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The Water-Energy-Food Nexus Index for Bulgaria – Overview and Comments

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KEYWORDS

- Water–Energy–Food (WEF)
- WEF Nexus Index
- Bulgaria

ABSTRACT

The 'Water–Energy–Food' (WEF) Nexus concept is evolving and expanding, as it is essential for finding synergies and compromises between these three sectors under climate change and for building a green economy. This work aims to present and analyse some indicators of the WEF Nexus Index for Bulgaria, according to which the country ranked 66th in the world in 2022. The data sources were the publications of the National Statistical Institute, the Ministry of Environment and Water, etc. The current study found that most indicators in the three pillars objectively assess the country's water resources, energy, and food sectors. The findings reveal a lack of information about the 'Food' pillar, resulting in an inability to assess this pillar objectively. Additionally, the evaluation of several sub-pillars based on the official data shows inaccuracies in the final WEF Index result for the country. This work represents the first presentation of the WEF Nexus Index for Bulgaria and continues the authors' study on the dynamics of the water, energy, and food sectors.

Introduction

Although discussions and criticism (Williams et al., 2019) about the meaning of the Food-Energy-Water (WEF) nexus framework continue (Wichelns, 2017; Pandey & Shrestha, 2017), the concept is developing and broadening because it is crucial for achieving Sustainable Development Goals water-, energy-, and food-related (Yue et al., 2021; Cansino-Loeza et al., 2021; Proctor et al., 2021; Senzanje et al., 2022; Segovia-Hernández et al., 2023), for the transition toward a green economy (Brears, 2023), and to promote sustainability (Cansino-Loeza et al., 2022). The WEF is a systems-based approach for objectively analysing the synergies, conflicts, and trade-offs between these critical linkages (Albrecht et al., 2018). This framework is also significant because the link between vital water, energy, and food systems is essential for efficient governance and securitisation of resources (Leese & Meisch, 2015) to guide cross-sectoral policies (Albrecht et al., 2018) for poverty reduction. Understanding the links among water, energy, and food systems can improve climate change adaptation strategies (Herrera-Franco et al., 2023) and sustainable development of the socio-ecological systems (Jahel et al., 2023). The WEF Nexus aligns with the Stockholm Environment Institute's (SEI) concepts for societal development, which focus on integrating the lower socioeconomic classes, enhancing economic efficiency by "creating more with less," and maintaining ecosystem services (SEI,

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2011). The essence of the water, energy, and food framework is the interconnectedness of the three systems, and a change in one sector will have consequences for the others. By maintaining an ecologically sustainable balance among these critical sectors, the WEF framework can significantly shape future development strategies, particularly in regions where resource security is at risk.

Bulgaria's available renewable freshwater resources in 2022 are 15-16 m, less than the reference period 1961-1990. The freshwater abstraction for the economic sectors in the same year is 5.5 billion m³ cubic meters. Most water is abstracted for cooling processes in the energy sector, 66.4%. The water abstracted for water supply (from the water supply and sewerage) is 14.7%, and for irrigation in agriculture, it is 14.3% of all water used for the economy. More than 50% of abstracted freshwater in Bulgaria for cooling processes in energy production comes from the Danube River. Water reserves decrease significantly during the summer-autumn period, accounting for 12% and 18% of the annual river runoff. Over 200 settlements in the country experienced interrupted water supply. The water levels in the reservoirs are decreasing, hindering vegetable producers and hydropower generation in run-of-river hydropower plants. The described situation creates a need for compromises between available water reserves, water supply, hydropower generation, and irrigation. The state of the link between the water, energy, and food sectors in Bulgaria under climate change is described by Hristova & Nikolova (2024). The current study aims to present and comment on the "water-energy-food" index for Bulgaria in the last five years.

Data and Methods

The sources of the data for Bulgaria in the current study are the Ministry of Environmental and Water (MOEW), the Ministry of Health, the Ministry of Agriculture and Food, the National Statistical Institute (NSI), the Executive Environment Agency (ExEA), Strategy for Sustainable Energy Development of the Republic of Bulgaria until 2030 with a horizon until 2050, Strategic plan for the development of agriculture and rural areas 2023–2027, General strategy for the management and development of hydro melioration and protection from the harmful effects of water, River Basin Management Plans 2022–2027, Annual Report and Comparative Analysis of the State of the Water Supply Sector in the Republic of Bulgaria for 2021, Integrated plan in the field of energy and climate of the Republic of Bulgaria 2021–2030. There is no data in these sources for the following indicators: renewable energy consumption and renewable electricity outputs for 2022. There is no direct data on sub-pillar "Food Availability" indicators, except for cereal yield. The current study does not calculate WEF Nexus Index indicators because there is no statistical data for most indicators in pillar "Food". The NSI gives data for cereal yield in 2021 and CO2 emissions in the same year. The lack of information makes it impossible for the open-access COIN Tool to be used (Excel-based), and this study does not comment on these indicators.

Simpson et al. (2019) developed the WEF Nexus (for the countries in the South Africa region), a composite index with three pillars: water, energy, and food: pillar "water" measures access to water resources, availability, and quality; pillar "energy" assesses energy access, efficiency, and renewable energy use; and pillar "food" evaluates food availability, food security, and agricultural productivity. Each pillar has two sub-pillars: "access" (for the population's ability to access resources) and "availability" (for the quantity and quality of resources available in the country) (Fig. 1). Simpson et al. (2019) developed the WEF Nexus (for the countries in the South Africa region), a composite index with three pillars: water, energy, and food: pillar "water" measures access to water resources, availability, and quality; pillar "energy" assesses energy access, efficiency, and renewable energy use; and pillar "food" evaluates food availability, food security, and agricultural productivity. Each pillar has two sub-pillars: "access" (for the population's ability to access resources) and "availability" (for the quantity and quality of resources available in the country).

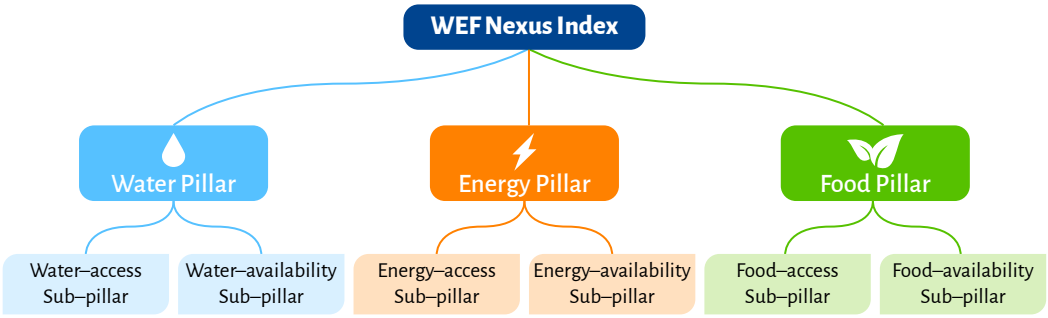

Figure 1. Pillars and sub-pillars of the WEF Nexus Index

Source: Simpson et al., 2023.

Results and discussions

The WEF Nexus Index value for Bulgaria varies between 58.3 for 2020 and 60 for 2022, placing the country in the 66th position among the other countries (Table 1). In comparison, the highest index was 83.9 for Iceland in 2020.

Table 1. WEF Nexus Index for Bulgaria during 2019–2022

Year	2019	2020	2021	2022	2023
WEF Nexus Index	58.5	58.3	60.0	60	59.2
Rank	72	78	70	66	69

Source: https://wefnexusindex.org

Table 2. Score and rank of Bulgaria by pillars of the WEF Nexus index, 2019–2023

Pillar	2019		2020		2021		2022		2023	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Water	60.5	89	59.9	92	62.2	84	61.7	73	60.1	70
Energy	55.9	67	55.0	68	57.5	66	57.5	68	55.6	75
Food	59.0	53	60.0	60	60.4	62	60.8	66	62.0	61

Source: https://wefnexusindex.org

Bulgaria's scores by pillars do not vary significantly for 2019–2023 (Table 2). The numeric index for the water pillar alters between 59.9 (92nd worldwide rank) in 2020 and 60.1 (70th worldwide rank) in 2023, showing progress towards achieving goals 6, 7 and 12 of the Sustainable Development Goals. The energy and food pillars data for 2023 put Bulgaria in a lower position than in previous years (Table 2).

Pillar "Water"

Sub-pillar: Water Access. The analysis of the first two indicators (01 and 02) in the sub-pillar "Water Access" shows that they are objectively evaluated (Table 3). Bulgaria has no settlements without a water supply and sanitation system (WSS). According to the "Annual Report and Comparative Analysis of the State of the Water Supply Sector in the Republic of Bulgaria for 2021," this indicator's score must be 99.7% (99% in the WEF Index). The same number of points must be assigned to the second indicator. The third indicator, the degree of integrated water resources management implementation, was calculated at 77 points. This estimate needs to be revised because Bulgaria implemented the Water Framework Directive according to all its requirements: develop the River Basin Management and Flood Risk Management Plans, and conduct studies and assessments. We agree that the score cannot also be 100 points because there is no National Real Time Water Management System, coordination between land use and flood management, and centers on increasing the population's preparedness for an adequate response to floods (for now so far). The last facts confirm the need to implement the Food–Energy–Water Nexus framework: only the coordination and policy coherence across the several ministries can effectively implement these activities.

Sub-pillar: Water Availability. The score of the annual water extraction is 26.9 (indicator 04), and renewable do-

Table 3. Score by indicators for pillar Water, 2019–2023

Sub-pillars	2019	2020	2021	2022	2023
Water Access					
01. Percentage of people using at least basic drinking water services (%)	99.3	99.1	99	99	99
02. Percentage of people using at least basic sanitation services (%)	86	86	86	72.2	72.2
03. Degree of integrated water resources management implementation (1–100)	60.2	60.9	69	77	69
Water Availability					
04. Annual freshwater withdrawals	27.2	26.6	26.9	26.9	24.2
05. Renewable internal freshwater resource per capita.	2.91	2.94	2.98	2.98	3.03
06. Environmental flow requirements (106 m3/annum)	7.8	7.8	7.8	7.8	7.8
07. Average precipitation (mm/year)	608	608	608	608	608

Source: https://wefnexusindex.org

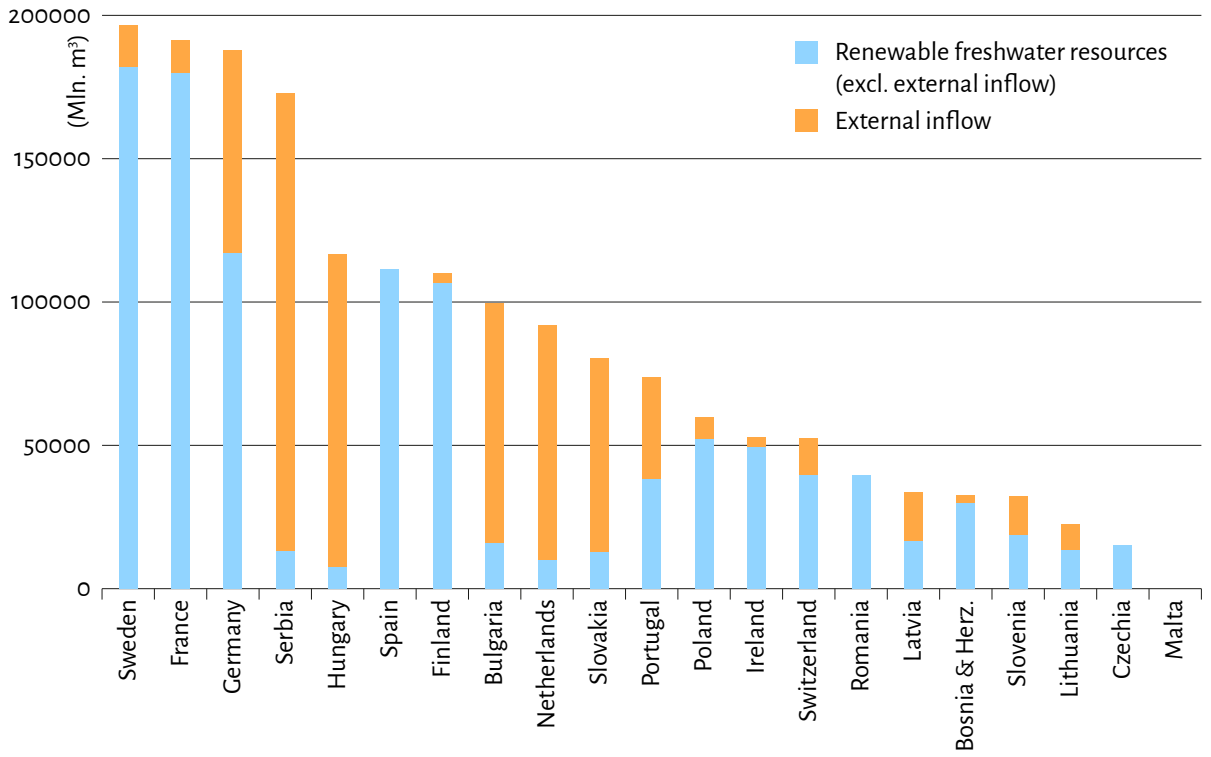

Figure 2. Available renewable freshwater resources in European countries

Source: Eurostat

mestic freshwater resources per capita were at 2.98 (indicator 05). Indicator 04 is objectively estimated. Available renewable freshwater resources in Bulgaria, excluding external inflow for 1981–2020, is 15,789 million m³ (National Statistical Institute, 2022). The renewable internal freshwater resource per capita in 2021 is 14,452 m³ with the Danube River and 2,936 m³ without the Danube River. Furthermore, is that there is no "water stress" in the country (annual water resources are above 1,700 m³ per capita, 5.1% for 2021, close to the average for 2000–2019, 6.0%) (Fig. 2). These two facts raise (or must raise) the score of the 05 indicator from the WEF Nexus point of view.

The indicator environmental flow requirements score of 7.8 (106 m³/annum) for 2021 is wrong. The ecological flow in 2019 is 51 106 m³/annum (10% by annual streamflow of 20,195.1 × 10⁶ m³ in the same year). The indicator for the average precipitation (mm/year) has to rise. The average precipitation for 1997–2022 in Bulgaria is 632 mm (between 377.0 and 963.0 mm). The difference with published data of 603 mm is insignificant, but it will be better to calculate this indicator for the equal study period in different countries.

Pillar "Energy"

Sub-pillar: Energy Access. The score for the first two indicators ((% of the population, % of the population) in the sub-pillar for energy access is constant in 2019, 2020, and 2021 (Table 4). There is no reason for the decrease in the numeric index from 100 to 99.7 points in 2021 and 2021 because there has been no change in access to electricity. The

Table 4. Score by indicators for pillar "Energy", 2019–2023

Sub-pillars	2019	2020	2021	2022	2023
Energy Access					
08. Access to electricity (% of the population)	100	100	100	99.7	99.7
09. Renewable energy consumption (% of total energy consumption)	17.7	17.7	17.7	19.3	21.1
10. Renewable electricity outputs (% of electricity output)	18	18	18	18	18
11. CO_2 emission (metric tons per capita)	5.9	5.9	5.9	5.6	4.9
Energy Availability					
12. Electric power consumption (kWh per capita)	4.71	4.71	4.71	4.71	4.71
13. Energy imports (net % of energy use).	36.6	36.6	36.6	36.6	36.6

Source: https://wefnexusindex.org

following indicator, "renewable energy consumption (% of total energy consumption), takes into account the country's electricity production structure changes. Renewable energy consumption (% of total energy consumption) rose from 2017 to 2021, except in 2021, renewable energy represented 17.0% of the energy consumed in the country, down from 23.3% in 2020 (Table 5). The same trend is in the EU for these two years (22.1% in 2020 and 21.8% in 2021). This indicator was close to the average for European countries during the first three years of this period (Fig. 3)

CO_2 per capita. This indicator varies substantially, but the trend in the last few years has been negative (Republic of Bulgaria Ministry of Environment and Water, 2021). The study by Harizanova-Metodieva and Harizanova-Bartos (2020) shows a positive relation between energy consumption and emitted carbon dioxide in the short run. Stoyanova-Asenova et al. (2024) did not find a correlation between government regulation and emission levels.

Sub-pillar: Energy Availability. According to the National Statistical Institute, Bulgaria, the gross electricity production in Bulgaria for 2023 is 40246 GWh, which is lower than in the previous year (2022 the production was 50385 GWh). The energy use shows a strong decrease in the period 1988–1991. In 1991 energy use decreased by approximately 20% in comparison to 1990. The difference in the values for the period 1999–2020 is not very big (Fig. 5). And the decrease in energy use in 2023 compared to 2022 is about 13%.

Table 5. Renewable energy consumption in Bulgaria (% of total energy consumption)

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
13.9	14.2	15.8	18.9	18.1	18.3	18.8	18.7	20.6	21.6	23.3	17.0

Source: National Statistical Institute

Renewable energy production capacity in Bulgaria is 4,532 megawatts in 2021 and 5,205 megawatts in 2022. The largest share of renewable energy capacity at the end of last year was hydropower capacity (2505 megawatts). Solar capacity has strong growth; their capacity increased to 1,948 megawatts in 2022 from 1,275 megawatts in 2021 (or by almost 53%). The share of renewable energy in the total electrical capacity in Bulgaria increased to 43.8% from 40.4% a year earlier and 35.3% ten years ago. Hence, the score of the indicator of renewable electricity outputs (% of electricity output) has to rise.

CO_2 emission (metric tons per capita) for 2020 is 4.9 and this is the lowest value for the period 1990–2020 (Fig. 4). In 2021, Bulgaria's carbon dioxide emissions were 6.33 tons of

The country's energy dependence in the period 2018–2022 varies between 36 and 39% (Table 6). Energy dependence on imports as of in 2021 was 36.1%, lower than the European Union average of 57.5%, less than Germany, Greece, Belgium, Ireland, etc. Bulgaria is a net exporter of electricity (Ministry of Energy of Bulgaria, 2021). Bulgaria is

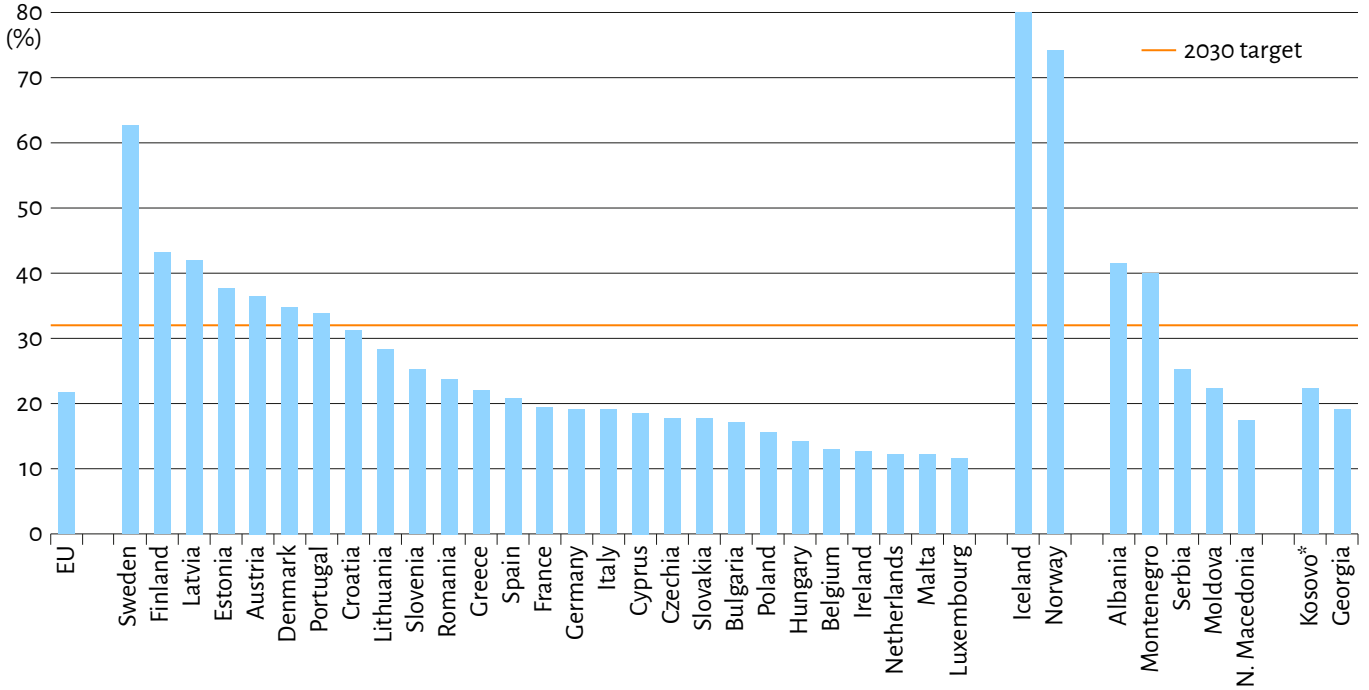

Figure 3. Share of energy from renewable sources, 2021 (% of gross final energy consumption)

Source: Eurostat

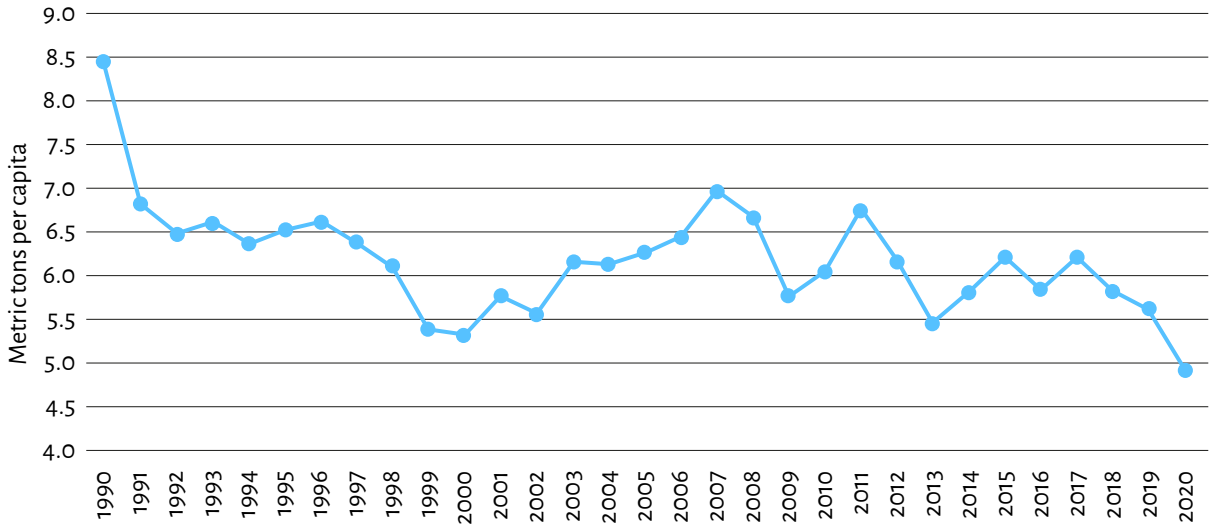

Figure 4. CO_2 emission in Bulgaria (metric tons per capita)
Source: World Resources Institute, 2023

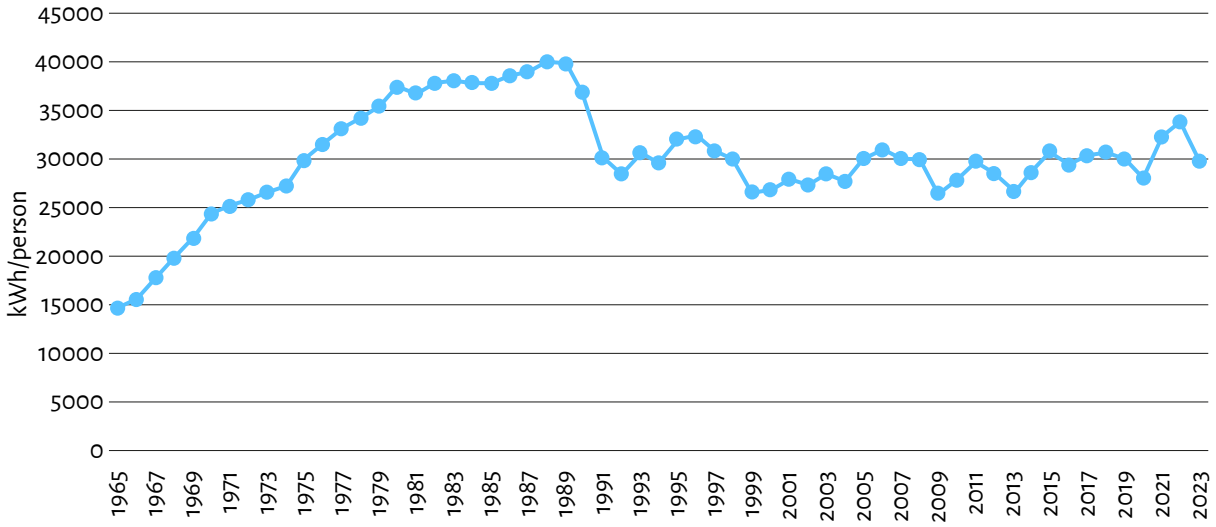

Figure 5. Energy use per person in Bulgaria
Source: ourworldindata.org/

among the five countries best dealing with energy vulnerability in Eastern Europe in the Euromonitor International index (on data on energy efficiency, energy import dependence, energy mix and electricity generation capacity). According to these indicators, Bulgaria is around the average level globally, and it is among the leaders in the region of Eastern Europe. The reason is the large share of nuclear energy, which provides an alternative to fossil fuels. The country has excellent access to the energy grid and one of the region's highest electricity generation levels per capita.

Table 6. The energy dependence of Bulgaria (%)

2017	2018	2019	2020	2021	2022
39.4	36.6	38.5	38.2	36.1	37.1

Source: National Statistical Institute

Pillar "Food"

Sub-pillar: Food Access. The first three indicators in this sub-pillar are prevalence of undernourishment, children under five years old affected by wasting, and children under five years old who are stunted are challenging to assess due to the lack of publicly available data (Table 7). Therefore, we can only comment on the last indicator: the prevalence of obesity in the adult population (aged 18 and older).

The indicator "prevalence of obesity in the adult population" was calculated in the WEF Nexus Index for Bulgaria at 25. This calculation was based on data related to body mass index (BMI), underweight, overweight, and obesity from 1975 to 2016. However, more recent data from 2022 show that this indicator is 23.2% (https://renewbariatrics.com, 2023). The prevalence of obesity in the adult popu-

Table 7. Score by indicators for pillar "Food", 2019–2023

Sub-pillars	2019	2020	2021	2022	2023
Food Access					
14. Prevalence of undernourishment (%)	3	3	3	3	3
15. Percentage of children under 5 affected by wasting (%)	3.2	6.3	6.3		
16. Percentage of children under 5 who are stunted (%)	8.8	7.0	6.4	6.4	5.6
17. Prevalence of obesity in the adult population	27.4	25	25	25	25
Food Availability					
18. Average protein supply (gr/caput/day)	94	82.7	84.3	83.3	80.7
19. Cereal yield (kg/ha)	4817.8	5479.7	5463.8	5463.8	5949.6
20. Average dietary energy supply adequacy	117	113	115	116	119
21. Average value of food production ($/capita).	457	456	157	157	157

Source: https://wefnexusindex.org

lation in Bulgaria by body mass index above 30 kg/m^2 for 2022 is 14.8% (Table 8). This data indicates that adult obesity in Bulgaria is lower than the average in the European Region, which is 59% (WHO European Regional Obesity Report 2022). Therefore, this indicator in the WEF Nexus Index should be corrected. According to the World Obesity Federation (2022), the percentage of the adult population with obesity in Bulgaria is projected to rise to 31.4% by 2030.

Sub-pillar: Food Availability. There is only data for this sub-pillar for cereal yield (indicator 19). According to the World Bank, the cereal yield (kg per hectare) in the European Union was 5,666 kg/ha in 2021, and in Bulgaria, it was 5,666 kg/ha for the same year (Ministry of Agriculture and Food, 2023), but without rice, millet, buckwheat, and mixed grains (Table 9). The cereal yield (kg per hectare) in the world was 4,153 kg/ha in 2021.

Table 8. Prevalence of obesity in the adult population (18 years and older) in Bulgaria in 2022 (%)

Body mass index	Total	Men	Women
Overweight (25.00–29.99)	39.2	46.7	32.6
Obesity (30.00+)	14.8	15.5	14.2

Source: National Statistical Institute, 2023

Table 9. Cereals in Bulgaria in 2021 (Source: Ministry of Agriculture and Food, 2023)

Cereals	ha	kg/ha
Wheat	1 208 457	5902
Rye	8088	2170
Barley	126 957	5411
Oats	10 335	2373
Maize	579 613	5892
Sorghum	2405	2784

Conclusions

The WEF Nexus Index for 2019-2023 places Bulgaria in a mid-range position among 164 countries. The water pillar numeric indexes increase and show at the same time that further action is needed to enhance water management: Bulgaria is gradually growing renewable energy production, but water consumption in the energy sector is still high; the water resources in the summer are not enough for irrigation. Nevertheless, the database by Nexus index indicates the need for a more aggressive strategy to transition towards sustainable energy practices. The food pillar presents the most significant challenge in the WEF Nexus assessment for Bulgaria due to insufficient information.

The current study proves that the WEF Nexus Index provides valuable insights into Bulgaria's water, energy, and food sectors, but its objectivity depends heavily on the quality and availability of data. The results also show that the index methodology needs refinement regarding some indicators and the database used.

In relation to the achievement of the Sustainable Development Goals (SDGs), this study contributes to advancing adaptation strategies for climate change, particularly at the local scale, where microclimate conditions are further altered by anthropogenic activities (SDG 13).

Acknowledgments

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