sustainability

MDPI

Article

A Life Cycle Assessment of Snack Bar Prototypes Created with Ingredients Compatible with the Mediterranean Diet

Gökhan Ekrem Üstün [1,*] and Metin Güldaş [2]

[1] Environmental Engineering Department, Faculty of Engineering, Görükle Campus, Bursa Uludag University, 16059 Nilufer-Bursa, Türkiye
[2] Nutrition and Dietetics Department, Faculty of Health Sciences, Görükle Campus, Bursa Uludag University, 16059 Nilufer-Bursa, Türkiye; mguldas@uludag.edu.tr
* Correspondence: gokhaneu@uludag.edu.tr

Abstract

Healthy nutrition is of great importance to maintain the physical and mental health of individuals. In recent years, products such as snack bars have become widely used to encourage healthy eating habits. This study compared the environmental footprints of four snack bar prototypes that adhere to the Mediterranean diet (MD) through a life cycle assessment (LCA). LCA is used to calculate an environmental footprint, encompassing six impact categories: Global Warming Potential (GWP), Abiotic Depletion (AD), Human Toxicity (Cancer (HTC) and Non-Cancer Effects (HTNC)), land use (LU), and water use (WU). The total impacts were as follows (prototypes 1–4, respectively): GWP 0.221/0.224/0.234/0.194 kg CO_2-eq; AD 2.35/2.87/2.63/2.01 MJ; HTC 9.13×10^{-10}/7.69×10^{-10}/9.82×10^{-10}/9.88×10^{-10} CTUh; HTNC 1.03×10^{-8}/1.51×10^{-9}/4.16×10^{-9}/3.03×10^{-9} CTUh; LU 14.8/21.6/21.8/10.8; WU 0.132/0.287/0.198/0.068 m^3. Prototype 4, which yielded the lowest value across four indicators (GWP, AD, LU, and WU), is the most environmentally favorable. A range of 89–91% of the GWP originates from raw material production, while the share attributed to transportation is 3–4%. Nuts and dried fruit contents are decisive for WU and LU. The findings suggest that environmental impacts are highly sensitive to ingredient composition and agricultural inputs, and that selecting raw materials and optimizing the supply chain is critical for mitigation.

Keywords: food sustainability; life cycle assessment; snack bar prototypes; Mediterranean diet

check for updates

Academic Editor: Alessandro Bonadonna

Received: 15 August 2025
Revised: 29 August 2025
Accepted: 8 September 2025
Published: 11 September 2025

Citation: Üstün, G.E.; Güldaş, M. A Life Cycle Assessment of Snack Bar Prototypes Created with Ingredients Compatible with the Mediterranean Diet. *Sustainability* **2025**, *17*, 8195. https://doi.org/10.3390/su17188195

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Fast-paced work environments and an urban lifestyle often lead people to seek quick and convenient nutrition options [1]. Therefore, developing products that promote healthy nutrition is crucial for both individual health and the overall well-being of society [2]. At the same time, there is a growing need in food systems to improve access to affordable, healthy, and sustainable diets [3]. In recent years, products such as snack bars have become widely used to promote healthy eating habits [4]. Snacks are foods and drinks that we eat outside of the main meals of the day and can be part of a healthy, balanced diet [5]. Snacking has become a common habit among children and adolescents, with snack sales increasing by 57% in Mediterranean countries over the last decade [6,7]. Research indicates that snacks account for about 27% of total daily caloric intake, exceeding the percentage consumed at breakfast (18%) and lunch (24%), but not dinner (31%) [8]. Food production

processes have significant environmental impacts, starting from the supply of raw materials and continuing through stages such as production, packaging, distribution, and waste management [9–11]. The agricultural sector, which plays a leading role in food production, is responsible for approximately 25% of GWP emissions, 50% of habitable LU, 70% of freshwater WU, and 78% of global eutrophication (EU) [12,13]. Food systems are responsible for a third of global anthropogenic GHG emissions [14]. It has been reported that increasing nut consumption in the EU may lead to increased WU impacts due to the global nut market [15]. Food systems are the main drivers of biodiversity loss due to EU consumption patterns [16]. The Sustainable Development Goals (SDGs) set by the United Nations (UN) also highlight the importance of productive and environmentally sustainable food systems focused on health and nutrition [17]. Ensuring sustainable food production and consumption is also one of the 17 SDGs [18]. The SDGs are crucial for promoting sustainable development, as they reflect the collective needs of stakeholders worldwide, striking a balance between social, economic, and environmental growth. However, food waste and loss pose significant challenges that are increasingly receiving global attention due to their links to food security, responsible consumption, and climate change [19]. Every year, the UN reports that 1.3 billion tons of food are lost, resulting in 795 million people lacking sufficient food and nearly 1 billion people being malnourished [20]. The environmental impact of food extends throughout its entire life cycle, from production to consumption. A life cycle assessment (LCA) can quantitatively analyze the environmental impacts of a product, process, or food, including its impact on ecology, resources, and human health [21]. In this context, analyzing the environmental impacts of foods and diets that promote healthy nutrition using the LCA method contributes to the development of sustainable food systems [22–24]. LCA offers a thorough assessment of a product's entire life cycle, considering the input and output of material, energy flows, and associated processes [25]. LCA allows for the evaluation of environmental impacts at every stage of food production, which includes agricultural production, industrial processing, packaging, distribution, retail, and waste management [26,27]. LCA has also been increasingly used in policy-making [28]. At the policy level, strategies such as promoting environmentally friendly agricultural methods or promoting sustainable consumption habits can be developed based on LCA findings [29]. LCA has been used worldwide to define sustainability in food production and diet menus [30–33]. The increasing interest in sustainable food systems and diets has sparked a growing focus on the MD [34,35]. There are several limitations in the literature regarding the evidence supporting the environmental sustainability of MD [36–40]. First, limited information is available about each step of the food production chain, which can lead to assumptions in environmental impact analyses [41,42]. Second, the food production system is inherently complex, and many factors need to be carefully managed and considered [43]. In this context, it has been stated that food production is a complex open system network, extending from water resources, soil, crops, and vegetation to interactions among the environment, climate, and trade [44]. Food processing is the least considered stage in food LCA, and therefore, limited information is available on the impacts of products like snack bars [22,45,46]. Given these considerations, our study is an LCA of four snack bar prototypes that were created based on the principles and components of the MD, containing different types and amounts of nuts, dried fruits, legumes, and grain-based products. This study aimed to evaluate and compare the prototypes in terms of sustainable food and environmental management. By comprehensively assessing the environmental impacts of snack bars using an LCA approach, this study represents an innovative example in the food and environmental sustainability literature.

2. Materials and Methods

2.1. Goal and Scope Definition

The LCA methodology assesses the environmental impacts of a product, process, or service throughout its life cycle within the scope of the International Standards ISO 14040 and ISO 14044 [47,48]. LCA comparison of the met and bar prototypes suitable for the MD was performed. The cradle-to-grave model covers system boundaries, including the production of raw materials, the transportation of raw materials to the production facility, production, the usage phase, and the end-of-life phase (Figure 1).

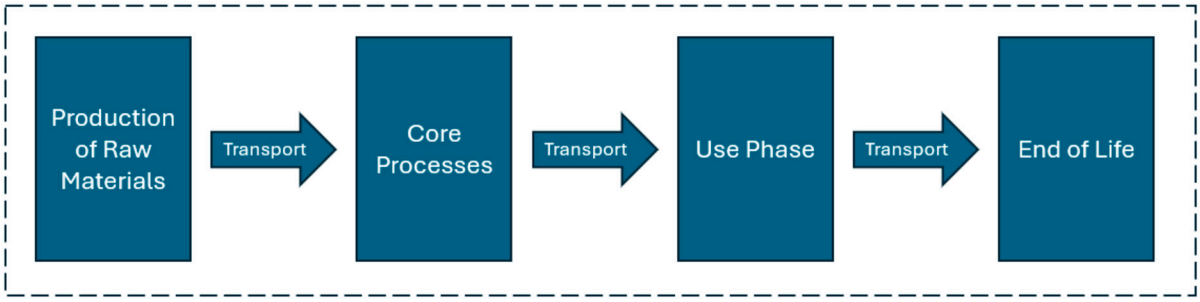


Figure 1. System boundary of LCA study.

2.2. Production of Bar Prototypes

In this study, four prototypes were created based on the principles and components of the MD. Before production, the cereal contents were preheated at 150–160 °C for 10 min. Dried fruits were also cut into small pieces of 0.5–0.6 mm in diameter. The production stages of the prototypes are given in Figure 2.

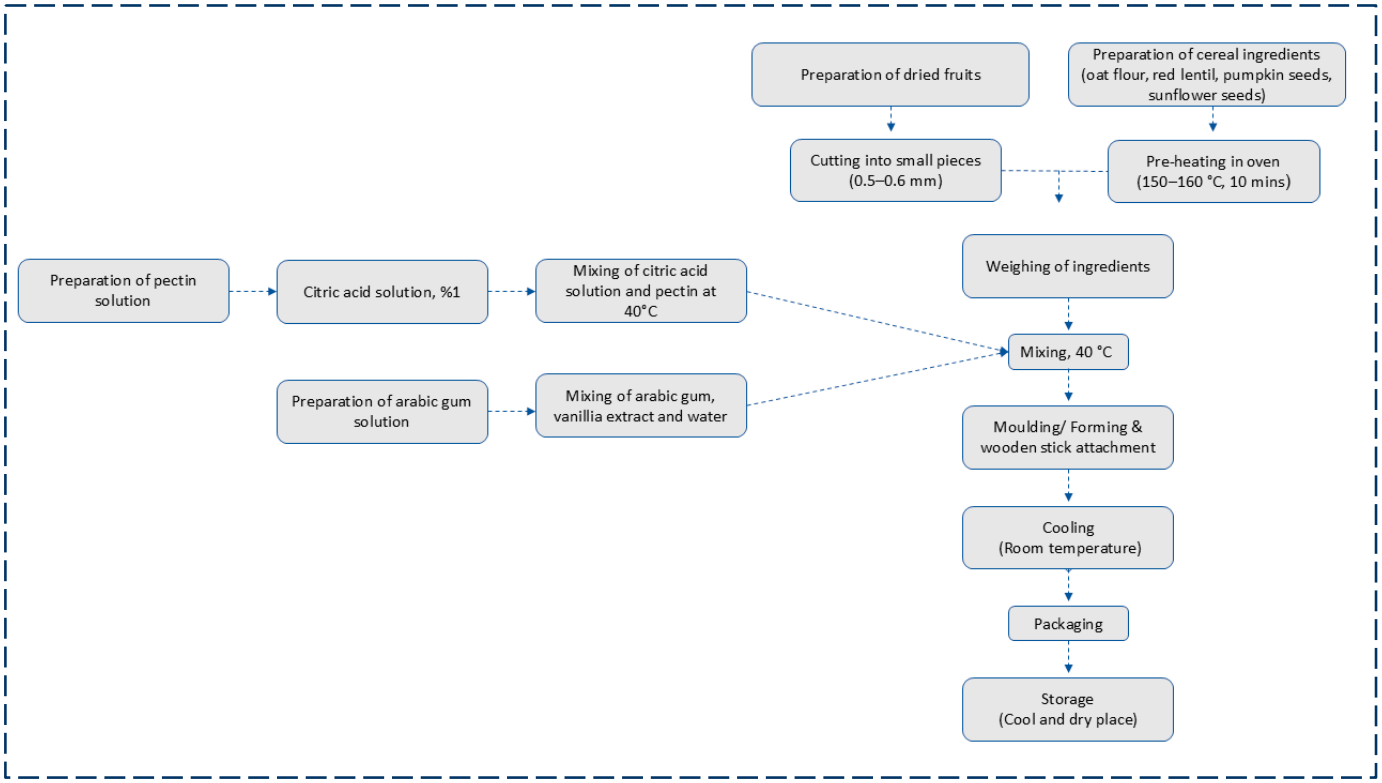


Figure 2. General production process diagram for prototypes.

All of the prototypes contained different healthy additional ingredients found in the MD. The prototypes used plant-based food ingredients rich in healthy bioactive compounds

(such as carotenoids, phenolic compounds, terpenoids, fatty acids, minerals, and vitamins) that play an important role in Mediterranean culture [49]. The prototypes used dried nuts and fruits grown in Türkiye, a Mediterranean country, resulting in products with low water activity and high microbiological stability [50]. The dried nature of the foods used in the prototypes also provided advantages such as being usable during periods when not in production, extending the shelf life for food safety, and ensuring an economic balance between supply and demand [51,52]. The raw materials used in production were sourced from local suppliers whenever possible, and material transportation was kept to a minimum, reducing product carbon footprints [53]. The environmental impact of potential packaging waste was minimized by using lightweight, durable, environmentally friendly, and optimally sized packaging materials for the products. The prototypes used degradable, recyclable, and transparent polyethylene-based packaging [54]. Prototype 1 contained additional ingredients such as blackberry, apricot, and cinnamon. Prototype 2 contained additional ingredients such as blackberries, red lentils, pumpkin seeds, oranges, and cinnamon. Prototype 3 contained additional ingredients such as sunflower seeds, sesame, and date. For Prototype 3, only the coating step in the flow diagram given in Figure 2 is omitted. Prototype 4 contained additional ingredients such as pumpkin seed, red lentil, black fig, and cinnamon.

2.3. Life Cycle Inventory Analysis

Various raw materials were utilized in the production of prototypes, and the life cycle of these raw materials was assessed using inventory data and information from the LCA background data on raw material production processes. The ingredients used in the production of prototypes are presented in Table 1.

Table 1. The ingredients of the prototypes.

Ingredient List	**Amount (g)**			
	Prototype 1	**Prototype 2**	**Prototype 3**	**Prototype 4**
Oat flour	25	22	22	26
Almond flour	21			7.2
Walnut flour		12		
Walnut particles			14	10
Silverberry powder		3		
Pumpkin seeds		9		7
Sunflower seeds			7	
Sesame seeds			8.5	
Red lentils flour		5		5
Dried apricot	26			
Silverberry powder	4			
Dried orange powder		3		
Ground mulberry leaf powder			0.7	
Dried mulberry			7	10
Dried persimmon			8	
Dried fig				12
Date		22	10	

Table 1. *Cont.*

Ingredient List	Amount (g)			
	Prototype 1	**Prototype 2**	**Prototype 3**	**Prototype 4**
Inulin (Chicory)	1.5	1.848	1.8	1.498
Vanilla extract	0.002	0.002		0.002
Cinnamon powder	0.748	0.4		0.3
Arabic gum	10	10	10	10
Water	7	7	7	7
Pectin powder	1	1	1	1
Acidized water (for pectin solubilization)	3.75 (50 water:0.5 citric acid 1%)	3.75 (50 water:0.5 citric acid 1%)	3 (50 water:0.5 citric acid 1%)	3 (50 water:0.5 citric acid 1%)

The functional unit was a 100 g bar prototype. Each bar prototype was packaged with low-density polyethylene film (0.6 g), a printed paper pack (1.44 g), and a wooden stick (0.45 g). The production processes consisted of the drying and prototype production line. Both processes consumed electricity, and electrical data was used from the EcoInvent database. The bar production line consumed electricity, and 0.026 kWh/kg of energy was consumed during production. For the retail phase, a 250 km average transport distance was considered. The products do not need cool conditions, and other electricity consumptions like illumination were cut off according to ISO 14040/44 standards, so that the environmental impact would be less than 1%. The end of life step covers the disposal of packaging materials. According to the Turkish Statistical Institute (TURKSTAT), 61% of waste is landfilled, 36.5% is recycled, and there is a 2.5% energy recovery [55].

Transport of Raw Materials

Considering the place where raw food ingredients are produced, the transportation distances and transportation type according to the city of Bursa, where this study was conducted, are presented in detail in Table 2.

Table 2. Transport types and distances of raw food materials.

Raw Food Material	Region	Transport Type and Distance (Average km)
Almond	Mediterranean Sea Region in Türkiye	600 (Road)
Arabic Gum	Senegal	5850 (Sea)
Cinnamon	Indonesia	13100 (Sea)
Palm Date	Saudi Arabia	3000 (Road) 2500 (Sea)
Orange	Mediterranean Sea Region in Türkiye	600 (Road)
Apricot	Around Marmara Region in Türkiye	250 (Road)
Fig	Around Bursa Region in Türkiye	100 (Road)
Mulberry	Around Bursa Region in Türkiye	100 (Road)
Inulin	Around Marmara Region in Türkiye	250 (Road)
Oat	Inner Anatolia Region in Türkiye	600 (Road)
Pectin	Around Marmara Region in Türkiye	250 (Road)
Persimmon	Around Bursa Region in Türkiye	100 (Road)
Pumpkin Seed	Inner Anatolia Region in Türkiye	600 (Road)
Red Lentil	South-East Region of Anatolia in Türkiye	1200 (Road)

Table 2. *Cont.*

Raw Food Material	Region	Transport Type and Distance (Average km)
Sesame Seed	Aegean, Mediterranean, and South-East Anatolia Region in Türkiye	600 (Road)
Silverberry	Around Marmara Region in Türkiye	250 (Road)
Sunflower Seed	Around Bursa Region in Türkiye	100 (Road)
Vanilla	Around Marmara Region in Türkiye	250 (Road)
Walnut	Around Bursa Region in Türkiye	100 km (Road)

2.4. Life Cycle Impact Categories

The results for the impact category indicators were calculated using the Recipe Midpoint (H) V1.13 impact evaluation method, a widely used approach in current LCA studies. This study was conducted using SimaPro 9.6, a life cycle assessment software. The secondary data sources utilized included EcoInvent 3.10 (as of March 2024) and Agri-footprint version 6.3 (as of September 2022). Table 3 presents the life cycle impact assessment (LCIA) categories that are highly relevant to this study's goals. The Environmental Footprint (EF) 3.1 methodology [56] was employed to calculate the LCIA.

Table 3. Impact categories.

Impact Category	Indicator	Unit	Model
Global Warming Potential (GWP)	Global Warming Potential total (GWP-total)	kg CO_2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
Abiotic Depletions, Fossil Fuels (AD)	Abiotic Depletion potential (ADP-fossil) for fossil resources	MJ, net calorific value	CML 2002
Human Toxicity, Cancer (HTC), and Non-Cancer (HTNC) Effects	Potential Comparative Toxic Unit for humans (HTP-c) and (HTP-nc)	CTUh	Usetox version 2
Land Use-Related Impacts/Soil Quality (LU)	Potential Soil Quality Index (SQP)	dimensionless	Soil quality index based on LANCA
Water Use (WU)	Use of water	m^3	Inventory calculation

3. Results

The results obtained provide an assessment of the environmental footprints and nutritional properties of bar prototypes prepared according to the MD diet. The environmental impact results of prototypes 1, 2, 3, and 4 are given in Tables 4–7, respectively. The "Raw Material Production" column represents the environmental impacts resulting from inputs such as the fertilizers, pesticides, water, and energy used in the production phase of raw materials, including apricots, almonds, and dates. The "Raw Material Transportation" column represents the environmental impacts resulting from the transportation phase of raw materials. "Raw Material Production" and "Raw Material Transportation" are upstream processes. The "Production Process" column displays the direct environmental impacts of core process emissions. The "Retail Phase" and "End of Life" are downstream processes. The "Retail Phase" column shows the impacts of the retail phase. The "End of Life" column shows the effect of the waste management of packaging materials after the consumption of the bars. The "Total Impact" column shows the total environmental impact of the prototypes over their life cycle.

Table 4. Environmental impact results of prototype 1.

Impact Category	Unit	Production of Raw Materials	Transport of Raw Materials	Production Process	Retail Stage	End of Life	Total Impact
GWP	kg CO_2 eq	2.02×10^{-1}	5.54×10^{-3}	7.63 x10^{-3}	3.91×10^{-3}	2.11×10^{-3}	2.21×10^{-1}
AD	MJ	2.09	7.66×10^{-2}	1.19×10^{-1}	5.56×10^{-2}	1.31×10^{-2}	2.35
HTC	CTUh	8.42×10^{-10}	2.84×10^{-11}	1.73×10^{-11}	2.02×10^{-11}	4.93×10^{-12}	9.13×10^{-10}
HTNC	CTUh	1.02×10^{-8}	4.47×10^{-11}	6.03×10^{-11}	3.81×10^{-11}	1.52×10^{-11}	1.03×10^{-8}
LU	Pt	1.46×10^{1}	4.18×10^{-2}	1.82×10^{-1}	4.16×10^{-2}	1.08×10^{-2}	1.48×10^{1}
WU	m^3	1.32×10^{-1}	1.13×10^{-1}	1.26×10^{-4}	9.51×10^{-6}	2.61×10^{-6}	1.32×10^{-1}

Table 5. Environmental impact results of prototype 2.

Impact Category	Unit	Production of Raw Materials	Transport of Raw Materials	Production Process	Retail Stage	End of Life	Total Impact
GWP	kg CO_2 eq	2.01×10^{-1}	8.75×10^{-3}	8.23×10^{-3}	3.91×10^{-3}	2.11×10^{-3}	2.24×10^{-1}
AD	MJ	2.55	1.21×10^{-1}	1.29×10^{-1}	5.56×10^{-2}	1.31×10^{-2}	2.87
HTC	CTUh	6.81×10^{-10}	4.46×10^{-11}	1.84×10^{-11}	2.02×10^{-11}	4.93×10^{-12}	7.69×10^{-10}
HTNC	CTUh	1.32×10^{-9}	6.99×10^{-11}	6.15×10^{-11}	3.81×10^{-11}	1.52×10^{-11}	1.51×10^{-9}
LU	Pt	2.13×10^{1}	6.52×10^{-2}	1.82×10^{-1}	4.16×10^{-2}	1.08×10^{-2}	2.16×10^{1}
WU	m^3	2.86×10^{-1}	1.78×10^{-5}	1.27×10^{-4}	9.51×10^{-6}	2.61×10^{-6}	2.87×10^{-1}

Table 6. Environmental impact results of prototype 3.

Impact Category	Unit	Production of Raw Materials	Transport of Raw Materials	Production Process	Retail Stage	End of Life	Total Impact
GWP	kg CO_2 eq	2.14×10^{-1}	6.11×10^{-3}	8.08×10^{-3}	3.91×10^{-3}	2.11×10^{-3}	2.34×10^{-1}
AD	MJ	2.35	8.42×10^{-2}	1.26×10^{-1}	5.56×10^{-2}	1.31×10^{-2}	2.63
HTC	CTUh	9.08×10^{-10}	3.12×10^{-11}	1.81×10^{-11}	2.02×10^{-11}	4.93×10^{-12}	9.82×10^{-10}
HTNC	CTUh	3.99×10^{-9}	4.88×10^{-11}	6.12×10^{-11}	3.81×10^{-11}	1.52×10^{-11}	4.16×10^{-9}
LU	Pt	2.15×10^{1}	4.55×10^{-2}	1.82×10^{-1}	4.16×10^{-2}	1.08×10^{-2}	2.18×10^{1}
WU	m^3	1.98×10^{-1}	1.24×10^{-5}	1.27×10^{-4}	9.51×10^{-6}	2.61×10^{-6}	1.98×10^{-1}

Table 7. Environmental impact results of prototype 4.

Impact Category	Unit	Production of Raw Materials	Transport of Raw Materials	Production Process	Retail Stage	End of Life	Total Impact
GWP	kg CO_2 eq	1.74×10^{-1}	6.19×10^{-3}	8.23×10^{-3}	3.91×10^{-3}	2.11×10^{-3}	1.94×10^{-1}
AD	MJ	1.73	8.58×10^{-2}	1.29×10^{-1}	5.56×10^{-2}	1.31×10^{-2}	2.01
HTC	CTUh	9.13×10^{-10}	3.19×10^{-11}	1.84×10^{-11}	2.02×10^{-11}	4.93×10^{-12}	9.88×10^{-10}
HTNC	CTUh	2.86×10^{-9}	5.08×10^{-11}	6.15×10^{-11}	3.81×10^{-11}	1.52×10^{-11}	3.03×10^{-9}
LU	Pt	1.05×10^{1}	4.78×10^{-2}	1.82×10^{-1}	4.16×10^{-2}	1.08×10^{-2}	1.08×10^{1}
WU	m^3	6.83×10^{-2}	1.29×10^{-5}	1.27×10^{-4}	9.51×10^{-6}	2.61×10^{-6}	6.84×10^{-2}

The results of the environmental impact categories in Tables 4–7 differ according to the prototypes. Since each prototype weighing 100 g contains many different foods (dried fruits, legumes, cereal-based products, and random foods) in its structure, a direct comparison with the data in the literature was not possible. However, a study examining the average environmental impacts for the main food groups per 100 g of food in the Norwegian LCA food database gave the GWP for 100 g grains as 0.196 kg CO_2 eq., WU 0.019 m^3, and LU 0.233 m^2. For 100 g of fruits, berries, nuts, and seeds, the GWP was given as 0.162 kg CO_2 eq, WU 0.040 m^3, and LU 0.164 m^2 [57]. The results for the prototypes, as shown in the tables, are generally higher than the values reported in the literature. This discrepancy is likely due to prototypes containing various food components, utilizing local data, and providing a comprehensive evaluation of environmental impacts.

Figures 3–6 show the environmental impacts shared among the life cycle steps for prototype 1, prototype 2, prototype 3, and prototype 4, respectively. The raw material production stage is the primary environmental impact source in all categories for the prototypes. The research indicates that for most simple food products, the agricultural production phase is the primary source of environmental impacts, while later stages such as processing, transport, packaging, and distribution typically have a lesser impact [58]. This is especially true for impacts related to land use, such as biodiversity and soil quality. It also encompasses the effects of pesticide use (both aquatic and terrestrial ecotoxicity) and, in general, the impacts of fertilizer use and nutrient losses [59]. GWP and HTC are mainly affected by the AD impact category. The main reason for this is that these impact categories are dominated by fossil fuel use and combustion. European GHG emissions from the agricultural sector were reported to account for 10% of total GHG emissions [60]. Fossil fuel use is linked to adverse human health conditions, including cancer [61]. On the other hand, the secondary and third origins of HTC are fertilizer and pesticide use, respectively. HTNC takes a different path and originates from fertilizer and pesticide use in the production of fruits [62].

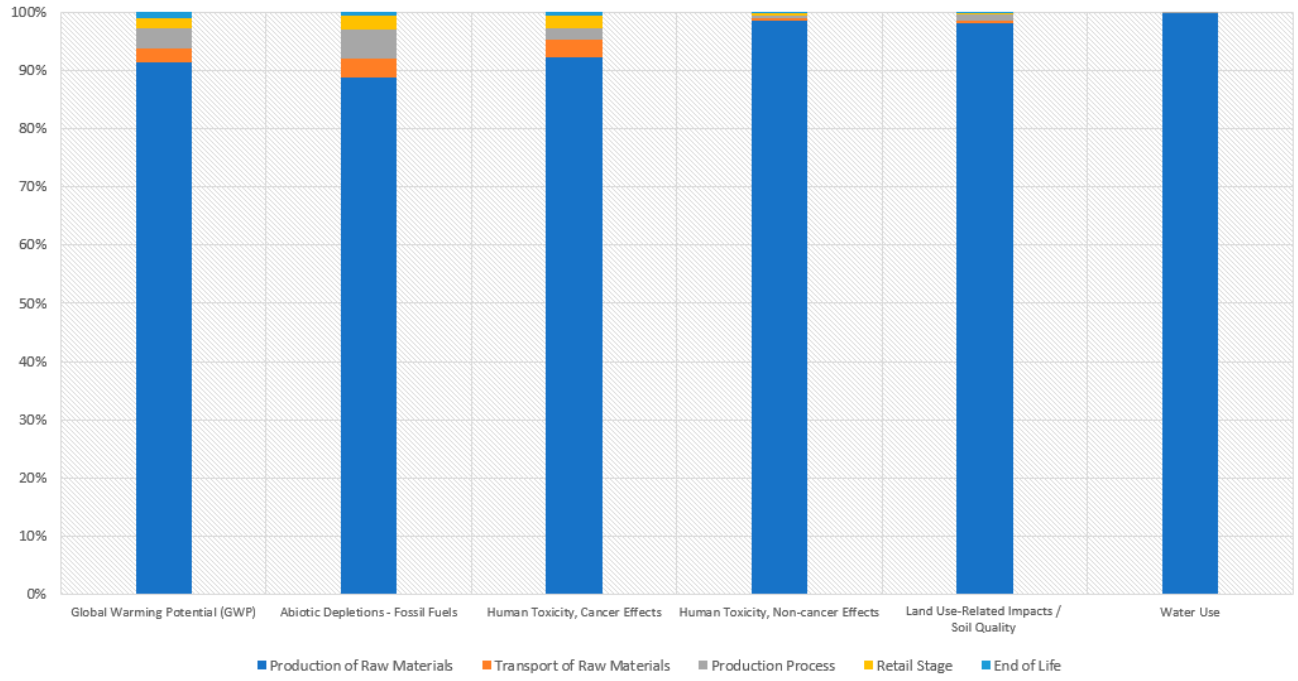


Figure 3. Environmental impact shares of prototype 1 by life cycle step.

During the life cycle of prototype 1, 91% of the GWP impact is due to the production of raw materials because of the use of fossil energy resources. A total of 3% of the impact is due to the transportation of raw materials. It has also been stated in the literature that the

transportation, processing, and packaging stages have lower environmental importance than the production stage [63]. Truck transportation is the main and sometimes the only option in Türkiye [64], and the use of fossil fuels during production increases the GWP impact by 3%. The impact rate is almost the same as transportation due to the use of fossil energy in the production process. The "Retail" and "End of Life" stages are downstream processes, and the GWP impact is due to the use of fossil fuels during the transportation of products (retail) and packaging waste (end of life). LU and WU are the main inputs of the farming stages of raw materials. For LU, almonds (33.8%), apricots (30.6%), corn (7.14%), and silverberries (9.37%) are the main contributors. Almond (56.4%), apricot (32.7%), silverberries (7.69%), and corn (2.76%) increase the WU effect dominantly [65].

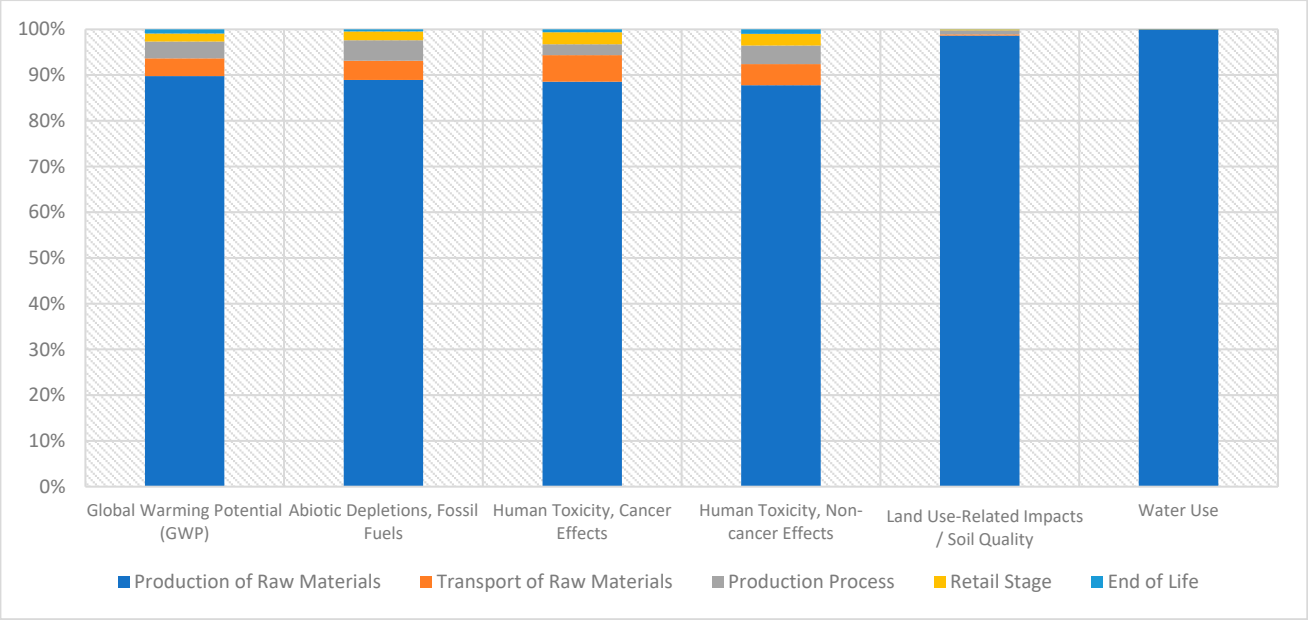


Figure 4. Environmental impact shares of prototype 2 by life cycle step.

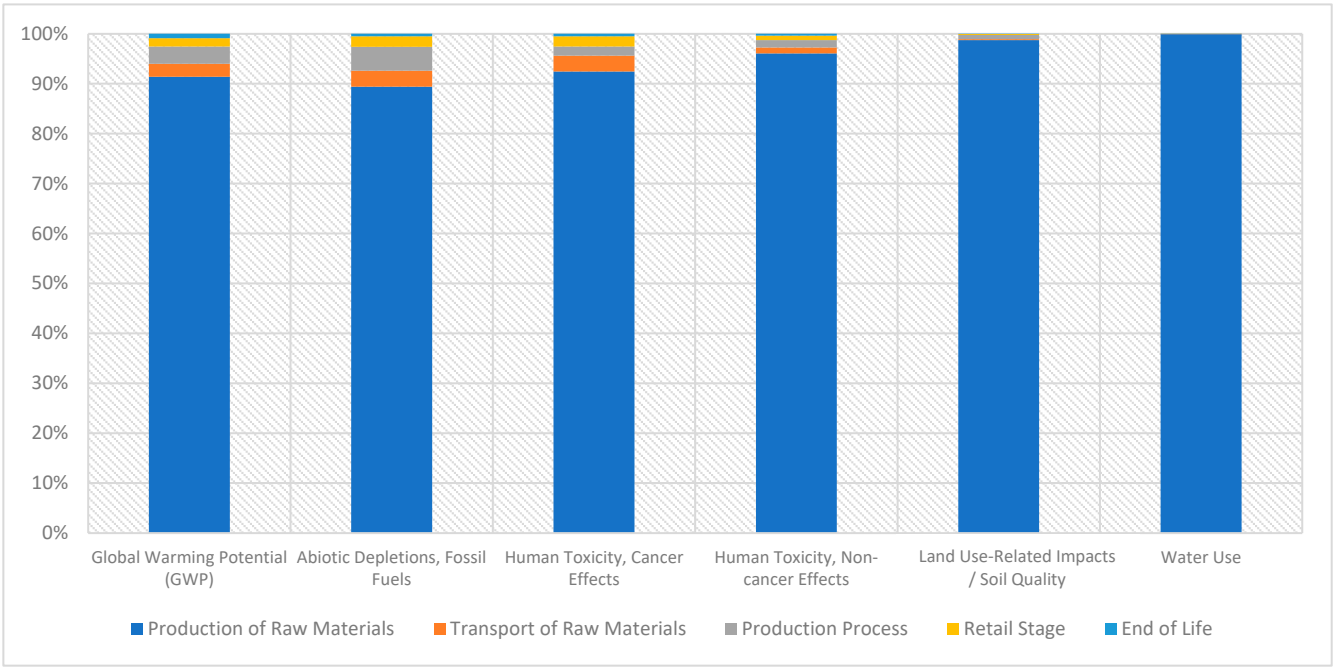


Figure 5. Environmental impact shares of prototype 3 by life cycle step.

When Figure 4 is examined, 90% of the total impact is due to the production of raw materials due to the fossil energy sources used, as explained above. A total of 4% of the impact is due to the transportation of raw materials. The use of fossil fuel in truck transportation during production increases the GWP impact by 4%. On the other hand, oat production reduces the HTNC impact due to the absorption of heavy metals by oats during cultivation [24]. The farming steps of oat and palm date dominate LU and WU impact categories. A total of 95.3% of the WU impact originates from palm date production. The LU impact category is dominated by palm date with a 79.2% share. Meanwhile, oat has 3.44% and silverberries have 3.13% of the total impact in this category.

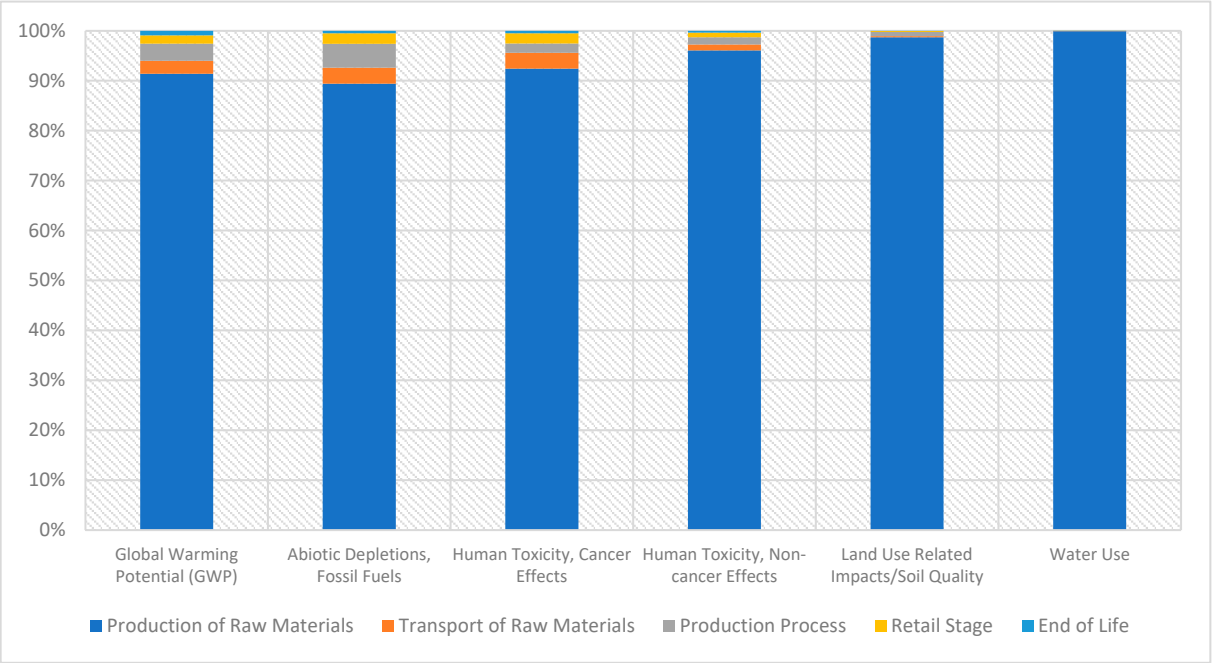


Figure 6. Environmental impact shares of prototype 4 by life cycle step.

Figure 5 shows that 91% of the GWP impact during the life cycle of prototype 3 is due to raw material production due to the use of fossil energy sources. A total of 3% of the impact is due to raw material transportation. LU and WU are the main inputs of the farming stages of raw materials. The WU impact is dominated by date palm production, with a share of 62.7% [27]. Meanwhile, sesame has a 12.9% impact on the total WU category, and mulberries have an 11.8% impact. The LU impact is due to oat (15.8%), sunflower seed (20%), sesame (8.1%), mulberries (10.5%), date (33.9%), and date (8.4%).

When the GWP impact shares for prototype 4 are examined throughout its life cycle in Figure 6, 89% is due to raw material production due to the use of fossil energy sources. A total of 3% of the impact is due to the transportation of raw materials. The production process represents 4% of the impact rate due to the use of fossil energy. For prototype 4, agricultural steps of oats and fruits are dominant in the LU and WU impact categories. A total of 93.9% of WU impact is due to mulberry and fig production [29,30]. In LU impact, the oat share is 11.2%, the fig share is 26.8%, and the mulberry production share is 34.3%.

Figure 7 summarizes the environmental impact comparison of the prototypes in a single graph. The relative environmental impacts of the prototypes vary by the impact category. Table 8, which was created to facilitate the evaluation of the prototypes for the environmentally greener product, can be helpful in decision-making.

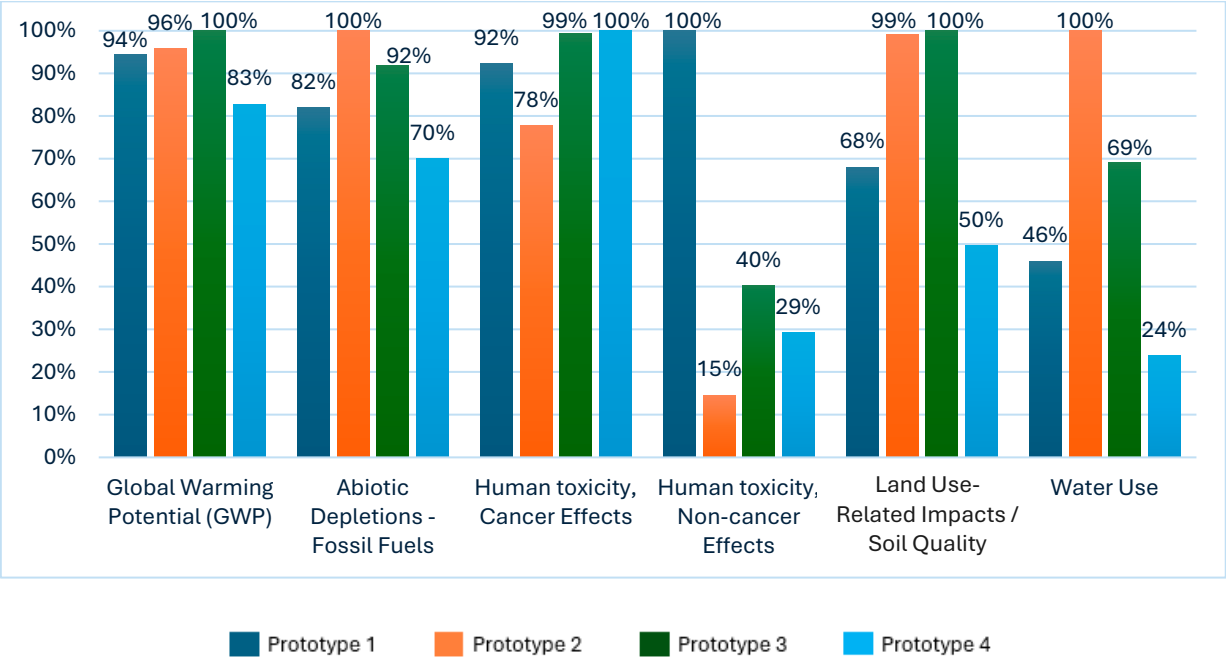


Figure 7. Environmental impact comparison of prototypes.

Table 8. Studies examining the environmental effects of foods and diets compatible with the MD.

Country	Foods/Diets	LCA Boards and Methods	Environmental Impact Categories	Highlights	Reference
Italy	meat, fish, eggs, milk and derivatives, tubers, cereals/derivatives, legumes, seasoning fats, fruit, vegetables, and random foods (sweets, snacks, sugary drinks, sugar, and alcoholic beverages)	cradle-to-gate ReCiPe 2016 Endpoint method	GWP, Ozone formation, Acidification; Eutrophication; Ecotoxicity, LU, WU, Stratospheric ozone depletion; Ionizing radiation; Fine particulate matter formation; HTC, HTNC	• Italian eating habits are less sustainable than the eating pattern recommended by the Mediterranean diet and, therefore, a transition to a Mediterranean dietary pattern may create less pressure on the environment and human health.	[66]
Lebanese	fruits, vegetables, legumes, olive oil, burghul (crushed whole wheat), milk and dairy products, starchy vegetables, and dried fruits, eggs	NA	GHG, Energy use, WU	• The MD has a positive impact on the protection and conservation of environmental resources, such as water and GHG emissions.	[67]
Spain	fruits, vegetables, pulses, potatoes, whole grains, fish, olive oil, poultry, red meat, dairy products with fat, and alcohol	NA	GHG, LU, Energy use, Acidification, Eutrophication	• MD adherence and calorie reduction mediate improved environmental impact. • An energy-reduced MD improves acidification, eutrophication, and land use. • Meat has a greater impact on acidification, eutrophication, land use, and energy.	[68]

Table 8. *Cont.*

Country	Foods/Diets	LCA Boards and Methods	Environmental Impact Categories	Highlights	Reference
Italy	bread, pasta, and flour products, potatoes, vegetables and fruits, meat and meat products, dairy products, and fish	NA	GHG	• The MD could represent the best compromise between the need to reduce the environmental impact of food consumption and maintain the cultural meaning of food consumption behavior.	[69]
Greece	meat, fish, dairy products, eggs, cereal-based products, sugar, oils, tubers, vegetables, legumes, fruits, and nuts	NA	LU, WU, GHG, Eutrophication	• The transition to an MD places less pressure on biodiversity, including lower LU, WU, GHG, and eutrophication emissions.	[70]
Türkiye	dried fruits, legumes, cereal-based products, and random foods (pectin powder, Arabic gum, and spices)	cradle-to-grave Environmental Footprint (EF) 3.1 method	GWP, AD, HTC, HTNC, LU, WU	• The environmental impact is mainly due to the use of fossil fuels, water, fertilizers, and pesticides/insecticides during the production phase.	This study

NA: not applicable.

Considering Figure 7, it is possible to evaluate prototype 4 as the greenest prototype with the lowest environmental impacts. Table 8 shows that different environmental impact assessment methods and categories are used for menus and foods prepared according to the MD diet.

Table 8 shows that most of the MD-compliant studies examined a limited number of environmental impact categories, and it is unclear which method was used to measure the categories. System boundaries are defined according to the objectives of a single study. Data quality and incompleteness, particularly the limited availability of life cycle inventory data for agricultural production systems in developing countries, make comparative analyses difficult. It has also been emphasized in the literature that environmental impacts should cover the production chain up to the point of sale, including agricultural production, processing, transportation, and distribution, for studies examining the analysis of food consumption [59]. Most studies that aim to estimate the environmental impacts associated with the food sector have limited the issue to climate change only; however, it is reported that the food sector can extend its impact to a wider range of environmental categories [71]. In addition, each country has a unique mix of foods from local, indigenous, and global food systems. Therefore, environmental and climate impacts of diets are assessed based on country or region-specific data reflecting specific local and domestic production and import impacts [72].

4. Discussion

This research aims to contribute to the understanding of how the environmental impacts of snack bars, which have been studied in limited numbers, are affected by the food used and production, transportation, and disposal processes, and to raise awareness of the importance of dietary behavior in protecting ecosystems. The environmental impact is mainly due to the use of fossil fuels, water, fertilizers, and pesticides/insecticides during the production phase. The transportation of raw materials also has a significant impact.

Using train or sea transportation is important to reduce this significant impact. However, transportation mode options are limited in Türkiye. To reduce the short-term impact related to transportation, raw materials can be supplied from nearby regions as much as possible. The environmental impacts of the production phase are due to the use of electrical energy. The end-of-life impact is due to packaging materials. The end-of-life impact can be reduced by reducing the use of packaging materials. Studies suggest that a diet rich in plant products and low in animal products will be more beneficial in terms of environmental sustainability [70,73]. The MD is primarily plant-based and can help protect the environment from further degradation and play an important role in supporting biodiversity [74]. It is widely accepted that replacing animal-based foods (such as meat, fish, eggs, milk, and dairy products) with plant-based alternatives (such as plant-based analogs and herbal beverages) will have a significant positive impact on human and global health. Plant-based dietary patterns, such as the Mediterranean, pescatarian, and vegetarian diets, have been associated with a 16–41% reduction in the incidence of type 2 diabetes, a 7–13% reduction in cancer incidence, and a 20–26% reduction in the mortality rate from coronary heart disease [75]. This transition will be facilitated by the availability of more affordable, easy-to-consume, sustainable, nutritious, and delicious plant-based foods, enabling consumers to change their dietary habits and adopt a healthier and more sustainable diet [76]. Sustainable diets are healthy diets derived from sustainable food systems that advance human well-being and protect ecological resources in socially acceptable ways. A key strategy for achieving the SDGs is to promote sustainable diets, or healthy diets derived from sustainable food systems [77]. It has also been emphasized that SDG 12 (responsible consumption and production) and SDG 3 (good health and well-being) are strongly linked to sustainable diets [78–80]. This characteristic of the MD has been reported to stem primarily from the greater consumption of local, seasonal plant-based foods and the lower consumption of animal products [81]. It has been reported that the MD can promote a healthier lifestyle and reduce the incidence of chronic diseases, offering a sustainable and effective strategy to improve health and quality of life in aging individuals [82]. It has been emphasized that the MD should be embraced because it provides both health and environmental benefits, and that it should not be limited to the population in the Mediterranean region but should be promoted and facilitated more generally [83]. By choosing and consuming environmentally friendly foods, we can promote biodiversity and reduce or eliminate the use of harmful chemicals that negatively affect both human and environmental health [84]. Studies on food and environmental sustainability should utilize region-specific life cycle inventory databases for food, agriculture, and energy. Furthermore, environmental impact categories other than GWG should be considered, and the scope of environmental assessments should be expanded [85].

5. Conclusions

This study assessed the environmental performance of four snack bar prototypes developed in line with the MD. The analysis covered the entire LCA, from the production of raw materials to waste management after consumption. The results clearly showed that the production of raw materials was the dominant source of environmental impacts, contributing nearly 90% of total greenhouse gas emissions. Transportation and manufacturing processes had much smaller effects, each responsible for only about 3–4% of the total impact. Ingredient composition was found to be the most decisive factor. Water- and land-intensive crops such as almonds, dates, and figs significantly increased environmental pressures, particularly in terms of land use and water consumption. For example, water use ranged from 0.068 m^3 in the most efficient prototype to 0.287 m^3 in the least efficient one. Across the prototypes, prototype 4 demonstrated the lowest impacts in four cate-

gories, indicating superior environmental performance. It had the lowest greenhouse gas emissions (0.194 kg CO_2-eq), the lowest fossil energy demand (2.01 MJ), and the smallest requirements for land and water.

In summary, selecting ingredients with lower environmental burdens and sourcing them responsibly can substantially reduce the ecological footprint of snack bar production. These results underline the importance of integrating sustainability considerations into food design and can inform both producers and policymakers seeking to promote healthier and more environmentally friendly diets.

Author Contributions: G.E.Ü.: Research conception, visualization, methodology, data collection, formal analysis, writing—original draft, and review. M.G.: funding acquisition, supervision, writing, review, and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by SWITCHtoHEALTHY (Switching Mediterranean consumers to Mediterranean sustainable healthy dietary patterns) grant number 2133 [European Union's Horizon 2020 Research and Innovation program—Partnership for Research and Innovation in the Mediterranean Area (PRIMA)].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article; further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the findings of this work.

References

1. Farzana, T.; Mohajan, S.; Saha, T.; Hossain, M.N.; Haque, M.Z. Formulation and Nutritional Evaluation of a Healthy Vegetable Soup Powder Supplemented with Soy Flour, Mushroom, and Moringa Leaf. *Food Sci. Nutr.* **2017**, *5*, 911–920. [CrossRef] [PubMed]
2. Vignesh, A.; Amal, T.C.; Sarvalingam, A.; Vasanth, K. A Review on the Influence of Nutraceuticals and Functional Foods on Health. *Food Chem. Adv.* **2024**, *5*, 100749. [CrossRef]
3. Ingram, J. Perspective: Look beyond Production. *Nature* **2017**, *544*, S17. [CrossRef] [PubMed]
4. Ciurzyńska, A.; Cieśluk, P.; Barwińska, M.; Marczak, W.; Ordyniak, A.; Lenart, A.; Janowicz, M. Eating Habits and Sustainable Food Production in the Development of Innovative "Healthy" Snacks. *Sustainability* **2019**, *11*, 2800. [CrossRef]
5. Almoraie, N.M.; Saqaan, R.; Alharthi, R.; Alamoudi, A.; Badh, L.; Shatwan, I.M. Snacking Patterns throughout the Life Span: Potential Implications on Health. *Nutr. Res.* **2021**, *91*, 81–94. [CrossRef]
6. Bes-Rastrollo, M.; Sanchez-Villegas, A.; Basterra-Gortari, F.J.; Nunez-Cordoba, J.M.; Toledo, E.; Serrano-Martinez, M. Prospective Study of Self-Reported Usual Snacking and Weight Gain in a Mediterranean Cohort: The SUN Project. *Clin. Nutr.* **2010**, *29*, 323–330. [CrossRef]
7. Astrup, A.; Bovy, M.W.L.; Nackenhorst, K.; Popova, A.E. Food for Thought or Thought for Food?—A Stakeholder Dialogue around the Role of the Snacking Industry in Addressing the Obesity Epidemic. *Obes. Rev.* **2006**, *7*, 303–312. [CrossRef]
8. Durazzo, A.; Lucarini, M.; Federici, G.; Marcotrigiano, V.; Bino, E.; Lovat, A.; Padoin, A.; Salerno, G.; D'incà, P.; Napoli, C.; et al. Healthy Snack Project: Improving Healthy Choices through Multidisciplinary Food Educ. Actions. *Nutrients* **2024**, *16*, 255. [CrossRef]
9. Vermeulen, S.J.; Campbell, B.M.; Ingram, J.S.I. Climate Change and Food Systems. *Annu. Rev. Environ. Resour.* **2012**, *37*, 195–222. [CrossRef]
10. Poore, J.; Nemecek, T. Reducing Food's Environmental Impacts through Producers and Consumers. *Science* **2018**, *360*, 987–992. [CrossRef]
11. Michel, M.; Eldridge, A.L.; Hartmann, C.; Klassen, P.; Ingram, J.; Meijer, G.W. Benefits and Challenges of Food Processing in the Context of Food Systems, Value Chains and Sustainable Development Goals. *Trends Food Sci. Technol.* **2024**, *153*, 104703. [CrossRef]
12. Environmental Impacts of Food Production—Our World in Data. Available online: https://ourworldindata.org/environmental-impacts-of-food (accessed on 23 March 2025).

13. Balasundram, S.K.; Shamshiri, R.R.; Sridhara, S.; Rizan, N. The Role of Digital Agriculture in Mitigating Climate Change and Ensuring Food Security: An Overview. *Sustainability* **2023**, *15*, 5325. [CrossRef]
14. Crippa, M.; Solazzo, E.; Guizzardi, D.; Monforti-Ferrario, F.; Tubiello, F.N.; Leip, A. Food Systems Are Responsible for a Third of Global Anthropogenic GHG Emissions. *Nat. Food* **2021**, *2*, 198–209. [CrossRef]
15. García-Herrero, L.; Gibin, D.; Damiani, M.; Sanyé-Mengual, E.; Sala, S. What Is the Water Footprint of EU Food Consumption? A Comparison of Water Footprint Assessment Methods. *J. Clean. Prod.* **2023**, *415*, 137807. [CrossRef]
16. Sanyé, M.E.; Sala, S. *Consumption Footprint and Domestic Footprint: Assessing the Environmental Impacts of EU Consumption and Production*; Publications Office of the European Union: Luxembourg, 2023. [CrossRef]
17. Mustafa, M.A.; Mabhaudhi, T.; Avvari, M.V.; Massawe, F. Transition toward Sustainable Food Systems: A Holistic Pathway toward Sustainable Development. *Food Secur. Nutr.* **2021**, 33–56. [CrossRef]
18. De Marchi, E.; Scappaticci, G.; Banterle, A.; Alamprese, C. What Is the Role of Environmental Sustainability Knowledge in Food Choices? A Case Study on Egg Consumers in Italy. *J. Clean. Prod.* **2024**, *441*, 141038. [CrossRef]
19. Manzoor, S.; Fayaz, U.; Dar, A.H.; Dash, K.K.; Shams, R.; Bashir, I.; Pandey, V.K.; Abdi, G. Sustainable Development Goals through Reducing Food Loss and Food Waste: A Comprehensive Review. *Future Foods* **2024**, *9*, 100362. [CrossRef]
20. Grosso, M.; Falasconi, L. Addressing Food Wastage in the Framework of the UN Sustainable Development Goals. *Waste Manag. Res.* **2018**, *36*, 97–98. [CrossRef]
21. Tang, M.; Miri, T.; Soltani, F.; Onyeaka, H.; Al-Sharify, Z.T. Life Cycle Assessment of Plant-Based vs. Beef Burgers: A Case Study in the UK. *Sustainability* **2024**, *16*, 4417. [CrossRef]
22. Fernández-Ríos, A.; Laso, J.; Aldaco, R.; Margallo, M. Life Cycle Assessment and Energy Return of Investment of Nutritionally-Enhanced Snacks Supplemented with Spanish Quinoa. *Sci. Total Environ.* **2024**, *954*, 176542. [CrossRef]
23. Mazac, R.; Järviö, N.; Tuomisto, H.L. Environmental and Nutritional Life Cycle Assessment of Novel Foods in Meals as Transformative Food for the Future. *Sci. Total Environ.* **2023**, *876*, 162796. [CrossRef] [PubMed]
24. Rai, P.; Mehrotra, S.; Sharma, S.K. Potential of Sensing Interventions in the Life Cycle Assessment of Fruits and Fruit Juices. *Trends Food Sci. Technol.* **2024**, *151*, 104614. [CrossRef]
25. Kheiralipour, K.; Rafiee, S.; Karimi, M.; Nadimi, M.; Paliwal, J. The Environmental Impacts of Commercial Poultry Production Systems Using Life Cycle Assessment: A Review. *Worlds Poult. Sci. J.* **2024**, *80*, 33–54. [CrossRef]
26. Finnveden, G.; Hauschild, M.Z.; Ekvall, T.; Guinée, J.; Heijungs, R.; Hellweg, S.; Koehler, A.; Pennington, D.; Suh, S. Recent Developments in Life Cycle Assessment. *J. Environ. Manag.* **2009**, *91*, 1–21. [CrossRef]
27. Heller, M.C.; Keoleian, G.A.; Willett, W.C. Toward a Life Cycle-Based, Diet-Level Framework for Food Environmental Impact and Nutritional Quality Assessment: A Critical Review. *Environ. Sci. Technol.* **2013**, *47*, 12632–12647. [CrossRef]
28. Sala, S.; Amadei, A.M.; Beylot, A.; Ardente, F. The Evolution of Life Cycle Assessment in European Policies over Three Decades. *Int. J. Life Cycle Assess.* **2021**, *26*, 2295–2314. [CrossRef]
29. Glavič, P.; Krajnc, D.; Cristina Rada, E. Evolution and Current Challenges of Sustainable Consumption and Production. *Sustainability* **2021**, *13*, 9379. [CrossRef]
30. Peano, C.; Girgenti, V.; Sciascia, S.; Barone, E.; Sottile, F. Dietary Patterns at the Individual Level through a Nutritional and Environmental Approach: The Case Study of a School Canteen. *Foods* **2022**, *11*, 1008. [CrossRef]
31. Trolle, E.; Nordman, M.; Lassen, A.D.; Colley, T.A.; Mogensen, L. Carbon Footprint Reduction by Transitioning to a Diet Consistent with the Danish Climate-Friendly Dietary Guidelines: A Comparison of Different Carbon Footprint Databases. *Foods* **2022**, *11*, 1119. [CrossRef]
32. Veliz, K.; Chico-Santamarta, L.; Ramirez, A.D. The Environmental Profile of Ecuadorian Export Banana: A Life Cycle Assessment. *Foods* **2022**, *11*, 3288. [CrossRef]
33. Abad-González, J.; Nadi, F.; Pérez-Neira, D. Energy-Water-Food Security Nexus in Mung Bean Production in Iran: An LCA Approach. *Ecol. Indic.* **2024**, *158*, 111442. [CrossRef]
34. Berry, E.M.; Dernini, S.; Burlingame, B.; Meybeck, A.; Conforti, P. Food Security and Sustainability: Can One Exist without the Other? *Public Health Nutr.* **2015**, *18*, 2293–2302. [CrossRef] [PubMed]
35. Burlingame, B.; Dernini, S. Sustainable Diets: The Mediterranean Diet as an Example. *Public Health Nutr.* **2011**, *14*, 2285–2287. [CrossRef] [PubMed]
36. Germani, A.; Vitiello, V.; Giusti, A.M.; Pinto, A.; Donini, L.M.; Del Balzo, V. Environmental and Economic Sustainability of the Mediterranean Diet. *Int. J. Food Sci. Nutr.* **2014**, *65*, 1008–1012. [CrossRef] [PubMed]
37. Bôto, J.M.; Rocha, A.; Miguéis, V.; Meireles, M.; Neto, B. Sustainability Dimensions of the Mediterranean Diet: A Systematic Review of the Indicators Used and Its Results. *Adv. Nutr.* **2022**, *13*, 2015–2038. [CrossRef]
38. Castaldi, S.; Dembska, K.; Antonelli, M.; Petersson, T.; Piccolo, M.G.; Valentini, R. The Positive Climate Impact of the Mediterranean Diet and Current Divergence of Mediterranean Countries towards Less Climate Sustainable Food Consumption Patterns. *Sci. Rep.* **2022**, *12*, 8847. [CrossRef]

39. Aboussaleh, Y.; El Bilali, H.; Bottalico, F.; Cardone, G.; Ottomano Palmisano, G.; Capone, R. Mediterranean Food and Environmental Impacts. In *The Mediterranean Diet: An Evidence-Based Approach*; Academic Press: Cambridge, MA, USA, 2020; pp. 103–110. [CrossRef]
40. Tepper, S.; Kissinger, M.; Avital, K.; Shahar, D.R. The Environmental Footprint Associated with the Mediterranean Diet, EAT-Lancet Diet, and the Sustainable Healthy Diet Index: A Population-Based Study. *Front. Nutr.* **2022**, *9*, 870883. [CrossRef]
41. Halpern, B.S.; Frazier, M.; Verstaen, J.; Rayner, P.E.; Clawson, G.; Blanchard, J.L.; Cottrell, R.S.; Froehlich, H.E.; Gephart, J.A.; Jacobsen, N.S.; et al. The Environmental Footprint of Global Food Production. *Nat. Sustain.* **2022**, *5*, 1027–1039. [CrossRef]
42. Smol, M.; Marcinek, P.; Duda, J. Circular Business Models (CBMs) in Environmental Management—Analysis of Definitions, Typologies and Methods of Creation in Organizations. *Sustainability* **2024**, *16*, 1209. [CrossRef]
43. Serra-Majem, L.; Tomaino, L.; Dernini, S.; Berry, E.M.; Lairon, D.; de la Cruz, J.N.; Bach-Faig, A.; Donini, L.M.; Medina, F.X.; Belahsen, R.; et al. Updating the Mediterranean Diet Pyramid towards Sustainability: Focus on Environmental Concerns. *Int. J. Environ. Res. Public Health* **2020**, *17*, 8758. [CrossRef]
44. Khatri, P.; Kumar, P.; Shakya, K.S.; Kirlas, M.C.; Tiwari, K.K. Understanding the Intertwined Nature of Rising Multiple Risks in Modern Agriculture and Food System. *Environ. Dev. Sustain.* **2024**, *26*, 24107–24150. [CrossRef]
45. Bandekar, P.A.; Putman, B.; Thoma, G.; Matlock, M. Cradle-to-Grave Life Cycle Assessment of Production and Consumption of Pulses in the United States. *J. Environ. Manag.* **2022**, *302*, 114062. [CrossRef]
46. Saxe, H.; Okkels, S.L.; Jensen, J.D. How to Obtain Forty Percent Less Environmental Impact by Healthy, Protein-Optimized Snacks for Older Adults. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1514. [CrossRef] [PubMed]
47. *ISO 14040*; Environmental Management—Life Cycle Assessment—Principles and Framework; International Organization for Standardization: Geneva, Switzerland, 2006.
48. *ISO 14044*; Environmental Management—Life Cycle Assessment—Requirements and Guidelines; International Organization for Standardization: Geneva, Switzerland, 2006.
49. Liu, R.H. Dietary Bioactive Compounds and Their Health Implications. *J. Food Sci.* **2013**, *78*, A18–A25. [CrossRef] [PubMed]
50. Anumudu, C.K.; Onyeaka, H.; Ekwueme, C.T.; Hart, A.; Isaac-Bamgboye, F.; Miri, T. Advances in the Application of Infrared in Food Processing for Improved Food Quality and Microbial Inactivation. *Foods* **2024**, *13*, 4001. [CrossRef] [PubMed]
51. Gürsu, H. Reusable Smart Lids for Improving Food Safety at Household Level with Programmable UV-C Technology. *Sustainability* **2024**, *16*, 5370. [CrossRef]
52. Nainggolan, E.A.; Banout, J.; Urbanova, K. Recent Trends in the Pre-Drying, Drying, and Post-Drying Processes for Cassava Tuber: A Review. *Foods* **2024**, *13*, 1778. [CrossRef]
53. Tang, J.; Xiao, X.; Han, M.; Shan, R.; Gu, D.; Hu, T.; Li, G.; Rao, P.; Zhang, N.; Lu, J. China's Sustainable Energy Transition Path to Low-Carbon Renewable Infrastructure Manufacturing under Green Trade Barriers. *Sustainability* **2024**, *16*, 3387. [CrossRef]
54. Jamal, T.; Chen, G.; Zheng, L.; Duan, H.; Muddassir, M.; Jamal, R.; Khan, N.H. Innovative Food Packaging Techniques for Space Exploration: Ensuring Safety and Sustainability. *Food Eng. Rev.* **2025**, 1–24. [CrossRef]
55. Waste Statistics, TÜİK. Available online: https://data.tuik.gov.tr/bulten/index?p=atik-istatistikleri-2022-49570 (accessed on 23 September 2024).
56. Andreasi Bassi, S.; Biganzoli, F.; Ferrara, N.; Amadei, A.; Valente, A.; Sala, S.; Ardente, F. *Updated Characterisation and Normalisation Factors for the Environmental Footprint 3.1 Method*; Publications Office of the European Union: Luxembourg, 2023; p. JRC130796. [CrossRef]
57. Carlsen, M.H.; Bjøntegaard, M.M.; van Oort, B.; Jafarzadeh, S.; Mehta, S.; Wright, E.C.; Andersen, L.F. Environmental Impact of Norwegian Food and Beverages: Compilation of a Life Cycle Assessment Food Database. *Food Nutr. Res.* **2025**, *69*, 10645. [CrossRef]
58. Foster, C.; Green, K.; Bleda, M.; Dewick, P.; Evans, B.; Flynn, A.; Mylan, J. *Environmental Impacts of Food Production and Consumption Final Report to the Department for Environment Food and Rural Affairs*; Defra: London, UK, 2006.
59. Nemecek, T.; Jungbluth, N.; i Canals, L.M.; Schenck, R. Environmental Impacts of Food Consumption and Nutrition: Where Are We and What Is Next? *Int. J. Life Cycle Assess.* **2016**, *21*, 607–620. [CrossRef]
60. Luksta, I.; Pakere, I.; Vamža, I.; Liberova, V.; Blumberga, D. Comparative Analysis of Agricultural Emissions Across European Countries. *Environ. Clim. Technol.* **2024**, *28*, 738–748. [CrossRef]
61. Woodruff, T.J. Health Effects of Fossil Fuel–Derived Endocrine Disruptors. *N. Engl. J. Med.* **2024**, *390*, 922–933. [CrossRef] [PubMed]
62. Machin Ferrero, L.M.; Araujo, P.Z.; Nishihara Hun, A.L.; Valdeón, D.H.; Mele, F.D. Water Footprint Assessment of Lemon and Its Derivatives in Argentina: A Case Study in the Province of Tucumán. *Int. J. Life Cycle Assess.* **2021**, *26*, 1505–1519. [CrossRef]
63. Jungbluth, N.; Ulrich, M.; Muir, K.; Meili, C.; Solin, S. *Analysis of Food and Environmental Impacts as a Scientific Basis for Swiss Dietary Recommendations*; ESU-Services GmbH: Schaffhausen, Switzerland, 2022.
64. Tuydes-Yaman, H.; Dalkic-Melek, G.; Chakarova, K.; Ozcelik, A.S. Barriers and Opportunities (B&O) for Developing Low Carbon Transportation (LCT) Policies in Turkey. *J. Transp. Geogr.* **2024**, *118*, 103903. [CrossRef]

65. Fulton, J.; Norton, M.; Shilling, F. Water-Indexed Benefits and Impacts of California Almonds. *Ecol. Indic.* **2019**, *96*, 711–717. [CrossRef]
66. Vinci, G.; Maddaloni, L.; Prencipe, S.A.; Ruggeri, M.; Di Loreto, M.V. A Comparison of the Mediterranean Diet and Current Food Patterns in Italy: A Life Cycle Thinking Approach for a Sustainable Consumption. *Int. J. Environ. Res. Public Health* **2022**, *19*, 12274. [CrossRef]
67. Naja, F.; Itani, L.; Hamade, R.; Chamieh, M.C.; Hwalla, N. Mediterranean Diet and Its Environmental Footprints Amid Nutrition Transition: The Case of Lebanon. *Sustainability* **2019**, *11*, 6690. [CrossRef]
68. Álvarez-Álvarez, L.; Rubín-García, M.; Vitelli-Storelli, F.; García, S.; Bouzas, C.; Martínez-González, M.Á.; Corella, D.; Salas-Salvadó, J.; Malcampo, M.; Martínez, J.A.; et al. Effect of a Nutritional Intervention Based on an Energy-Reduced Mediterranean Diet on Environmental Impact. *Sci. Total Environ.* **2024**, *928*, 172610. [CrossRef]
69. Pairotti, M.B.; Cerutti, A.K.; Martini, F.; Vesce, E.; Padovan, D.; Beltramo, R. Energy Consumption and GHG Emission of the Mediterranean Diet: A Systemic Assessment Using a Hybrid LCA-IO Method. *J. Clean. Prod.* **2015**, *103*, 507–516. [CrossRef]
70. Belgacem, W.; Mattas, K.; Arampatzis, G.; Baourakis, G. Changing Dietary Behavior for Better Biodiversity Preservation: A Preliminary Study. *Nutrients* **2021**, *13*, 2076. [CrossRef] [PubMed]
71. Arfelli, F.; Ciacci, L.; Cespi, D.; Vassura; Passarini, F. The "SQUIID Claim": A Novel LCA-Based Indicator for Food Dishes. *J. Clean. Prod.* **2024**, *434*, 140241. [CrossRef]
72. Webb, J.; Williams, A.G.; Hope, E.; Evans, D.; Moorhouse, E. Do Foods Imported into the UK Have a Greater Environmental Impact than the Same Foods Produced within the UK? *Int. J. Life Cycle Assess.* **2013**, *18*, 1325–1343. [CrossRef]
73. Aleksandrowicz, L.; Green, R.; Joy, E.J.M.; Smith, P.; Haines, A. The Impacts of Dietary Change on Greenhouse Gas Emissions, Land Use, Water Use, and Health: A Systematic Review. *PLoS ONE* **2016**, *11*, e0165797. [CrossRef]
74. Tucci, M.; Martini, D.; Del Bo', C.; Marino, M.; Battezzati, A.; Bertoli, S.; Porrini, M.; Riso, P. An Italian-Mediterranean Dietary Pattern Developed Based on the EAT-Lancet Reference Diet (EAT-IT): A Nutritional Evaluation. *Foods* **2021**, *10*, 558. [CrossRef]
75. Tilman, D.; Clark, M. Global Diets Link Environmental Sustainability and Human Health. *Nature* **2014**, *515*, 518–522. [CrossRef]
76. McClements, D.J.; Grossmann, L. A Brief Review of the Science behind the Design of Healthy and Sustainable Plant-Based Foods. *NPJ Sci. Food* **2021**, *5*, 17. [CrossRef]
77. Ahmed, S.; Byker Shanks, C. *Supporting Sustainable Development Goals Through Sustainable Diets*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 1–13. [CrossRef]
78. Raman, R.; Lathabai, H.H.; Nedungadi, P. Sustainable Development Goal 12 and Its Synergies with Other SDGs: Identification of Key Research Contributions and Policy Insights. *Discov. Sustain.* **2024**, *5*, 150. [CrossRef]
79. Jacob-John, J.; D'souza, C.; Marjoribanks, T.; Singaraju, S. Synergistic Interactions of SDGs in Food Supply Chains: A Review of Responsible Consumption and Production. *Sustainability* **2021**, *13*, 8809. [CrossRef]
80. Castellano, R.; De Bernardo, G.; Punzo, G. Sustainable Well-Being and Sustainable Consumption and Production: An Efficiency Analysis of Sustainable Development Goal 12. *Sustainability* **2024**, *16*, 7535. [CrossRef]
81. Ingrassia, M.; Altamore, L.; Columba, P.; Raffermati, S.; Lo Grasso, G.; Bacarella, S.; Chironi, S. Mediterranean Diet, Sustainability, and Tourism—A Study of the Market's Demand and Knowledge. *Foods* **2023**, *12*, 2463. [CrossRef]
82. Godos, J.; Guglielmetti, M.; Ferraris, C.; Frias-Toral, E.; Domínguez Azpíroz, I.; Lipari, V.; Di Mauro, A.; Furnari, F.; Castellano, S.; Galvano, F.; et al. Mediterranean Diet and Quality of Life in Adults: A Systematic Review. *Nutrients* **2025**, *17*, 577. [CrossRef]
83. Barber, T.M.; Kabisch, S.; Pfeiffer, A.F.H.; Weickert, M.O. The Effects of the Mediterranean Diet on Health and Gut Microbiota. *Nutrients* **2023**, *15*, 2150. [CrossRef] [PubMed]
84. Çakmakçı, R.; Salık, M.A.; Çakmakçı, S. Assessment and Principles of Environmentally Sustainable Food and Agriculture Systems. *Agriculture* **2023**, *13*, 1073. [CrossRef]
85. Boakes, E.; De Voogd, J.K.; Wauters, G.; Van Caneghem, J. The Influence of Energy Output and Substitution on the Environmental Impact of Waste-to-Energy Operation: Quantification by Means of a Case Study. *Clean. Technol. Environ. Policy* **2023**, *25*, 253–267. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.