89.53	86.23	87.76	71.40	88.91	86.64	98.88	87.55	86.93	93.94	89.32
Eggs	119.33	114.58	102.38	123.74	108.82	104.75	106.79	97.97	102.38	111.19	87.80	86.78	105.53
Legumes	16.56	20.61	14.22	16.83	14.49	13.14	15.93	17.37	14.04	13.95	13.05	12.51	15.23
Nuts	61.36	50.96	44.72	52.00	50.44	52.00	57.72	58.76	73.32	42.12	36.92	34.84	51.27
Vegetables	120.41	114.16	130.52	100.44	120.27	129.96	119.57	132.21	115.76	100.77	107.63	120.09	117.65
Fruits	63.65	77.05	83.80	69.85	91.25	94.85	102.90	83.40	86.05	61.70	80.20	71.65	80.53
Bread, cereals and bakery products	349.55	373.43	362.66	350.66	367.91	384.74	397.58	364.87	342.65	474.44	425.87	428.63	385.25
Oils and fats	73.70	82.08	78.24	76.11	68.87	73.41	62.05	70.29	70.29	64.18	60.21	58.22	69.81
Sugar and sweeteners	2.94	3.00	3.03	3.19	2.94	3.07	3.04	2.99	3.16	4.41	3.58	2.79	3.18
Soft drinks	325.62	349.44	377.74	359.58	386.30	365.86	297.34	323.62	271.46	376.58	304.06	318.80	220.28
Total	2941.73	2983.79	2864.59	2765.63	2847.79	2623.90	2793.18	2750.52	2879.09	2887.59	2758.91	2935.08	2718.29
Energy and macronutrients													
Grams per day													
kcal per day	1854.17	1968.75	1881.00	1841.03	1832.99	1877.28	1864.38	1840.03	1829.45	2032.95	1883.60	1875.29	1881.74
g of protein per day	54.71	56.61	52.92	51.99	52.82	51.18	54.45	52.64	52.67	58.47	55.02	57.74	54.27
% of kcal	11.80	11.50	11.25	11.30	11.53	10.91	11.68	11.44	11.52	11.50	11.68	12.32	11.54
g of fat per day	82.14	86.89	81.71	80.92	75.49	76.67	70.99	76.40	80.01	71.53	67.75	68.31	76.57
% of kcal	39.87	39.72	39.10	39.56	37.07	36.76	34.27	37.37	39.36	31.67	32.37	32.79	36.62
g of carbohydrate per day	224.02	240.07	233.49	226.19	235.57	245.62	251.91	235.48	224.67	288.83	263.45	257.37	243.89
% of kcal	48.33	48.78	49.65	49.15	51.41	52.34	54.05	51.19	49.12	56.83	55.95	54.90	51.84

[a] The values were calculated according to the total food consumption over the age of 15 and the GHGE values are expressed in g CO_2-eq. per person per day.

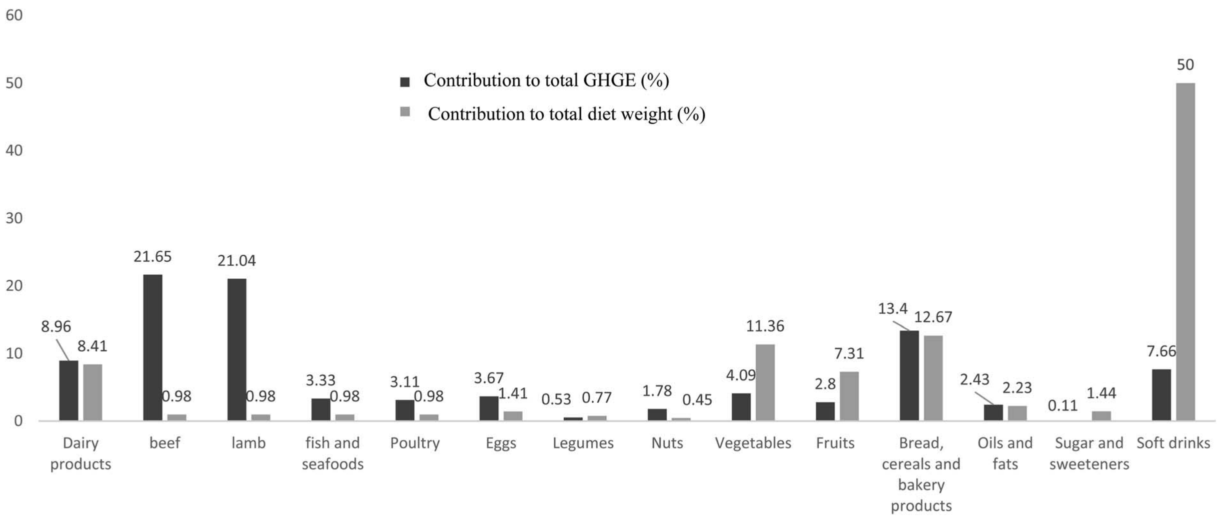

Fig. 2 The contributions of each food group in the average diet of all regions to total diet weight (% of total gram per day) and total greenhouse gas emission (% of total g CO_2 eq. per day).

Table 3 Correlation analysis of the average GHGE levels of diets, population, and other developmental parameters

	Population size	Population density	Population growth rate	Gross domestic product per capita	Socio-economic development scores	GHGE
Population size	—	r: 0.831, $p < 0.001$[b]	r: 0.986, $p < 0.001$[b]	r: 0.650, p: 0.022[a]	r: 0.503, p: 0.095	r: −0.140, p: 0.665
Population density	—	—	r: 0.803, p: 0.002[a]	r: 0.570, p: 0.053	r: 0.606, p: 0.037[a]	r: 0.120, p: 0.711
Population growth rate	—	—	—	r: 0.650, p: 0.022[a]	r: 0.510, p: 0.090	r: −0.084, p: 0.795
Gross domestic product per capita	—	—	—	—	r: 0.776, p: 0.03[a]	r: −0.217, p: 0.499
Socio-economic development scores	—	—	—	—	—	r: −0.021, p: 0.948

[a] $p < 0.05$. [b] $p < 0.001$.

growing population, it is very important to predict future energy consumption and related environmental problems as precisely as possible. In this way, the relationship between energy consumption and economic development parameters can be coordinated and energy efficiency policies can be determined on a regional basis. To our knowledge, this is a first and preliminary assessment of regional baseline trends using food consumption data and developmental parameters such as population size, density and growth rate, gross domestic product per capita, and socio-economic development scores of Turkey. The study results showed that the West Marmara region diet had the highest GHGE levels with 2983.79 g CO_2-eq. per person per day, followed by the Istanbul diet with 2941.73 g CO_2-eq. per person per day and the South-eastern Anatolia diet with 2935.08 g CO_2-eq. per person per day whereas the Mediterranean region diet had the lowest GHGE levels (2623.90 g CO_2-eq. per person per day). The contributions of beef and lamb to total GHGE were highest compared to the other food types (21.65% and 21.04%). Additionally, GHGE levels of diets were not associated with population size, density, and growth rate, gross domestic product per capita, and socio-economic development scores and no statistical differences were found between GHGE-linked different geographical diets and these parameters.

Table 4 Linear regression analysis of the average GHGE levels linked to different geographical diets according to developmental parameters

Parameters	All regions
Population size	0.860
Population density	0.490
Population growth rate	0.846
Gross domestic product per capita	0.956
Socio-economic development scores	0.788

The global population increases day by day, and it is estimated that it will require an increase in food production over the next 30 years, particularly in developing countries.[31] Countries need to increase domestic agricultural production to meet this increasing food demand and remain self-sufficient.[32] Food consumption is associated with behaviour, life, and cultural norms, and has a crucial influence on energy use, and leads to a high contribution to GHGE.[33] 65% of global GHGE and 50–80% of the land, water, and material use can be directly and indirectly related to household food consumption.[34] Additionally, it is suggested that consumption of more plant-based, organic and regional-based diets is important for reducing GHGE.[8,10] Our result showed that the Mediterranean region diet has the lowest GHGE levels. The Mediterranean diet includes all vegetables and fruits, predominantly green leafy vegetables, and lower consumption of red meat, and meat products.[35] Therefore, it causes less environmental impact than other nutrition models (except vegetarian diets), due to the lower contribution to the GHGE.[36] Additionally, the protective effects of this diet model against many diseases, especially cardiovascular diseases, have been shown.[37] Thus, it can be interpreted as a nutritional model that contributes to both health and sustainability.

Meat and meat products have a higher contribution to the diet GHGE, therefore, a strategy for reducing diet-related GHGE is to replace red meat and meat products with alternative protein sources, including vegetarian alternatives.[38] In this study, the contributions of beef had the highest value to the average GHGE levels linked to geographical diets at 21.65%, followed by lamb at 21.04%. While consumption of meat and meat products was lowest in the Mediterranean region diet, it was followed by the Eastern Marmara diet. In addition, the dietary GHGE levels of Eastern Marmara were ranked 9th among all regions. Considering that the total dietary GHGE showed little change, it could be said that the reduction in meat consumption has a positive effect on the GHGE.

From 1990 to 2018, the total GHGE rapidly increased in Turkey. Although the total GHGE in 2019 decreased by 1.4% compared to 2018 emissions, there is a 161% increase compared to 1990. While the energy sector had the largest portion of total GHGE at 72%, followed by agriculture at 13.4%, industrial processes and product use stood at 11.2%, and waste at 3.4%.[20] Additionally, in parallel with economic growth, the population size has increased since 1990, but this increase showed the lowest level of 0.55% from 2018 to 2019.[39] But, it is not known how much the GHGE levels linked to geographical diets contribute to the total GHGE and what the relationship between the GHGE levels of diets and economic growth factors is. In the present study, there were no statistical differences between the GHGE levels of diets and population size, density, and growth rate, gross domestic product per capita, and socio-economic development scores. These results showed that regional diet-linked GHGE was not related to developmental parameters. Additionally, there were no details of the GHGE levels of any of the environmental factors from the production of food to wastage. Only one stage of a product's life was used in this study. Therefore, it may not have found a statistically significant result.

The present study had some limitations. First, GHGE data from food production was limited in Turkey. The GHGE levels from the literature reviews were used. However, food production has similar standards worldwide and the reviews seem to be confident, most of the impacts affect GHGE such as energy carriers, climate characteristics, regional soil, water use, *etc.* Second, this study did not use all of the life cycle steps of food products such as transportation, cooking, and wasting. Third, the NNHS had limited data about food choices in the diet of regions. Therefore, the overall levels of GHGE from the literature reviews were used, but these results may not reflect the exact diet-related GHGE.

Conclusions

Our study highlighted the importance of regional differences between GHGE of diets. The current study showed that dietary changes would significantly contribute to lowering GHGE such as the Mediterranean region's diet. Thus, sustainable diets such as the Mediterranean diet, which is consumed in the Mediterranean region and recommended for consumption all over the world, can both reduce GHGE and positively affect health. Additionally, GHGE of diet might be associated with population size, density, growth rates, per capita income, and socio-economic development scores, but we did not find statistical differences. If the balance between natural resources and economic growth factors cannot be achieved in developing countries such as Turkey, which is a member of the United Nations, the environment will start to suffer and environmental sustainability will become a distant goal. Future studies are needed to analyze food consumption more accurately, and evaluate the relationship between economic growth parameters and other factors that increase greenhouse gas emissions.

Author contributions

HMB and AO – conceptualisation/design of the study, analysis and interpretation, and review and writing of the manuscript; HMB – literature review and data collection; AO – supervision.

Conflicts of interest

There are no conflicts to declare.

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