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Analyzing the water-energy-environment nexus of irrigated wheat and maize production in Albania

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ABSTRACT

This paper analyzed the water-energy-environmental interactions in conventional wheat and maize production on a generic farm in Albania using a cradle-to-farm gate life cycle assessment (LCA) and energy analysis. The inputs considered were seeds, fuel, electricity, fertilizers, plant protection, irrigation water, and machinery. Energy use efficiency, specific energy, energy productivity, and net energy gain in wheat production were calculated as 4.95, 2.63 MJ kg^{-1}, 0.38 kg MJ $^{-1}$, and 49,692 MJ ha^{-1}, respectively. For maize, these values were 7.63, 1.93 MJ kg^{-1}, 0.52 MJ kg^{-1}, and 82,513 MJ ha^{-1}, respectively. Producing 1 ton of wheat requires 2626 MJ of energy, 288 m^3 of water, and generates a global warming potential (GWP) of 242.2 kg CO_2-eq, terrestrial acidification potential (TAP) of 4.05 kg SO_2-eq, and freshwater eutrophication (FEP) of 0.135 kg P-eq. On other hand, maize requires 1927.1 MJ of energy, 561 m^3 of water, and generates a GWP of 181.1 kg CO_2-eq, TAP of 2.82 kg SO_2-eq, and FEP of 0.1 kg P-eq. The wheat and maize production produces a single environmental score of 69.3 and 60.2 points where the foreground subsystem (on-farm) contributes to more than 75% of the total environmental load. Irrigation, machinery use, and fertilizer use and application caused most of the environmental impacts and energy consumption. As a wide range of agriculture modernization projects is taking place across Albania, footprint indicators and energy analysis are recommended to design sound farming and irrigation practices and explore synergies and trade-offs of agricultural intensification.

1. Introduction

Agricultural output is expected to rise in the coming years, with competing demand for key resources and complex trade-offs of water, energy, environment, and food [1]. Population growth, economic development, and climate change are already exerting pressure on agriculture and food systems with considerable water and energy consumption [2] and environmental impacts like water footprint, land-use change, greenhouse gas emissions, eutrophication, ecotoxicity, and human health [3]. That's why, the interdependencies between water, energy, and environmental impacts on crop production are commanding increasing attention.

On a life-cycle basis, water, energy, food, and environment are closely intertwined calling for a holistic and inclusive approach to address complex resource and development challenges [4]. The nexus concept is gaining increasing attention in sustainability research and policymaking communities for considering the interdependencies of nexus domains [5]. Among nexus approaches, the water-energy-environment nexus (WEEN) is a focus of much research to address synergies, tensions, and potential trade-offs between food, energy, water, and environment at multiple spatial and temporal scales [6]. Life cycle thinking indicators and life cycle assessment (LCA) is used to capture the complex and often "hidden" linkages between resources from a WEEN nexus perspective [7]. Because of its holistic nature, the LCA is one of the most used tools for nexus thinking [8]. On other hand, energy input-output analysis has been widely applied to explore and assess energy use efficiency environmental impacts, and their relationships with system sustainability [9].

Agriculture is one of the most important sectors of the Albanian economy, with feed crops (wheat, maize, and barley) occupying more than 30% of a typical cropping pattern [10]. Crop production in Albania demands higher amounts of crop inputs for considerably lower productivity generating synergies and trade-offs. Crop production includes a wide range of different impacts caused by fertilizers and pesticides and the fuel use embedded in fertilizers and field operations. They include water and energy consumption, air emissions (ammonia volatilization, dinitrogen monoxide), soil emissions (heavy metals), and water emissions (nitrate leaching), which themselves contribute to different environmental effects.

Intensifying agriculture in a sustainable manner call for studying the links between diets, agricultural production practices, and environmental degradation [11]. Wheat and maize cultivation in literature has been

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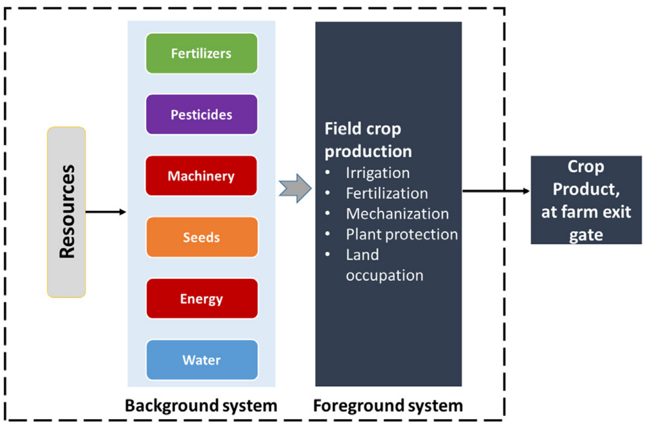


Fig. 1. System boundary for the wheat and maize production systems.

examined for energy performance and environmental impact, but, to our knowledge, there is no evidence of the impact of resource consumption and emissions associated with them in Albania through a systemic approach. Henceforth, we investigated water-energy-environmental interactions in conventional wheat and maize production on a generic farm in Albania. Nexus is assessed by applying the environmental footprint indicators and energy analysis. The assessment enables us to the identification of benchmarks and proof of performance, synthesize and generate LCA information, and determine the main 'hotspots' following a life cycle perspective.

2. Material and methods

2.1. Scope of the study

The goal of this study is to analyze the conventional irrigated wheat and maize production from a cradle-to-farm gate perspective which covers all background (upstream or off-farm) and foreground (downstream or on-farm) processes related to crop cultivation up to harvest (Fig. 1). The background processes include the production of inputs to the farm, including the production of seeds, fertilizers, pesticides, electricity, and the fuel used in the crop operations and auxiliary products and machinery (i.e., lubricants and tractors). The downstream processes include the emission of fuel consumption in tractors, fertilizer consumption, and water for irrigation and their associated emissions. The performance indicators are defined for a functional unit of 1 ton of product and 1 hectare of cultivated land.

2.2. Data sources and inventory

Table 1 presents the list of inventory data developed for the crops under study. Main input data (crop yield, data on nitrogen application rates, pesticide use, and information on field processes and machinery use) for the life-cycle inventory were retrieved from the LEAP database [12].

The water for irrigation was obtained from data from the Ministry of Agriculture. The energy for irrigation was estimated based on water sources used for irrigation, i.e. considering 86% surface water and 14% groundwater [11]. Theoretical energy requirements were computed for a depth of 5 meters for surface water and 15 meters for groundwater and overall pump efficiency of 40%. The direct emissions on the field from fertilizer (soil atmospheric nitrous oxide, ammonia volatilization, nitrate leaching, and phosphorus emission) and fuel combustion emissions were quantified using emission models as previously explained by Canaj et al. [13]. The manure is considered to originate 50% from poultry and 50% from dairy cattle. The quantified on-field emission from fertilizer, fuel combustion, and pesticide are presented in Supplementary information. No allocation criteria were used for allocating the impacts because it was assumed that straw is left on the field [14]. It is difficult to establish shares of straw removed from the field, the final destination of straw, co-product prices, and other relevant factors for performing a sensitivity analysis of the allocation of co-products.

2.1.1. Energy and footprint indicators

To evaluate the energy consumption, various energy indices such as energy use efficiency, net energy, energy productivity, and specific energy were used (Table 2).

The energy input was obtained as a product of each input and by their corresponding energy coefficient. The total input of energy was calculated as the sum of all energy inputs used. The output energy was obtained as a product of yield and its equivalent energy representative. Energy equivalents of inputs and outputs in wheat maize production are presented in Table 3.

For environmental footprint indicators, one of the most recent and updated impact assessment methods such as ReCiPe 2016 [18] was applied for analysis. We calculated twenty-two indicators, but the emphasis was on global warming, water consumption, terrestrial acidification, and freshwater eutrophication potential because these indicators have received the most attention in the international literature. Additional calculated ReCiPe2016 impact categories are presented in the supplementary data. Each crop's final index was calculated by aggregating environmental impacts into a single score using normalization and weighting set World ReCiPe H/A (human health 400; ecosystem quality 400 and resources 200). The openLCA 1.10.3 software [19] was used for life cycle impact assessment. The Ecoinvent LCA database v.3.1 [20] was used for retrieving secondary life cycle inventory data about investigated crops.

3. Results and discussion

3.1. Water-energy-environment nexus of wheat production

The results of the analysis for wheat production are presented in Table 4. The total energy input in wheat production was estimated at 12,578 MJ ha^{-1} or 2626 MJ t^{-1}. Among all the production practices (Fig. 2a), fuel and machinery mechanization was the most energy-consuming input with 46%, followed by seed (26%), irrigation (21%), and fertilizers (8%). Pesticides have negligible impacts.

The estimated energy input for growing wheat is generally lower in comparison with other studies. Ghorbani et al. [21] estimated the energy input in irrigated wheat systems in North Iran was 15,835 MJ t^{-1}or 45367.6 MJ ha^{-1}. Ghasemi-Mobtaker et al. [22] calculated 43054.63 MJ ha^{-1} or 8143.5 MJ t^{-1} for a given yield of 5.287 t ha^{-1} in West Iran. In Turkey [23], the total energy input in wheat was calculated to be 23,231 MJ ha^{-1} or 5162.5 MJ t^{-1} for a given yield of 4.5 t ha^{-1}. In New Zealand [24], total energy consumption in wheat production was estimated at 22,566 MJ ha^{-1}. In Sudan [25], it ranged from 30,638 MJ ha^{-1} (12,050 MJ t^{-1}) to 33,160 MJ ha^{-1} (11,689 MJ t^{-1}) depending on the tillage system. In Pakistan [15], the energy consumed for the inputs in the production of wheat crops is 34,430.98 MJ ha^{-1}, with an average wheat yield of 3712.85 kg ha^{-1}.

Energy use efficiency, specific energy, energy productivity, and net energy gain in wheat production (Table 4) were calculated as 4.95, 2.63 MJ kg^{-1}, 0.38 kg MJ $^{-1}$, and 49,692 MJ ha^{-1}, respectively. The values of energy indices vary throughout the literature. Singh et al [17] reported an energy use efficiency of 5.20 and specific energy up to 9 MJ kg^{-1} for irrigated wheat in India. Khan et al [26] reported an energy efficiency for wheat as 9.21, specific energy of 2.23 MJ kg^{-1}, and energy productivity of 0.44 kg MJ^{-1} in Australia. In Iran, Ghorbani et al. [21] calculated energy use efficiency as 1.44, specific energy as 15.83 MJ kg^{-1}, energy productivity as 0.06 kg MJ^{-1}, and net energy as 19968.69 MJ ha^{-1}. These values were 3.52, 5.16 MJ kg^{-1}, 0.19 kg MJ^{-1}, and 58,489 MJ

Table 1
Input and yield data for wheat and maize production in Albania [12].

Parameter	Wheat	Maize	Unit
Inputs			
Seeds for sowing	33.4	9.29	kg t^{-1}
Organic Fertilizer (50% poultry-50% dairy cattle)	4.11	3.05	kg N t^{-1}
Syntethic nitrogen-based fertilizers	3.7	2.74	kg N t^{-1}
Phosphorus based fertilizers	1.4	1.0	kg P_2O_5 t^{-1}
Potassium based fertilizers	0.33	0.25	kg K_2O t^{-1}
Pesticide, unspecified	0.063	0.046	kg t^{-1}
Tractor fuel use	20.3	14.6	kg t^{-1}
Working time	2.0	1.4	hours t^{-1}
Tractor, module manufacturing	1.0	0.7	kg t^{-1}
Water for irrigation	324.3	715.2	m^3 t^{-1}
Electricity for irrigation	17.6	39.0	kWh t^{-1}
Land occupation	1878.9	1300	m^2 t^{-1}
Crop yield output			
Crop Yield	4.78	6.46	tha^{-1}

Table 2
Formula to calculate energy indices in crop production.

Indicator	Unit	Formula
Energy use efficiency	-	$\text{Energy use efficiency} = \frac{\text{Energy output (MJ ha}^{-1})}{\text{Energy input (MJ ha}^{-1})}$
Energy productivity	kg MJ^{-1}	$\text{Energy productivity} = \frac{\text{Crop output (kg ha}^{-1})}{\text{Energy input (MJ ha}^{-1})}$
Specific energy	MJ kg $^{-1}$	$\text{Specific energy} = \frac{\text{Energy input (MJ ha}^{-1})}{\text{Crop output (kg ha}^{-1})}$
Net energy	MJ ha^{-1}	$\text{Net energy} = \text{Energy output (MJ ha}^{-1}) - \text{Energy input (MJ ha}^{-1})$

Table 3
Energy equivalents were used in the study for different agricultural operations.

Parameter	Energy equivalents (MJ $unit^{-1}$)	Unit	Refs.
Seeds, wheat (average hybrid and general)	20.1	kg	[32]
Seeds, maize	9	kg	[16]
Manure	0.3	kg	[32]
Nitrogen-based fertilizers	47.1	kg	[32]
Phosphorus based fertilizers	15.8	kg	[32]
Potassium based fertilizers	9.28	kg	[32]
Pesticide, unspecified	193	kg	[15]
Diesel fuel	47.8	kg	[15,32]
Tractor machinery	62.7	kg	[15]
Water for irrigation	1.02	m^3	[15,32]
Electricity for irrigation	12	kWh	[15]
Wheat, yield	13	kg	[15]
Maize, yield	14.7	kg	[17]

Table 4
Energy and footprint indices for wheat production in Albania.

Item	Unit	Amount
Energy input	MJ ha^{-1}	2626
Energy use efficiency	-	4.95
Energy productivity	kg MJ^{-1}	0.38
Specific energy	MJ kg^{-1}	2.63
Net energy	MJ ha^{-1}	49,692
Global warming potential	kg CO_2-eq t^{-1}	242.2
Acidification potential	kg SO_2-eq t^{-1}	4.05
Water consumption potential	m^3 t^{-1}	288
Freshwater eutrophication potential	kg P eq t^{-1}	0.135
Marine eutrophication potential	kg N eq t^{-1}	0.91
Fossil fuel scarcity	kg oil eq t^{-1}	47.2
Mineral resource scarcity	kg Cu eq t^{-1}	1.1

ha^{-1} in Turkey [23] and 1.4, 9.27 MJ kg^{-1}, 0.107 kg MJ^{-1}, and 13,836 MJ ha^{-1} in Pakistan [15].

In terms of GWP, wheat produced generated 242.2 kg CO_2-eq per ton of product or 1211 kg CO_2-eq ha^{-1}. Fertilization contributed 41% while mechanization represented 39% (Fig. 2b). It was found that 19% of the gross GWP100 was a result of soil N_2O emissions. The production of fertilizers contributed 19% of the gross GWP100 where N-fertilizer was responsible for most of the impact. Our findings are consistent with Awadalla [25], who estimated the GWP of wheat in Pakistan to be 233.36 kg CO_2-eq per ton of product. However, the results differ from other studies. The GWP for a ton of wheat production in Australia [27] was found to be 304 kg CO_2-eq, 560 kg CO_2-eq with a range of 300–1070 kg CO_2-eq in Europe [28], 440 kg CO_2-eq in Northern Italy [29], 190 to 435.3 kg CO_2-eq in Southern Italy [30] depending on fertilizer and water input, 450 to 910 kg CO_2-eq in Iran [31] according to their yield level (high, medium, low) for irrigated and rain-fed production, 317.81 to 380.16 kg CO_2-eq of irrigated and rain-fed wheat in central Iran, Mahyar plain [32], 560 to 640 kg CO_2-eq in China [33] when the crop is irrigated with reclaimed water and groundwater.

The water consumption indicator for wheat production was 288 m^3 t^{-1}, with on-farm irrigation accounting for 84% of total water consumption (Fig. 2c). Other inputs have a smaller share, with fertilizers accounting for 12% and seeds accounting for 4%. Usually, direct freshwater consumption primarily contributes to the impact on water consumption [34]. Todorović et al. [30] estimated a WCP from 137.03 to 497.3 m^3 in

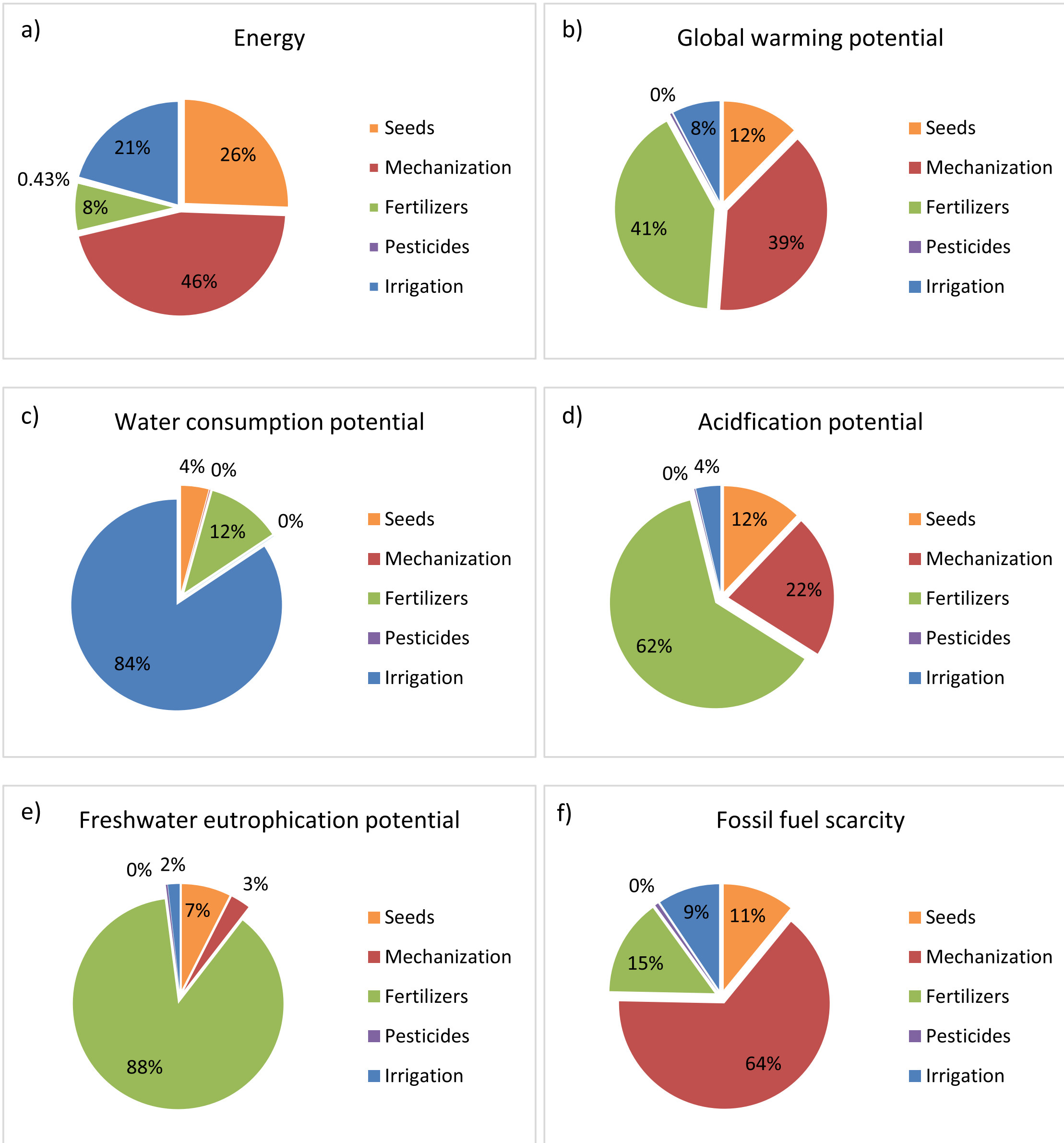


Fig. 2. Process contribution to energy and environmental impacts of wheat production in Albania.

Southern Italy depending on fertilizer and water input which is similar to the results of this study. The terrestrial acidification was estimated at 4.05 kg SO_2-eq t^{-1} while freshwater eutrophication was 0.135 kg P-eq t^{-1}. These impacts were mainly due to the application and production of fertilizers (Fig. 2d and e). Achten and Van Acker [28] reported that acidification of wheat production in Europe varies from 1.95 to kg SO_2-eq t^{-1} with an average of 3.05 kg SO_2-eq t^{-1} while eutrophication potential is 0.34 to 3.04 kg PO_4-eq t^{-1} with an average 1.67 kg PO_4-eq t^{-1}. Fossil fuel scarcity, representing the non-renewable depletion of coal, gas, and oil was estimated at 47.17 kg oil eq. It was mostly impacted by mechanization sharing 64% of the impact.

The total environmental footprint (ReCiPe single score) of wheat in Albania is 69.3 points (Fig. 3). Fuel and machinery mechanization induces 56% of the total environmental footprint, followed by irrigation (17%), fertilizers (13%), land occupation (10%), and seed production (5%). With a 79% contribution, foreground processes (on-farm) make a significant contribution to the total footprint.

3.2. Water-energy-environment nexus of maize production

The results of the analysis for wheat production are presented in Table 5. The total energy input per ton of production in maize production was 1927.1 MJ t^{-1} or 12,448.6 MJ ha^{-1}. For this crop, irrigation emerges as the main energy input, accounting for 62% of total energy input (Fig. 4a). Mechanization constituted 25% of the total input energy, while fertilizers and seeds 8% and 4%, respectively. The energy input for maize production varies throughout literature depending on farm input and corresponding yield. The energy input for maize was estimated at 4,200 to 10,400 MJ ha^{-1} in Northern Italy [35] depending on tillage systems; 39295.50 MJ ha^{-1} in Iran [36], 16,482 to 23,338 MJ ha^{-1} for organic and conventional maize in Greece [37]; 16,100 to 18,100 MJ ha^{-1} in Baltic countries depending on tillage systems [38]; 9803.78 MJ ha^{-1} in Nigeria [39]. Energy use efficiency, specific energy, energy productivity, and net energy gain in maize production (Table 5) were calculated as 7.63, 1.93 kg MJ $^{-1}$, 0.52 MJ kg^{-1}, and 82,513 MJ ha^{-1},

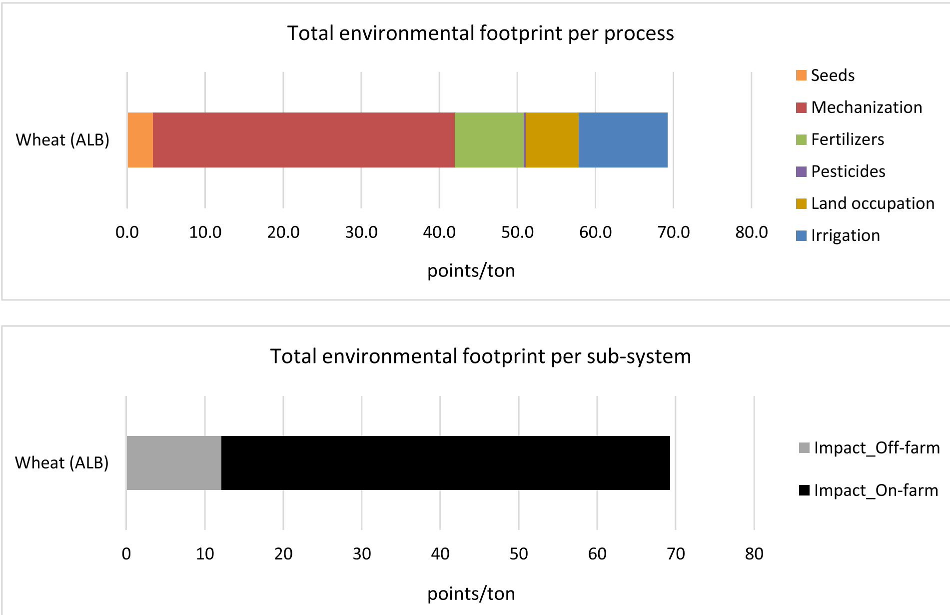


Fig. 3. Process and sub-system contribution to the total environmental footprint of wheat production in Albania.

Table 5
Energy and footprint indices for maize production in Albania.

Item	Unit	Amount
Energy input	MJ ha^{-1}	1927.3
Energy use efficiency	-	7.63
Energy productivity	kg MJ^{-1}	0.52
Specific energy	MJ kg^{-1}	1.93
Net energy	MJ ha^{-1}	82,513
Global warming potential	kg CO_2-eq t^{-1}	181
Acidification potential	kg SO_2-eq t^{-1}	2.82
Water consumption potential	m^3 t^{-1}	561
Freshwater eutrophication potential	kg P eq t^{-1}	0.1
Marine eutrophication potential	kg N eq t^{-1}	0.67
Fossil fuel scarcity	kg oil eq t^{-1}	35.13
Mineral resource scarcity	kg Cu eq t^{-1}	0.94

respectively. In Iran [36], these indicators were calculated as 1.48, 5.28 MJ kg^{-1}, 0.1 kg MJ $^{-1}$, and 18,769 MJ ha^{-1}, respectively. In Nigeria [40] these values were 3.43, 9.95 MJ kg^{-1}, 0.19 kg MJ $^{-1}$, and 33,510 MJ ha^{-1}. Bilalis et al. [37] in Greece estimated energy use efficiency, energy productivity, and net energy gain in maize production as 8.63, 0.59 MJ kg^{-1}, and 178,052 MJ ha^{-1}, respectively.

Maize produced 181.1 $kgCO_2$-eq per ton of product. Both fertilizers and diesel combustion in field operations contributed with 38% and 28% while irrigation with 23% of total GWP (Fig. 4b). Around 11% was attributed to seed production. For 1 of ton maize production, the reported GWP is 393.86 kg CO_2-eq in North China Plain [41], 620 kg CO_2-eq in Northeast China [42], 410 kg CO_2-eq in Northern Italy [29], and 590 to 850 kg CO_2-eq in Poland [43].

For maize, the water consumption indicator was estimated at 561 m^3 t^{-1}. Most of the water consumption (96%) was caused by water for irrigation and the rest was made from fertilizers (4%). The terrestrial acidification was estimated at 2.82 kg SO_2-eq t^{-1} while freshwater eutrophication was 0.1 kg P-eq t^{-1}. Król-Badziak et al. [43] estimated a similar range of AP from 2.21 to 3.02 kg SO_2-eq t^{-1}. Fossil fuel scarcity was estimated at 35.13 kg oil eq with 45% from mechanization and 28% from irrigation and the rest from fertilizers and seeds.

The total environmental impact of maize production in Albania is 60.2 points (Fig. 5). The most important factors governing maize's environmental footprint were the application of irrigation (41.5%) and mechanization (34%). Fertilizers share about 9% of the total environmental footprint while seeds 7%. Similar to whet production, foreground processes (on-farm) contribute 75% of the total environmental footprint.

3.3. *Discussion*

Agriculture production frequently consumes large amounts of land, water, fertilizer, and pesticides, resulting in significant environmental changes in many parts of the world. Crop production necessitates both water and energy; pumping, treating, and transporting water necessitates energy; and energy production necessitates water. Energy, water, and environmental issues are inextricably linked because it is nearly impossible to produce, transport, or consume water and energy without causing environmental damage. Knowledge gaps exist in process, system, technology, and policy linking water with food and energy [44]. As a result, research on the nexus of food, water, and energy resources and their impact on the Earth system is a must to provide affordable and reliable resources in an environmentally sustainable way [45]. Understanding how alternative agricultural production systems, agricultural input efficiency, and food choice contribute to environmental degradation is critical for mitigating agriculture's environmental impacts [46]. Our effort is a preliminary attempt to provide useful insights into the connected and evolving consequences of feed crop production in Albania by explicitly modeling food-energy-water-environment interactions using LCA. Our analyses show that crop production in Albania is associated with multiple environmental impacts, with the majority of the cultivation environmental impact caused by on-farm fertilizer emissions, diesel emissions from machine use, and irrigation water, confirming that the on-farm (foreground) subsystem is important from an environmental standpoint. Yet, from a methodological point of view, this study underlines the need for a life cycle perspective to capture trade-offs and avoid burden shifting as the production and transportation of farm input account for more than one-quarter of the impacts. A comparison with other scientific studies demonstrated that the energy input for wheat production in Albania is less compared to Iran [21,22], Turkey [23], New Zealand [24], Sudan [25], and Pakistan [15]. The global warming potential was found to be lower than the European average [28], Iran [31,32], and China [33]. For maize, the energy input for maize production was lower than in Northern Italy [35], Iran [36], Greece [37], and Baltic countries [38] while the global warming was less than in China [41,42], Italy [29] and Poland [43]. Wheat and maize production in

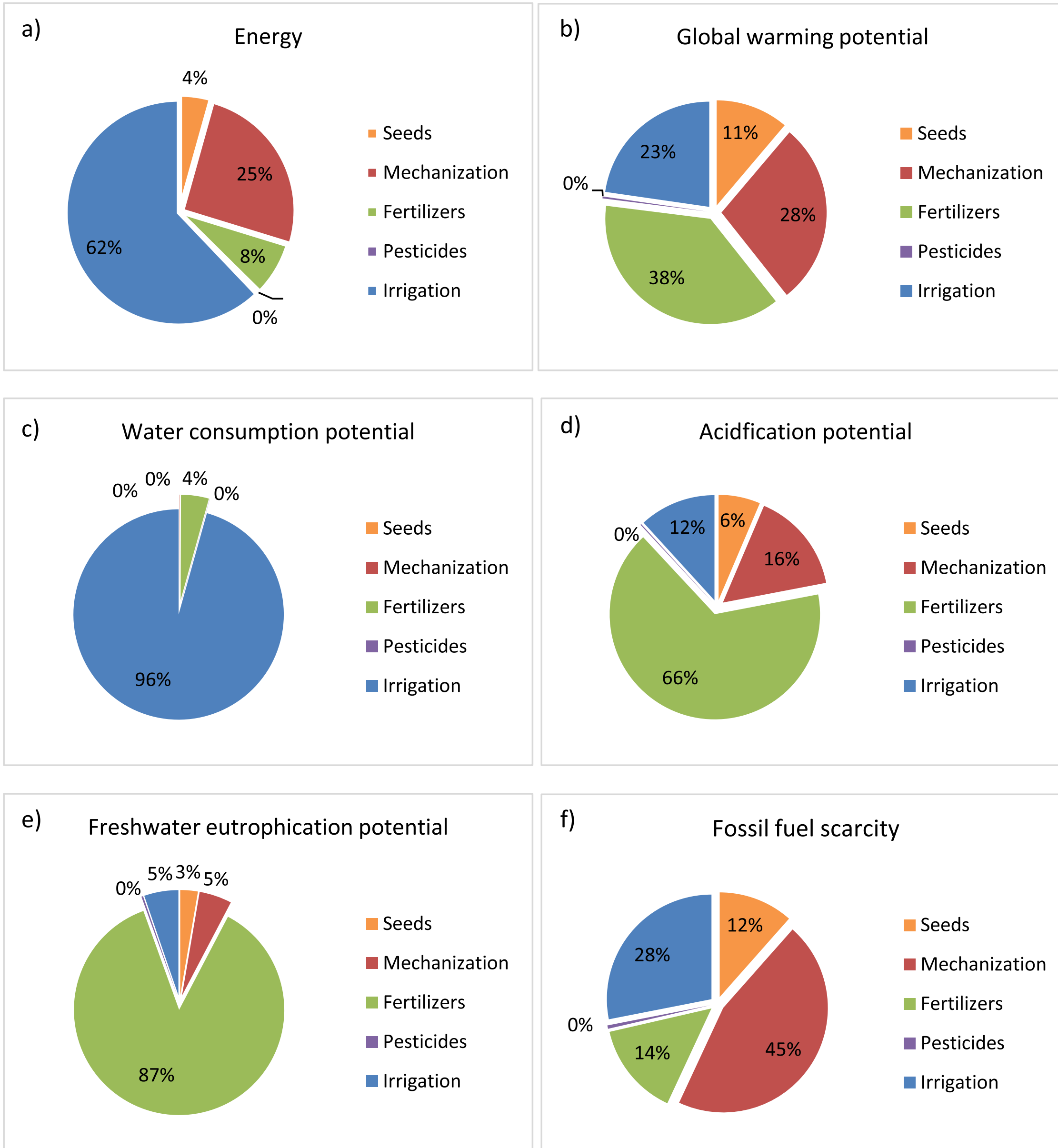
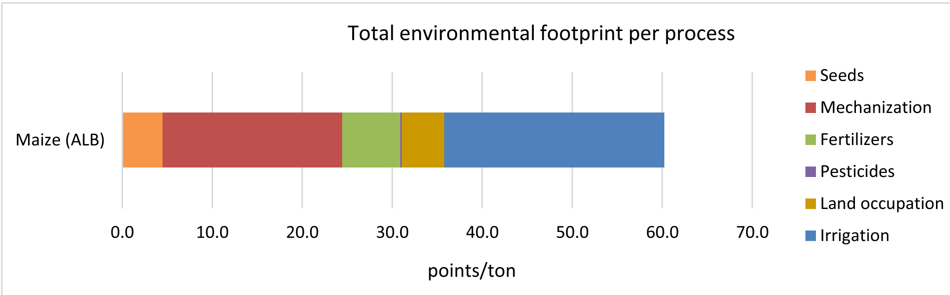


Fig. 4. Process contribution to energy and environmental impacts of maize production in Albania.

Albania is less resource-intensive, and thereby more environmentally friendly as the limited access to agricultural inputs in Albania has implied low input agriculture. The use of mineral fertilizers in Albania has been drastically reduced since 1990 [47]. Moreover, energy consumption is relatively low in Albanian arable farming subsystems due to the low level of farm mechanization. Meanwhile, irrigation is characterized by relatively lowest energy needs and related emissions since water for irrigation is pumped mainly from surface water, and the uptake of high energy demanding pressurized irrigation systems is still very limited [11]. Low-input cropping systems were introduced in Western Europe to reduce the environmental impacts of intensive farming, but some of their benefits are offset by lower yields and land-use efficiency [48]. Low-energy inputs can lead to lower yields and perversely to higher energy demands per ton of harvested product [49]. Hence, the choice of the functional unit (land vs. productivity) may strongly influence the environmental impacts of crop cultivation.

Albanian agriculture is currently undergoing modernization measures to increase the agri-food sector's competitiveness and progressively align it with the EU acquis. Modernization is characterized by a gradual increase in productivity, efficient irrigation systems, new tractor machines, and improved fertilizer use due to farmland nutrient management methods. Modernization indicates that the irrigation withdrawals will likely increase, thus a general challenge is the calibration of the irrigation withdrawals and accounting for the water competition with the energy sector. Albania is relatively water-rich, however, 98% of installed electricity capacity is based on hydropower. The annual energy demand in Albania is expected to increase by 77% in 2030 compared to 2018 levels [50]. It is recognized that numerous tensions may arise within the water-energy-food nexus, which are primarily related to the interacting water demands of the energy sector [51]. As a consequence, multiple components of the food-energy-water-environment should be the subject of scientific research. Advocating for agricultural intensification must be accompanied by a multi-indicator and life cycle perspective to mitigate the unexpected negative effects of these modernization processes (e.g. rebound effect on water consumption due to energy use, increased fertilizer, and energy input and infrastructure, etc.). Assessing



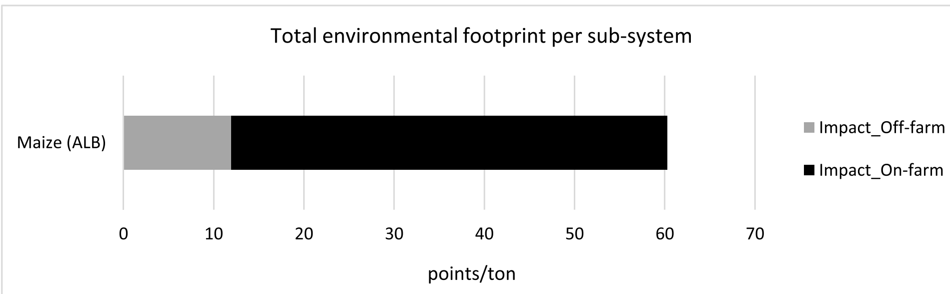


Fig. 5. Process contribution to the total environmental footprint of maize production in Albania.

the food-energy-water nexus is a complicated task that requires the integration of highly heterogeneous data sets and multiple models with different spatial and temporal resolutions. The nexus is complex and exists on many scales, from the global and national scale down to the end-user. Currently, available databases and software make LCA, a key tool for integrated nexus assessments [7] enabling understanding of the nexus and other environmental impact categories from a 'cradle-to-grave' perspective [52] and the tradeoffs and synergies throughout the value chain [46].

4. Conclusions

This study used LCA-based indicators to provide insights into the water-energy-environment nexus associated with wheat and maize production in Albania. The results indicate that growing 1 ton of wheat requires 2626 MJ of energy, 288 m^3 of water, and generates 242.2 $kgCO_2$-eq while 1 ton of maize requires 2008.3 MJ of energy, 561 m^3 of water, and generates 181.1 $kgCO_2$-eq. Energy use efficiency, specific energy, energy productivity, and net energy gain in wheat production were calculated as 4.95, 2.63 MJ kg^{-1}, 0.38 kg MJ $^{-1,}$ and 49,692 MJ ha^{-1}, respectively. Maize performs better with 7.63, 1.93 kg MJ $^{-1}$, 0.52 MJ kg^{-1}, and 82,513 MJ ha^{-1}, respectively. Calculating a final environmental index due to resource use and emissions we found that maize has a 13% lower environmental footprint, i.e. generate 60.2 points versus 69.3 points of wheat production. Wheat uses more seed and mechanization but lower irrigation energy in comparison to maize production. On the other hand, maize has better crop productivity. The results demonstrated highlight that efficient use of irrigation water, fertilizers, and fuel is needed to improve global warming, energy performance, and the overall environmental sustainability of wheat and maize production in Albania.

Our assessment is the first attempt to model, map, and quantify the connections of water, energy, and the environment of feed crops in Albanian agriculture. The information derived was useful to generate a baseline understanding of energy performance and environmental footprint of crops and explore benefits and trade-offs from a holistic perspective. Modernization projects are providing opportunities for Albanian agriculture, yet, technology and policy changes can end with either co-benefits or unintended tradeoffs and environmental impacts. As a result, quantitative studies involving nexus modeling and thinking are crucial to assess the resource demands and environmental impacts of technology and policy changes, thus helping to identify interventions for improving the eco-efficiency of cropping systems.

Declaration of Competing Interest

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nexus.2022.100100.

References

[1] D. Giovannucci, S.J. Scherr, D. Nierenberg, C. Hebebrand, J. Shapiro, J. Milder, K. Wheeler, agriculture Food, the future of sustainability. A Strateg. input to Sustain, Dev. 21st Century Proj. 194, doi:10.2139/ssrn.2054838.

[2] V. Correa-Porcel, L. Piedra-Muñoz, E. Galdeano-Gómez, Water–energy–food nexus in the agri-food sector: research trends and innovating practices, Int. J. Environ. Res. Public Health 18 (24) (2021) 12966, doi:10.3390/ijerph182412966.

[3] K.R. Caffrey, M.W. Veal, Conducting an agricultural life cycle assessment: challenges and perspectives, Sci. World J. (2013), doi:10.1155/2013/472431.

[4] A. Momblanch, L. Papadimitriou, S.K. Jain, A. Kulkarni, C.S.P. Ojha, A.J. Adeloye, I.P. Holman, Untangling the water-food-energy-environment nexus for global change adaptation in a complex Himalayan water resource system, Sci. Total Environ. 655 (2021) 35–47, doi:10.1016/j.scitotenv.2018.11.045.

[5] V. Cabello, A. Renner, M. Giampietro, Relational analysis of the resource nexus in arid land crop production, Adv. Water Resour. 130 (2019) 258–269, doi:10.1016/j.advwatres.2019.06.014.

[6] H. Leck, D. Conway, M. Bradshaw, J. Rees, Tracing the water–energy–food nexus: description, theory and practice, Geogr. Compass 9 (8) (2015) 445–460, doi:10.1111/gec3.12222.

[7] G. Salmoral, X. Yan, Food-energy-water nexus: a life cycle analysis on virtual water and embodied energy in food consumption in the Tamar catchment, UK, Resour. Conserv. Recycl. 133 (2018) 320–330, doi:10.1016/j.resconrec.2018.01.018.

[8] C.J.F. Torres, C.H.P. de Lima, B.S. de A.Goodwin, T.R. de Aguiar Junior, A.S. Fontes, D.V. Ribeiro, R.S.X. da Silva, Y.D.P. Medeiros, A literature review to propose a systematic procedure to develop "nexus thinking" considering the water-energy-food nexus, Sustain 11 (24) (2019) 7205, doi:10.3390/SU11247205.

[9] S. Yuan, S. Peng, Food-energy-emission nexus of rice production in China, Crop Environ. 1 (2022) 59–67, doi:10.1016/j.crope.2022.03.007.

[10] Agricultural statistics. National Institute of Statistics in Albania, http://www.instat.gov.al/al/temat/bujq%C3%ABsia-dhe-peshkimi/bujq%C3%ABsia/#tab2, 2020 (accessed 01 March 2022).

[11] A. Daccache, J.S. Ciurana, J.A. Rodriguez Diaz, J.W. Knox, Water and energy footprint of irrigated agriculture in the Mediterranean region, Environ. Res. Lett. 912 (2014) 124014, doi:10.1088/1748-9326/9/12/124014.

[12] FAO. "Global Database of GHG Emissions Related to Feed Crops: Methodology. Version 1. Livestock Environmental Assessment and Performance Partnership." (2017).

[13] K. Canaj, A. Mehmeti, V. Cantore, M. Todorović, LCA of tomato greenhouse production using spatially differentiated life cycle impact assessment indicators: an Albanian case study, Environ. Sci. Pollut. Res. 27 (7) (2020) 6960–6970, doi:10.1007/s11356-019-07191-7.
[14] S. Corrado, V. Castellani, L. Zampori, S. Sala, Systematic analysis of secondary life cycle inventories when modelling agricultural production: a case study for arable crops, J. Clean. Prod. 172 (2019) 3990–4000, doi:10.1016/j.jclepro.2017.03.179.
[15] S. Ilahi, Y. Wu, M.A.A. Raza, W. Wei, M. Imran, L. Bayasgalankhuu, Optimization approach for improving energy efficiency and evaluation of greenhouse gas emission of wheat crop using Data Envelopment Analysis, Sustainability 11 (12) (2019) 3409, doi:10.3390/SU11123409.
[16] A. Konieczna, K. Roman, M. Roman, D. Śliwiński, M. Roman, Energy efficiency of maize production technology: Evidence from Polish farms, Energies 14 (1) (2020) 170, doi:10.3390/en14010170.
[17] H. Singh, A.K. Singh, H.L. Kushwaha, A. Singh, Energy consumption pattern of wheat production in India, Energy 32 (10) (2007) 1848–1854, doi:10.1016/j.energy.2007.03.001.
[18] M.A. Huijbregts, Z.J. Steinmann, P.M. Elshout, G. Stam, F. Verones, M. Vieira, R. van Zelm, ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level, Int. J. Life Cycle Assess. 22 (2) (2017) 138–147, doi:10.1007/s11367-016-1246-y.
[19] A. Ciroth, ICT for environment in life cycle applications openLCA—A new open source software for life cycle assessment, Int. J. Life Cycle Assess. 12 (4) (2007) 209–210, doi:10.1065/lca2007.06.337.
[20] Ecoinvent Database Version 3.1 Swiss Centre for Life Cycle Inventories, Switzerland. Available online: https://www.ecoinvent.org/database/ecoinvent-371/ecoinvent-371.html (accessed on 01 March 2022).
[21] R. Ghorbani, F. Mondani, S. Amirmoradi, H. Feizi, S. Khorramdel, M. Teimouri, S. Sanjani, S. Anvarkhah, H. Aghel, A case study of energy use and economical analysis of irrigated and dryland wheat production systems, Appl. Energy 88 (1) (2011) 283–288, doi:10.1016/j.apenergy.2010.04.028.
[22] H. Ghasemi-Mobtaker, A. Kaab, S. Rafiee, Application of life cycle analysis to assess environmental sustainability of wheat cultivation in the west of Iran, Energy 193 (2020) 116768, doi:10.1016/j.energy.2019.116768.
[23] G. Unakıtan, B. Aydın, A comparison of energy use efficiency and economic analysis of wheat and sunflower production in Turkey: a case study in Thrace Region, Energy 149 (2018) 279–285, doi:10.1016/j.energy.2018.02.033.
[24] M. Safa, S. Samarasinghe, Determination and modelling of energy consumption in wheat production using neural networks: a case study in Canterbury province New Zealand, Energy 36 (8) (2011) 5140–5147, doi:10.1016/j.energy.2011.06.016.
[25] A.M.E. Awadalla, Energy consumption for wheat production under two different tillage systems in River Nile State Sudan, J. Agric. Biotechnol. Sustain. Dev. 13 (2021) 28–32, doi:10.5897/JABSD2018.0330.
[26] S. Khan, M.A. Khan, M.A. Hanjra, J. Mu, Pathways to reduce the environmental footprints of water and energy inputs in food production, Food Policy 34 (2) (2009) 141–149, doi:10.1016/j.foodpol.2008.11.002.
[27] W.K. Biswas, L. Barton, D. Carter, Global warming potential of wheat production in Western Australia: a life cycle assessment, Water Environ. J. 22 (2008) 206–216, doi:10.1111/j.1747-6593.2008.00127.x.
[28] W.M.J. Achten, K. Van Acker, EU-average impacts of wheat production: a meta-analysis of life cycle assessments, J. Ind. Ecol. 20 (1) (2016) 132–144, doi:10.1111/jiec.12278.
[29] V. Fantin, S. Righi, I. Rondini, P. Masoni, Environmental assessment of wheat and maize production in an Italian farmers' cooperative, J. Clean. Prod. 140 (2017) 631–643, doi:10.1016/j.jclepro.2016.06.136.
[30] M. Todorović, A. Mehmeti, V. Cantore, Impact of different water and nitrogen inputs on the eco-efficiency of durum wheat cultivation in Mediterranean environments, J. Clean. Prod. 183 (2018) 1276–1288, doi:10.1016/j.jclepro.2018.02.200.
[31] M. Tahmasebi, T. Feike, A. Soltani, M. Ramroudi, N. Ha, Trade-off between productivity and environmental sustainability in irrigated vs. rainfed wheat production in Iran, J. Clean. Prod. 174 (2018) 367–379, doi:10.1016/j.jclepro.2017.10.305.
[32] M. Taki, F. Soheili-Fard, A. Rohani, G. Chen, H. Yildizhan, Life cycle assessment to compare the environmental impacts of different wheat production systems, J. Clean. Prod. 197 (2018) 195–207, doi:10.1016/j.jclepro.2018.06.173.
[33] X.X. Romeiko, A comparative life cycle assessment of crop systems irrigated with the groundwater and reclaimed water in Northern China, Sustainability 11 (10) (2019) 2743, doi:10.3390/su11102743.
[34] Z. Jiang, H. Zheng, B. Xing, Environmental life cycle assessment of wheat production using chemical fertilizer, manure compost, and biochar-amended manure compost strategies, Sci. Total Environ. 760 (2021) 143442, doi:10.1016/j.scitotenv.2020.143342.
[35] M. Bertocco, B. Basso, L. Sartori, E.C. Martin, Evaluating energy efficiency of site-specific tillage in maize in NE Italy, Bioresour. Technol. 99 (15) (2008) 6957–6965, doi:10.1016/j.biortech.2008.01.027.
[36] S.H Lorzadeh, A. Mahdavidamghani, M.R. Enayatgholizadeh, M. Yousefi, Energy input-output analysis for maize production systems in Shooshtar, Iran, Adv. Environ. Biol. 5 (11) (2011) 3641–3645 ISSN 1995-0756.
[37] D. Bilalis, P.E. Kamariari, A. Karkanis, A. Efthimiadou, A. Zorpas, I. Kakabouki, Energy inputs, output and productivity in organic and conventional maize and tomato production, under mediterranean conditions, Not. Bot. Horti Agrobot. Cluj Napoca 41 (1) (2013) 190–194, doi:10.15835/nbha4119081.
[38] E. Šarauskis, S. Buragiene, L. Masilionyte, K. Romaneckas, D. Avižienyte, A. Sakalauskas, Energy balance, costs and CO_2 analysis of tillage technologies in maize cultivation, Energy 69 (2014) 227–235, doi:10.1016/j.energy.2014.02.090.
[39] B.S. Kosemani, A.I. Bamgboye, Modelling energy use pattern for maize (Zea mays L.) production in Nigeria, Clean. Eng. Technol. 2 (2021) 100051, doi:10.1016/j.clet.2021.100051.
[40] A.I. Lawal, R. Akinoso, M.R. Olubiyi, K.K. Olatoye, Embedded energy of on farm losses and energy analysis for maize production in Nigeria, Int. J. Eng. Sci. 62 (2014) 109–173 1.75.
[41] M.X. Wang, W.L. Wu, W.N. Liu, Y.H. Bao, Life cycle assessment of the winter wheat-summer maize production system on the North China Plain, Int. J. Sustain. Dev. World Ecol. 14 (4) (2007) 400–407, doi:10.1080/13504500709469740.
[42] H. Wang, Y. Yang, X. Zhang, G. Tian, Carbon footprint analysis for mechanization of maize production based on life cycle assessment: a case study in Jilin Province, China, Sustainability 7 (11) (2015) 15772–15784, doi:10.3390/su71115772.
[43] A. Król-Badziak, S.H. Pishgar-Komleh, S. Rozakis, J. Księżak, Environmental and socio-economic performance of different tillage systems in maize grain production: application of life cycle assessment and multi-criteria decision making, J. Clean. Prod. 278 (2021) 123792, doi:10.1016/j.jclepro.2020.123792.
[44] X. Cai, K. Wallington, M. Shafiee-Jood, L. Marston, Understanding and managing the food-energy-water nexus – opportunities for water resources research, Adv. Water Resour. 111 (2018) 259–273, doi:10.1016/j.advwatres.2017.11.014.
[45] B.R. Scanlon, B.L. Ruddell, P.M. Reed, R.I. Hook, C. Zheng, V.C. Tidwell, S. Siebert, The food-energy-water nexus: transforming science for society, Water Resour. Res. 53 (5) (2017) 3550–3556, doi:10.1002/2017WR020889.
[46] M. Clark, D. Tilman, Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice, Environ. Res. Lett. 12 (6) (2017) 064016, doi:10.1088/1748-9326/aa6cd5.
[47] A. Binaj, P. Veizi, E. Beqiraj, F. Gjoka, E. Kasa, Economic losses from soil degradation in agricultural areas in Albania, Agric. Econ. 60 (6) (2014) 287–293, doi:10.17221/12/2013-AGRICECON.
[48] M. Kulak, T. Nemecek, E. Frossard, G. Gaillard, How eco-efficient are low-input cropping systems in Western Europe, and what can be done to improve their eco-efficiency? Sustainability 5 (9) (2013) 3722–3743, doi:10.3390/su5093722.
[49] J. Woods, A. Williams, J.K. Hughes, M. Black, R. Murphy, Energy and the food system, Philos. Trans. R. Soc. B Biol. Sci. 365 (1554) (2010) 2991–3006, doi:10.1098/rstb.2010.0172.
[50] IRENARenewables Readiness Assessment: Albania, International Renewable Energy Agency, Abu Dhabi, 2021.
[51] P. D'Odorico, K.F. Davis, L. Rosa, J.A. Carr, D. Chiarelli, J. Dell'Angelo, J. Gephart, G.K. MacDonald, D.A. Seekell, S. Suweis, M.C. Rulli, The global food-energy-water Nexus, Rev. Geophys. 56 (3) (2018) 456–531, doi:10.1029/2017RG000591.
[52] L. Armengot, M.J. Beltrán, M. Schneider, X. Simón, D. Pérez-Neira, Food-energy-water nexus of different cacao production systems from a LCA approach, J. Clean. Prod. 304 (2021) 126941.