

Environmental impact assessment of dryland winter wheat cultivation in different tillage systems

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Abstract: Tillage operations account for the major of energy consumption in agricultural operation and reducing non-renewable energy use in tillage has important results for decreasing greenhouse gases emissions. So, the purpose of present study was to survey the energy consumption and environmental effects of two tillage systems in dryland winter wheat cultivation. The required data were collected using oral questionnaire and direct visiting from farmers in the west of Iran. Life cycle assessment was used by ReCiPe2016 method for survey wheat production environmental impacts under two tillage systems. The results indicated that the conservation system consumes about 16% less energy compared to the conventional system. The energy ratio of conservation system was about 19% higher than that of conventional system. The CO₂ emission amounts due to the use of diesel fuel were calculated about 297 and 186 kg ha⁻¹ in conventional and conservation tillage systems, respectively. Life cycle assessment results showed that all the investigated environmental indicators in the conservation system are better than the conventional system. Also, direct emissions were the main hotspots of environmental damages in two systems. It was concluded that in conservation system, dryland wheat can be produced with lower environmental impacts than conventional systems.

Keywords: dryland wheat, conservation tillage, life cycle assessment, sustainability.

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1 Introduction

Today, soil erosion is considered as one of the main threats to soil resources. Beside loss of soil organic matter and nutrients, erosion can destroy topsoil and influence soil physical and chemical properties (Jia et al., 2019). Conservation tillage beside plant residue management have the potential to reduce climate change by controlling soil erosion, influencing the nitrogen and carbon cycles and

decreasing greenhouse gas (GHG) emissions (Khakbazan et al., 2019; Alskaf et al., 2021). It can also have a positive result on crop yield in dryland cultivation by storing soil moisture content for a longer period of growth (Sarker et al., 2018). Moreover, since tillage operations account for the major of energy consumption in agricultural operations, the use of conservation or minimum tillage has a significant impact on reducing energy consumption, especially non-renewable energy and fossil fuels, which leads to the reduction of negative environmental effects in agricultural systems. Wheat is widely cultivated all over the world because of its compatibility to various climates (Liu et al., 2019). Wheat is a strategic product in Iran, because it has a significant contribution to the Iranian diet. A great

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part of the agricultural lands in the central and eastern regions of Hamedan province are related to the dryland wheat cultivation and the continuous use of conventional tillage systems along with intensive chemical fertilizers application has severely affected the quality of these soils. This has severely affected the sustainable production of wheat in the Hamedan province. The current approach in this area is to use conservation tillage to control soil erosion and increase the sustainability of dryland wheat production.

The results of previous studies have showed that tillage activities is one of the greatest energy consumers in agricultural system (Nasserri 2019; Ghasemi-Mobtaker et al., 2020a). This is especially more evident in traditional tillage methods, that it is led to generate high environmental risks in this method. High GHG emissions and environmental threat are the main consequences of fossil fuels consumption.

Today, there is a need to manage energy use in agriculture sector to decrease environmental footprints of inputs consumption and operating costs (Olczak et al., 2022). Life cycle assessment (LCA) is a technique for estimating environmental effects of agricultural productions (Ferronato et al., 2023). So, in order to find out the harmful consequences of excessive use of different energy sources on human health and environmental safety, it is very important to examine energy consumption patterns in different agricultural systems (Nabavi-Pelesaraei et al., 2017).

In recent years, several studies have been conducted in agriculture sector for review and comparison energy consumption and environmental footprints associate with inputs usage in different agricultural systems (Ghasemi-Mobtaker et al., 2020b; Mohanty et al., 2020). In a study conducted in Poland, environmental effects of various tillage systems were investigated using LCA approach. The investigated systems were conventional tillage, reduced tillage and no tillage and their effects on maize grain production were studied. The results indicated that reduced tillage and no tillage had better performances from

environmental point of view; while from social and economic viewpoint, conventional tillage had better performance (Król-Badziak et al., 2021). In another study carried out in India, environmental and energy indices of different tillage systems were studied. the results showed that conventional tillage consumed higher input energy an so has higher GHG emission than no-tillage system (Chaudhary et al., 2021). Naseri et al. (2021) studied energy and environmental indicators in sugarcane cultivation for conservation and conventional tillage systems in heavy and arid land. The environmental impacts results indicated that the maximum emissions were related to conventional tillage systems. In addition, a summary of some studies on energy use and environmental impacts in different tillage systems are listed in Table 1.

Conservation tillage in rainfed agriculture in Hamadan province has been studied from various aspects, but no study found to survey this system in terms of energy use pattern and environmental effects. So, the aim of this study was to survey the sustainability in the two dryland wheat cultivation systems in central and eastern regions of Hamedan province. For this purpose, firstly, considering the inputs and outputs, energy use pattern was studied in conventional and conservation tillage systems. Then using LCA approach, the environmental aspects of different tillage systems which implement for dryland wheat production in study region was specified to introduce the sustainable system.

2 Methodology

2.1 Energy analyses of wheat farms

The present study was carried out during production period of 2021-2022 in central and eastern regions of Hamedan province, Iran. This province located in the west part of Iran; within 33° 59' and 35° 48' north latitude and 47° 34' and 49° 36' east longitude. A significant amount of wheat produced in this area is related to rainfed cultivation and moldboard plow and chisel are the two main implements used for primary tillage in dryland cultivation (Ministry of Jihad-e-Agriculture of Iran,

2021). Two different tillage systems were investigated based on tillage operations as follows:

System 1: Conventional tillage including moldboard ploughing in spring, field leveling in late summer and planting in early autumn.

System 2: Conservation tillage including chisel ploughing in autumn, secondary tillage using

Sweep+roller in late spring and planting in early autumn.

Using oral questionnaires from farmers and direct visiting, the needed data for research were collected in studied region. The consumed physical inputs for wheat production (per hectare) were recorded during production period in two mentioned systems and using energy equivalent of inputs, energy equivalences were calculated. The physical inputs used in dryland wheat farms and their energy equivalent are presented in Table 2.

Table 1 A list of researches done on energy consumption and environmental aspects in different tillage systems

Reviewed study	Region	Energy use analysis	Environmental assessment	LCA method	Crop
Košutić et al. (2005)	Slavonia	Yes	-	-	maize, winter wheat and soybean
Tabatabaefar et al. (2009)	Iran	Yes	-	-	Wheat
Arvidsson (2010)	Sweden	Yes	-	-	Winter wheat
Alluvione et al. (2011)	Italy	Yes	-	-	Wheat–maize–soybean rotation
Barut et al. (2011)	Turkey	Yes	-	-	Corn silage
Sharma et al. (2011)	India	Yes	-	-	Maize–wheat rotation
Alhajj Ali et al. (2013)	Italy	Yes	-	-	Rainfed durum wheat
Kumar et al. (2013)	India	Yes	-	-	Wheat
Bacenetti et al. (2015)	Italy	-	Yes	CML 2000	Cereal silage
Keshavarz-Afshar et al. (2015)	USA	Yes	Yes	GHG emissions	Camelina
Meena et al. (2015)	India	Yes	-	-	Greengram
Hamzei & Seyyedi (2016)	Iran	Yes	-	-	Sunflower
Parihar et al. (2016)	India	Yes	-	-	Maize-based systems
Nunes et al. (2017)	Brazil	-	Yes	CML 2001	White and brown rice
Özgöz et al. (2017)	Turkey	Yes	-	-	Potato
Piastrellini et al. (2017)	Argentina	Yes	-	-	Soybean biodiesel
Moitzi et al. (2019)	Austria	Yes	-	-	Winter wheat
Naujokienė et al. (2019)	Lithuania	-	Yes	EDIP 2003	Winter wheat and rapeseed
Šarauskis et al. (2020)	Lithuania	Yes	Yes	GHG emissions	Faba bean
Saldukaitė et al. (2020)	Lithuania	Yes	Yes	GHG emissions	Winter wheat
Nisar et al. (2021)	India	Yes	Yes	GHG intensity	Maize–wheat sequence
Present study	Iran	Yes	Yes	ReCiPe2016	Dryland winter wheat

Table 2 The inputs and outputs energy coefficients in dryland wheat production

Items	Units	Energy equivalent (MJ unit ⁻¹)	Reference
Inputs	1. Human labour	h	1.96 (Pahlavan et al., 2012)
	2. Machinery	h	62.70 (Raheli et al., 2017)
	3. Diesel fuel	L	56.31 (Ghasemi-Mobtaker et al., 2010)
	4. Fertilizers	kg	
	- N		66.14 (Zangeneh et al., 2010)
	- P ₂ O ₅		12.44 (Ghasemi-Mobtaker et al., 2020a)
	- Farmyard manure		0.3 (Ozkan et al., 2004)
	5. Pesticides	kg	
	- Fungicides		216 (Mousavi-Avval et al., 2011)
	- Herbicides		238 (Mousavi-Avval et al., 2011)
- Insecticides		101.2 (Mousavi-Avval et al., 2011)	
6. Seed	kg	14.7 (Ozkan et al., 2004)	
Output	1. Wheat grain yield (kg)	kg	14.7 (Ozkan et al., 2004)
	2. Wheat straw yield (kg)	kg	12.5 (Mohammadi et al., 2014)

One of the goals of determining the quantities of inputs and outputs energy in any production system is

to calculate energy indices. The most important of these indices include energy ratio (*ER*), energy

efficiency (*EP*) and net energy (*NE*), which was calculated using Equations 1-3 (Salehi et al., 2014; Ghasemi-Mobtaker et al., 2020b; Nabavi-Pelesaraci et al., 2021).

$$R = \frac{OE(MJ)}{IE(MJ)} \tag{1}$$

$$EP = \frac{WGY(kg)}{IE(MJ)} \tag{2}$$

$$NE = OE(MJ) - IE(MJ) \tag{3}$$

In which, *OE*, is the output energy, *IE* is input energy and *WGY* is the wheat grain yield.

2.2 LCA

LCA as an environmental management approach is expressed as an estimation of the whole environmental effects associated with different steps and processes in the product's lifetime (Kaab et al., 2019). The relation between the primary energy resources consumption and the pollutions emissions in the entire production chain including raw material extraction, manufacturing, transportation, distribution, operation, repair, maintenance and recycling; are investigate in this approach (Brenttrup et al., 2004; Roy et al., 2009). For considering all the involved in the materials and energies in the life cycle assessment of each product, the systematic approach is required. Generally LCA consists of four phases or steps (Khatri and Jan, 2017; Wang et al., 2021).

2.2.1 Goal and scope statement

The two basic and essential factors for LCA which must be clearly stated are purpose and scope. In the present study, the LCA goal was to determine all the environmental effects of dryland winter wheat cultivation from the extraction of raw material up to the wheat outputs harvesting (grain and straw) in two systems under study. For meet this purpose, the functional unit (FU) and system boundary must be specified (Rebitzer et al., 2004).

The level of detail and system boundaries of LCA depend on the project subject and desired application. The system boundary includes all field operations as well as all used inputs in dryland wheat fields (Ghasemi-Mobtaker et al., 2020a). The different stages of dryland wheat cultivation are similar in the two systems except for tillage operations. The stages of cultivating dryland wheat include preparing of the land, spreading livestock manure on the farm (in some cases), seed planting (with grain drill), spraying and harvesting. Figure 1 shows a schematic diagram of the boundaries of the two systems under study.

FU is one of the most important and essential components of LCA and should be clearly defined. It is a concept used to analyse and compare different systems or services and also ascertains which outputs and inputs are connected to each other (Rebitzer et al., 2004; Cerutti et al., 2011). In this research, one ton of dryland winter wheat was determined as FU.

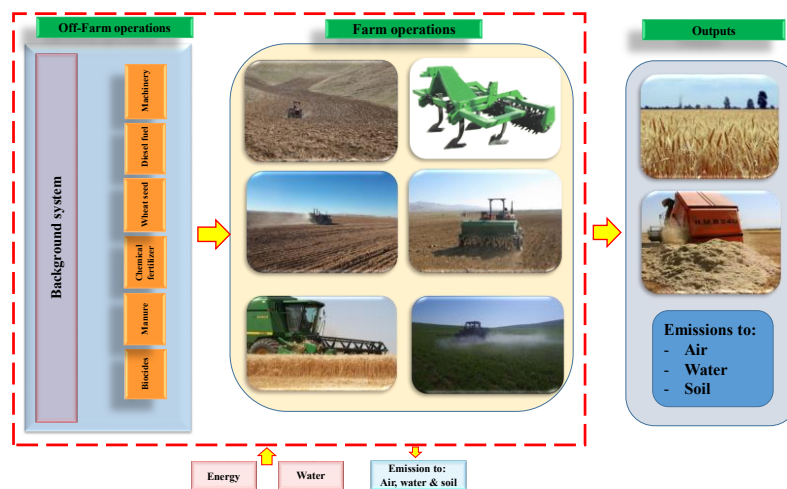


Figure 1 System boundaries of dryland wheat production

2.2.2 LCI

Analyzing the life cycle inventory (LCI) is the next step of LCA approach. This step include an

accurate and complete collection of all materials or inputs applied in various processes as well as whole relevant outputs in total phases of the life cycle based

on a reference unit (Guinée 2002; ISO, 2006). In this phase the value of used resources and the energy required are specified for each FU and according to the emissions coefficient values, pollutant emissions of the production system to environment including emissions to air, soil and water are calculated during its whole life cycle (Mousavi-Avval et al., 2017; Khanali et al., 2018; Kaab et al., 2019). For calculating the off-farm emissions related to inputs production process, EcoInvent database data were used (Ghasemi-Mobtaker et al., 2020b). In the current study, inputs included resources usage which obtained using oral questionnaire and direct visiting of farms. In addition, the outputs were wheat grain and straw yield. These inputs and outputs were specified for two systems under study.

2.2.3 LCIA

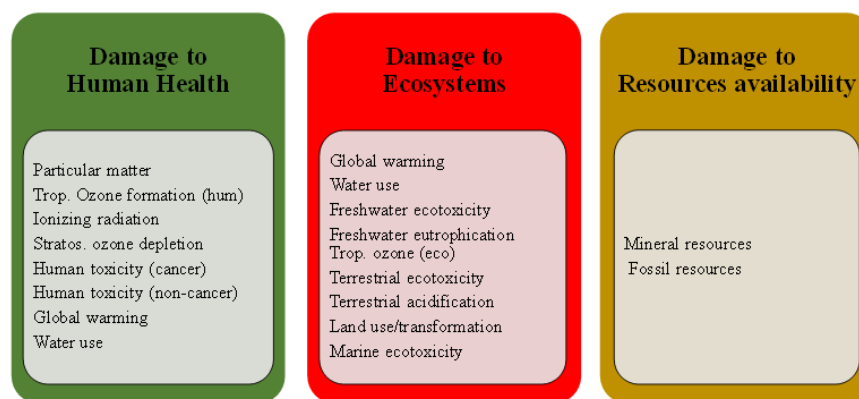


Figure 2 The links between endpoints and midpoints in ReCiPe2016 method

2.2.4 Interpretation

Interpretation of LCA results as the fourth step of LCA, is principled method to evaluate and quantify results of LCI and LCIA (Grados and Schrevels, 2019). In this step the results of the LCI and LCIA stages are summarized (ISO, 2006). Based on the results of LCI and LCIA, this phase identifies the important issues and limitations and provides conclusions and recommendations (Milutinović et al., 2017).

Initial analyzing of the inputs and outputs data of wheat in two investigated systems was conducted using Excel software. Also, for LCA evaluation SimaPro 9.1.1.7 software was used.

3 Results and discussion

The third phase of LCA is life cycle impact assessment (LCIA) and gathers data on extraction of raw material and diffusion of material regarding the life cycle of a product (ISO, 2006). The purpose of this stage is to assess and estimate the value and significance of various human health and potential environmental impacts resulting from the initially flows specified in the previous step (Nabavi-Pelesaraei et al., 2017). In previous studies several methods of LCIA are used. The current study was carried out based on ReCiPe2016 methodology. Each mentioned impact categories can have an impact on human health, ecosystems and resource availability (Mostashari-Rad et al., 2021). The links between midpoints and endpoints in ReCiPe2016 methodology are illustrated in Figure 2.

3.1 Results from wheat energy estimation

Table 3 presents the inputs and outputs in dryland wheat production under two investigated systems in the study area. Also, energy equivalents of inputs and output for two systems are illustrated in this table. The results indicate that 8997.91 MJ and 7523.36 MJ of energy are needed per hectare of wheat production in conventional and conservation system, respectively. In other words, the conservation system consumes about 16% less energy compared to the conventional system. This is in agreement with results found by other researchers. In a study carried out in Slavonia, Košutić et al. (2005) reported that energy consumption for the production of various crops in the conservation tillage system was 35% less than

traditional system. In another study in Turkey, energy efficiency of various tillage systems was reported different from each other; So that using chisels in the autumn and discs in the spring worked best (Özgöz et al., 2017). As previously mentioned, due to high usage of diesel fuel tillage activity is the greatest energy consumers in dryland wheat production system. In conservation system, the amount of diesel fuel is reduced by about 66% compared to the conventional system, which not only reduces energy consumption but also reduces GHG emissions.

The total energy output for conventional and conservation systems, which is obtained by multiplying the weight of outputs (wheat grain and straw) in their energy equivalent, was estimated to be 35220 and 35125.00 MJ ha⁻¹, respectively. These

results indicate that the output energy in the two systems are not significantly different. Hamzei and Seyyedi (2016) investigated the effects of various tillage systems on energy use and grain yield in a soybean- sunflower intercropping system. The results indicated that sunflower yield was not significantly affected by the tillage methods; so, the use of minimum tillage was introduced as a suitable tillage method due to its less energy consumption. It should be noted that in many studies it has been reported that conservation tillage in the early years will not have a positive effect on yield, however if this method is continued with proper management of nitrogen fertilizer, the physical and chemical conditions of the soil will improve. This can lead to increase in yield and production sustainability.

Table 3 Amounts of inputs- outputs and their energy equivalent for two different systems in dryland wheat production

Inputs	Quantity per ha		Energy equivalent (MJ ha ⁻¹)	
	Conventional tillage	Conservation tillage	Conventional tillage	Conservation tillage
1. Human labour (h)	18.40	16.90	36.06	33.12
2. Machines (kg)	10.30	9.40	645.81	589.38
3. Diesel fuel (L)	70.80	44.40	3986.75	2500.16
4. Fertilizers (kg)				
- N	32.50	32.50	2149.55	2149.55
- P ₂ O ₅	18.00	18.00	223.92	223.92
- Farmacyard manure	1100.00	1100.00	330.00	330.00
5. Biocides (kg)				
- Fungicides	0.10	0.10	21.60	21.60
- Herbicides	-	0.30	-	71.40
- Insecticides	0.60	0.60	60.72	60.72
6. Seed	105.00	105.00	1543.50	1543.50
Total energy input (MJ)			8997.91	7523.36
Outputs				
1. Wheat grain yield (kg)	1350.00	1250.00	19845.00	18375.00
2. Wheat straw yield (kg)	1230.00	1340.00	15375.00	16750.00
Total energy output (MJ)			35220.00	35125.00

The results showed that in both system, diesel fuel energy has the highest percentage of total energy input; in the conventional system, about 44% and in the conventional system, about 33% of the total energy consumption is related to diesel fuel (Figure 3). In other words, the use of a conservation system reduces the energy consumption of diesel fuels by about 37% (about 26 L ha⁻¹ of diesel fuel). The results also indicated that the highest fuel usage in both systems is related to primary and secondary tillage.

Use of worn and inefficient tractors as well as the allocation of fuel subsidies in the country are among the reasons for the high usage of diesel fuels.

Among other inputs that have a major contribution to input energy in both tillage systems are chemical fertilizers (especially nitrogen fertilizer). The share of nitrogen fertilizers energy from the total energy used was about 24% and 29% in conventional and conservation systems, respectively. Similar results have been presented in previous studies that in

agricultural productions, the nitrogen fertilizers energy has the significant share of the total energy input (Mohammadi et al., 2010; Rafiee et al., 2010; Nasser, 2019; Ghasemi-Mobtaker et al., 2020a). A shift toward appropriate crop rotation, such as use of leguminous to nitrogen fixing purpose in crop

rotation can lead to less consumption of nitrogen fertilizer. Also, since the nitrogen use efficiency depends on the presence of water, obtaining accurate rainfall information is very important in managing nitrogen topdress fertilizer consumption in dryland cultivation.

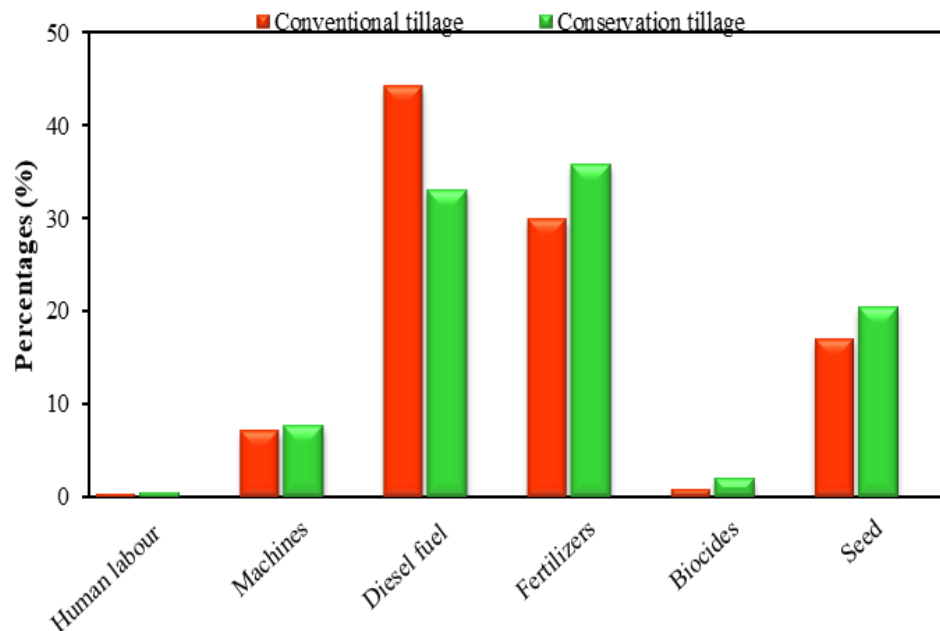


Figure 3 Energy use pattern for two different systems in dryland wheat production

Table 4 Energy indices for two different systems in dryland wheat production

Energy indices	Units	Average	
		Conventional tillage	Conservation tillage
ER	-	3.91	4.67
EP	kg MJ ⁻¹	0.15	0.17
EI	MJ kg ⁻¹	6.67	6.02
NE	MJ ha ⁻¹	26222.09	27601.64
DE	MJ ha ⁻¹	4022.81 (45%)	2533.29 (34%)
IDE	MJ ha ⁻¹	4975.10 (55%)	4990.07 (66%)
RE	MJ ha ⁻¹	1909.56 (21%)	1906.62 (25%)
NRE	MJ ha ⁻¹	7088.35 (79%)	5616.73 (75%)

The energy indices of dryland wheat cultivation for two investigated systems are showed in Table 4. These indices are general tool to evaluate the energy efficiency of various systems. The energy ratio of dryland wheat production was calculated as 3.91 and 4.67 for conventional and conservation systems, respectively. In other words, the energy ratio of conservation system is found to be about 19% higher than that of conventional system. In the previous studies conducted in dryland cultivation, various results were reported for energy ratio of wheat

production. For example, in study conducted out in north-west of Iran the significant differences among the treatments in terms of energy indices were reported; so that the energy ratio of conservation systems is reported higher than that of conventional system (Tabatabaefar et al., 2009). In another study Taki et al. (2018) studied energy use pattern of different wheat cultivation systems in central Iran and reported energy ratio in range of 3.1 to 4.1 for rainfed wheat. The energy ratio for some dryland production systems are reported as 3.4 for rainfed wheat

(Ghorbani et al., 2011), 2.90 for rainfed chickpea (Koocheki et al., 2011), 3.44 for rainfed canola (Kazemi et al., 2016), 3.85 for rainfed wheat (Mondani et al., 2017) and 4.69 for rainfed durum wheat (Failla et al., 2020). In generally the comparing findings of this study with same studies indicates that rainfed fields can produce wheat more efficiently than irrigated fields.

The results also indicated that energy productivity in conventional and conservation systems was 0.15 and 0.17 kg MJ⁻¹, respectively. This indicates that energy productivity of conservation system is about 13% higher than that of conventional system. In other words, compared to the conventional system, in the conservation system, 20 kg more wheat grain is produced per each GJ of energy consumed. This is in agreement with findings of several studies (Tabatabaefar et al., 2009; Arvidsson, 2010; Kumar et al., 2013; Chaudhary et al., 2021). The net energy was estimated to be about 26222 and 27602 MJ ha⁻¹ for conventional and conservation systems, respectively; which shows that energy has been obtained in both studied systems.

The energy forms percentage including RE, NRE, DE and IDE for two systems is also presented in Table 4. The results showed that percentage of NRE in both systems is high; however, the conservation system consumes about 21% less NRE compared to the conventional system (about 1472 MJ ha⁻¹). In several studies have reported that in agricultural systems the percentage of NRE is higher than that of RE (Kizilaslan, 2009; Ghasemi-Mobtaker et al., 2012; Salehi et al. 2014; Mondani et al. 2017). Houshyar and Grundmann (2017) investigated energy consumption of different tillage system in wheat cultivation and reported that conservation tillage systems consume less non-renewable energy than conventional systems.

3.2 Results from LCA estimation

Table 5 illustrated LCI of different systems for 1 ha of dryland wheat farms in the central and eastern

regions of Hamedan province. The results indicated that CO₂ emissions to air, occurs due to human labor activities were 12.88 and 11.83 kg ha⁻¹ in conventional and conservation systems, respectively. Moreover, the amounts of CO₂ emission due to the diesel fuel consumption in dryland wheat cultivation were calculated about 297 and 186 kg ha⁻¹ in conventional and conservation systems, respectively. In other words, the conservation system emits about 37% less CO₂ to the conventional system. The results also showed that in both investigated systems, nitrate and phosphate emissions to water were 7.62 and 0.55 kg ha⁻¹, respectively. The results of this study indicated that the conservation system, in addition to other benefits such as increasing organic matter and improving the chemical and physical conditions of the soil, has fewer environmental effects on the environment.

In study carried out at central Montana USA, the tillage method effect was investigated on energy use and GHG emissions in dryland Camelina production. The results showed that energy usage and GHG emission of no-tillage were 5% and 8% lower than conventional tillage (Keshavarz-Afshar et al., 2015). Ghasemi-Mobtaker et al. (2020a) surveyed environmental effects of irrigated wheat production in the west of Iran and reported that about 427 kg ha⁻¹ of CO₂ can be emitted from diesel fuels usage in wheat fields. Their results also indicated that tillage was one of the main operations for diesel fuel usage in studied region. Comparing the results of this study regarding the emission of CO₂ with the results of a similar study conducted in this region in irrigated fields shows that the amount of CO₂ emission per ton of wheat produced in rainfed fields is much higher and this is due to the low yield of rainfed farms.

Table 6 shows the damage assessment of the ReCiPe2016 endpoint for dryland wheat production in two investigated systems. As shown in this table, all the investigated environmental indicators in the conservation system are better than the conventional system. The results of conventional and conservation

systems indicated that index of damage to human health calculated for 1 ton of dryland wheat production is 5.94×10^{-2} and 4.59×10^{-2} DALY, respectively. This shows that conservation system can decrease this index by 22.7%. Comparing this study findings with similar studies conducted in the studied

area in irrigated fields shows that the amounts of environmental loads per ton of wheat produced in rainfed farms is far more than other grains produced in irrigated fields. As mentioned, the reason for this is the low yield in rainfed farms compared to irrigated farms.

Table 5 LCI of various systems for 1 ha of dryland wheat cultivation

Item (unit)	Systems	
	Conventional	Conservation
<i>On-Farm</i>		
Emissions to air (kg)		
By human labor		
CO ₂	12.88	11.83
By diesel fuel		
CO ₂	297.01	186.26
SO ₂	0.1	0.06
CH ₄	0.01	0.01
Benzene	6.94E-04	4.35E-04
Cd	9.53E-07	5.98E-07
Cr	4.74E-06	2.98E-06
Cu	1.62E-04	1.02E-04
N ₂ O	0.01	0.01
Ni	6.66E-06	4.18E-06
Zn	9.53E-05	5.98E-05
Benzo (a) pyrene	2.85E-06	1.79E-06
NH ₃	1.90E-03	1.19E-03
Se	9.53E-07	5.98E-07
PAH	3.13E-04	1.96E-04
HC, as NMVOC	0.27	0.17
NO _x	4.23	2.65
CO	0.60	0.38
Particulates (b2.5 μm)	0.43	0.27
By fertilizers		
N ₂ O	0.90	0.90
NH ₃ by chemical fertilizers	3.95	3.95
NH ₃ by FYM	6.04	6.04
By atmospheric deposition of fertilizers		
N ₂ O by chemical fertilizers	0.033	0.033
N ₂ O by FYM	0.075	0.075
By N ₂ O of fertilizers and soil		
NO _x	0.18	0.18
By pesticides		
Deltamethrin, ...	0.07	0.10
Emissions to soil (kg)		
By heavy metals of fertilizers		
Cd	9.1E-04	9.1E-04
Cu	2.5E-03	2.5E-03
Zn	2.2E-02	2.2E-02
Pb	1.8E-01	1.8E-01
Ni	2.3E-03	2.3E-03
Cr	1.2E-02	1.2E-02
Hg	8.7E-06	8.7E-06
By biocides		
Deltamethrin, ...	0.60	0.85
Emissions to water (kg)		
By fertilizers		
Nitrate	7.62	7.62
Phosphate	0.55	0.55

Figure 4 shows the percentage of different inputs effect on the endpoints of wheat production in conventional and conservation systems. The results demonstrated that in both investigated systems, the greatest effect in index of human health damage was from direct emissions. Direct emissions are related to the input's usage such as diesel fuel inside the farm,

whose consumption is accompanied by the direct emission of pollutants such as carbon dioxide. In many studies, the effect of direct emissions on the environmental indicators has been mentioned as the most important factor (Fathollahi et al., 2018; Saber et al., 2020; Khanali et al., 2021). The results also showed that the next input that had a great impact on

the human health index in both systems is chemical fertilizers.

Table 6 Damage assessment of the ReCiPe2016 endpoint for two investigated systems

Damage category	Unit	Systems	
		Conventional	Conservation
Damage to human health	DALY	5.94×10^{-2}	4.59×10^{-2}
Damage to ecosystems	species. yr	1.15×10^{-4}	8.87×10^{-5}
Damage to resources availability	USD2013	49.72	36.36

In study conducted in Hamedan province of Iran on environmental performance of irrigated wheat production, Ghasemi-Mobtaker et al. (2020a) reported that electricity input was the most important hotspot in most environmental indicators. In a similar study, in case of barley, in human health damage categories, the greatest effects was reported from direct emissions (Ghasemi-Mobtaker et al., 2020b).

Regarding the damage to ecosystems index, the results indicated better conditions in the conservation system than the conventional system. The results

indicated that index of damage to ecosystems for 1 ton of dryland wheat production is 1.15×10^{-4} and 8.87×10^{-5} species. yr, in conventional and conservation system, respectively. This shows that conservation system can decrease this index by 22.9%. The results also showed that in both investigated systems, the greatest effect in index of ecosystems damage was from direct emissions. It should be noted that due to the reduction of fuel consumption in the conservation system, direct emissions are reduced to some extent in this system.

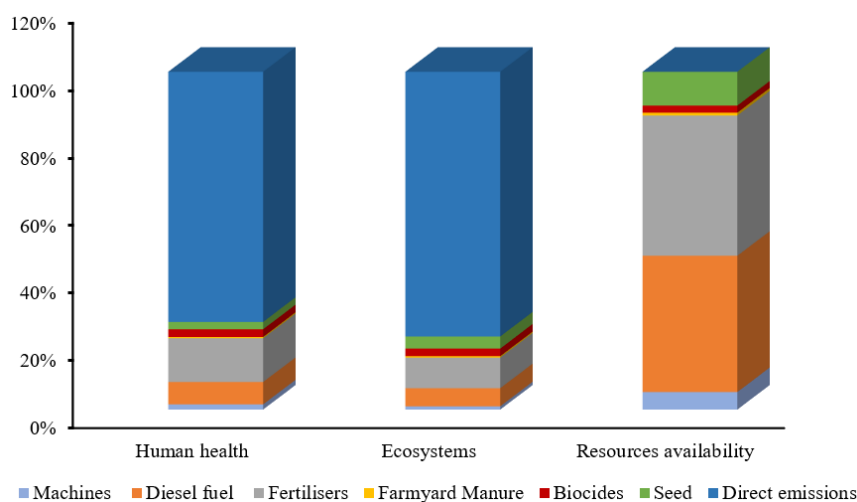
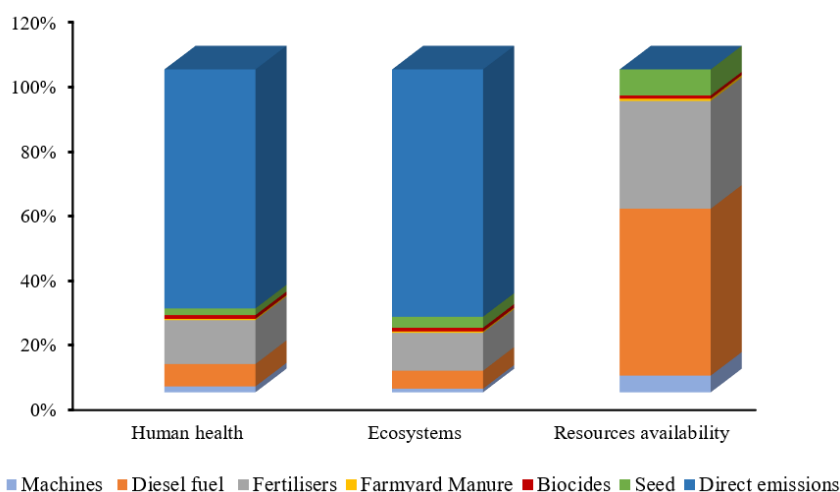


Figure 4 Percentage of inputs to emit environmental impact categories for investigated systems

In the case of index of damage to resources availability, almost a similar trend was obtained; so that the conservation system decreased this index by 26.9%. The results showed that this index was 49.72 and 36.36 \$ in conventional and conservation system, respectively. The results also showed that in both investigated systems, the greatest effect in this index were from fertilizers and diesel fuel.

In general, the findings of this study indicated that the conservation system in rainfed wheat cultivation improves energy and environmental indicators without causing a significant decrease in wheat yield. Therefore, this system can be recommended as an environmentally friendly tillage system in the region.

4 Conclusions

The most important results of this study are as follows:

(1) Total energy consumption of system 1 and system 2 were calculated as 8997.91 and 7523.36 MJ ha⁻¹, respectively indicating that conservation tillage system consumes about 16% less energy.

(2) Diesel fuel used in tractors had the highest share of total energy input in both systems, was followed by fertilizers. In other words, implementation conservation system can reduce the consumption of diesel fuels by about 37% (about 26 L ha⁻¹).

(3) The NRE consumption in both systems were rather high. However, the conservation system consumes about 21% less NRE compared to the conventional system.

(4) LCA results of two investigated systems showed that in human health and ecosystems damage categories, direct emissions have the highest portion. Furthermore, in resources damage category, diesel fuel and fertilizers had the most significant impact.

(5) In addition to reducing energy consumption, the conservation system had less adverse on the environment, so it was introduced as an environmentally friendly system.

(16) It is suggested that new policies be adopted by policymakers to encourage farmers to use

conservation tillage system.

References

- Alhajj Ali, S., L. Tedone, and G. De Mastro. 2013. A comparison of the energy consumption of rainfed durum wheat under different management scenarios in southern Italy. *Energy*, 61: 308–318.
- Alluvione, F., B. Moretti, D. Sacco, and C. Grignani. 2011. EUE (energy use efficiency) of cropping systems for a sustainable agriculture. *Energy*, 36(7): 4468–4481.
- Alsakaf, K., S. J. Mooney, D. L. Sparkes, P. Wilson, and S. Sjögersten. 2021. Short-term impacts of different tillage practices and plant residue retention on soil physical properties and greenhouse gas emissions. *Soil & Tillage Research*, 206: 104803.
- Arvidsson, J. 2010. Energy use efficiency in different tillage systems for winter wheat on a clay and silt loam in Sweden. *European Journal of Agronomy*, 33(3): 250–256.
- Bacenetti, J., A. Fusi, M. Negri, and M. Fiala. 2015. Impact of cropping system and soil tillage on environmental performance of cereal silage productions. *Journal of Cleaner Production*, 86: 49–59.
- Barut, Z. B., C. Ertekin, and H. A. Karaagac. 2011. Tillage effects on energy use for corn silage in Mediterranean Coastal of Turkey. *Energy*, 36(9): 5466–5475.
- Brenttrup, F., J. Küsters, H. Kuhlmann, and J. Lammel. 2004. Environmental impact assessment of agricultural production systems using the life cycle assessment methodology: I. Theoretical concept of a LCA method tailored to crop production. *European Journal of Agronomy*, 20(3): 247–264.
- Cerutti, A. K., S. Bruun, G. L. Beccaro, and G. Bounous. 2011. A review of studies applying environmental impact assessment methods on fruit production systems. *Journal of Environmental Management*, 92(10): 2277–2286.
- Chaudhary, V. P., R. Chandra, R. Chaudhary, and R. Bhattacharyya. 2021. Global warming potential and energy dynamics of conservation tillage practices for different *rabi* crops in the Indo-Gangetic Plains. *Journal of Environmental Management*, 296: 113182.
- Failla, S., C. Ingraio, and C. Arcidiacono. 2020. Energy consumption of rainfed durum wheat cultivation in a Mediterranean area using three different soil management systems. *Energy*, 195: 116960.
- Fathollahi, H., S. H. Mousavi-Avval, A. Akram, and S. Rafiee. 2018. Comparative energy, economic and environmental analyses of forage production systems for dairy farming. *Journal of Cleaner Production*, 182:

- 852–862.
- Ferronato, N., A. P. D. Baltrocchi, F. Romagnoli, I. J. Calle Mendoza, M. A. Gorrity Portillo, and V. Torretta. 2023. Environmental Life Cycle Assessment of biomass and cardboard waste-based briquettes production and consumption in Andean areas. *Energy for Sustainable Development*, 72: 139–150.
- Ghasemi-Mobtaker, H. G., A. Keyhani, A. Mohammadi, S. Rafiee, and A. Akram. 2010. Sensitivity analysis of energy inputs for barley production in Hamedan Province of Iran. *Agriculture, Ecosystems & Environment*, 137(3-4): 367–372.
- Ghasemi-Mobtaker, H., A. Akram, and A. Keyhani. 2012. Energy use and sensitivity analysis of energy inputs for alfalfa production in Iran. *Energy for Sustainable Development*, 16(1): 84–89.
- Ghasemi-Mobtaker, H., A. Kaab, and S. Rafiee. 2020a. Application of life cycle analysis to assess environmental sustainability of wheat cultivation in the west of Iran. *Energy*, 193: 116768.
- Ghasemi-Mobtaker, H., F. Mostashari-Rad, Z. Saber, K. W. Chau, and A. Nabavi-Pelesaraei. 2020b. Application of photovoltaic system to modify energy use, environmental damages and cumulative exergy demand of two irrigation systems-A case study: Barley production of Iran. *Renewable Energy*, 160: 1316–1334.
- Ghorbani, R., F. Mondani, S. Amirmoradi, H. Feizi, S. Khorramdel, M. Teimouri, S. Sanjani, S. Anvarkhah, and H. Aghel. 2011. A case study of energy use and economical analysis of irrigated and dryland wheat production systems. *Applied Energy*, 88(1): 283–288.
- Grados, D., and E. Schrevels. 2019. Multidimensional analysis of environmental impacts from potato agricultural production in the Peruvian Central Andes. *Science of The Total Environment*, 663: 927–934.
- Guinée, J. B., 2002. *Handbook on Life Cycle Assessment Operational Guide to the ISO Standards*. New York, USA:Kluwer Academic Publishers.
- Hamzei, J., and M. Seyyedi. 2016. Energy use and input-output costs for sunflower production in sole and intercropping with soybean under different tillage systems. *Soil & Tillage Research*, 175: 73–82.
- Houshyar, E., and P. Grundmann. 2017. Environmental impacts of energy use in wheat tillage systems: A comparative life cycle assessment (LCA) study in Iran. *Energy*, 122: 11–24.
- ISO. 2006. ISO 14040. Environmental Management–Life Cycle Assessment–Principles and Framework. Geneva, Switzerland: ISO.
- Jia, L., W. Zhao, R. Zhai, Y. Liu, M. Kang, and X. Zhang. 2019. Regional differences in the soil and water conservation efficiency of conservation tillage in China. *CATENA*, 175: 18–26.
- Kaab, A., M. Sharifi, H. Mobli, A. Nabavi-Pelesaraei, and K. W. Chau. 2019. Combined life cycle assessment and artificial intelligence for prediction of output energy and environmental impacts of sugarcane production. *Science of The Total Environment*, 664: 1005–1019.
- Kazemi, H., S. H. Bourkheili, B. Kamkar, A. Soltani, K. Gharanjic, and N. M. Nazari. 2016. Estimation of greenhouse gas (GHG) emission and energy use efficiency (EUE) analysis in rainfed canola production (case study: Golestan province, Iran). *Energy*, 116: 694–700.
- Keshavarz-Afshar, R., Y. A. Mohammed, and C. Chen. 2015. Energy balance and greenhouse gas emissions of dryland camelina as influenced by tillage and nitrogen. *Energy*, 91: 1057–1063.
- Khakbazan, M., R. M. Mohr, J. Huang, R. Xie, K. M. Volkmar, D. J. Tomasiewicz, A. P. Moulin, D. A. Derksen, B. R. Irvine, D. L. McLaren, and A. Nelson. 2019. Effects of crop rotation on energy use efficiency of irrigated potato with cereals, canola, and alfalfa over a 14-year period in Manitoba, Canada. *Soil & Tillage Research*, 195: 104357.
- Khanali, M., S. A. Mousavi, M. Sharifi, F. K. Nasab, and K. W. Chau. 2018. Life cycle assessment of canola edible oil production in Iran: a case study in Isfahan Province. *Journal of Cleaner Production*, 196: 714–725.
- Khanali, M., A. Akram, J. Behzadi, F. Mostashari-Rad, Z. Saber, K. W. Chau, and A. Nabavi-Pelesaraei. 2021. Multi-objective optimization of energy use and environmental emissions for walnut production using imperialist competitive algorithm. *Applied Energy*, 284: 116342.
- Khatrri, P., and S. Jain. 2017. Environmental life cycle assessment of edible oils: A review of current knowledge and future research challenges. *Journal of Cleaner Production*, 152: 63–76.
- Kizilaslan, H. 2009. Input–output energy analysis of cherries production in Tokat Province of Turkey. *Applied Energy*, 86(7-8): 1354–1358.
- Koocheki, A., R. Ghorbani, F. Mondani, and Y. Alizade. 2011. Pulses production systems in term of energy use efficiency and economical analysis in Iran. *International Journal of Energy Economics and Policy*, 1(4): 95–106.
- Košutić, S., D. Filipović, Z. Gospodarić, S. Husnjak, I. Kovačev, and K. Čopec. 2005. Effects of different soil tillage systems on yields of maize, winter wheat and soybean on albic luvisol in north-west Slavonia. *Journal of Central European Agriculture*, 6(3): 241–248.1

- Król-Badziak, A., S. H. Pishgar-Komleh, S. Rozakis, and J. Księżak. 2021. Environmental and socio-economic performance of different tillage systems in maize grain production: Application of Life Cycle Assessment and Multi-Criteria Decision Making. *Journal of Cleaner Production*, 278: 123792.
- Kumar, V., Y. S. Saharawat, M. K. Gathala, A. S. Jat, S. K. Singh, N. Chaudhary, and M. L. Jat. 2013. Effect of different tillage and seeding methods on energy use efficiency and productivity of wheat in the Indo-Gangetic Plains. *Field Crops Research*, 142: 1–8.
- Liu, J., H. Feng, J. He, H. Chen, D. Ding, X. Luo, and Q. Dong. 2019. Modeling wheat nutritional quality with a modified CERES-wheat model. *European Journal of Agronomy*, 109: 125901.
- Meena, J. R., U. K. Behera, D. Chakraborty, and A. R. Sharma. 2015. Tillage and residue management effect on soil properties, crop performance and energy relations in greengram (*Vigna radiata* L.) under maize-based cropping systems. *International Soil and Water Conservation Research*, 3(4): 261–272.
- Milutinović, B., G. Stefanović, P. S. Đekić, I. Mijailović, and M. Tomić. 2017. Environmental assessment of waste management scenarios with energy recovery using life cycle assessment and multi-criteria analysis. *Energy*, 137: 917–926.
- Ministry of Jihad-e-Agriculture of Iran. 2021. Annual Agricultural Statistics. Available at: www.maj.ir. Accessed 6 July 2021.
- Mohammadi, A., S. Rafiee, S. S. Mohtasebi, and H. Rafiee. 2010. Energy inputs – yield relationship and cost analysis of kiwifruit production in Iran. *Renewable Energy*, 35(5): 1071–1075.
- Mohammadi, A., S. Rafiee, A. Jafari, A. Keyhani, S. H. Mousavi-Avval, and S. Nonhebel. 2014. Energy use efficiency and greenhouse gas emissions of farming systems in north Iran. *Renewable and Sustainable Energy Reviews*, 30: 724–733.
- Mohanty, S., A. K. Nayak, C. K. Swain, B. R. Dhal, A. Kumar, U. Kumar, R. Tripathi, M. Shahid, and K. K. Behera. 2020. Impact of integrated nutrient management options on GHG emission, N loss and N use efficiency of low land rice. *Soil & Tillage Research*, 200: 104616.
- Moitzi, G., R. W. Neugschwandner, H. P. Kaul, and H. Wagentristl. 2019. Energy efficiency of winter wheat in a long-term tillage experiment under Pannonian climate conditions. *European Journal of Agronomy*, 103: 24–31.
- Mondani, F., S. Alegha, M. Khoramivafa, and R. Ghobadi. 2017. Evaluation of greenhouse gases emission based on energy consumption in wheat Agroecosystems. *Energy Reports*, 3: 37–45.
- Mostashari-Rad, F., H. Ghasemi-Mobtaker, M. Taki, M. Ghahderijani, A. Kaab, K. W. Chau, and A. Nabavi-Pelesaraei. 2021. Exergoenvironmental damages assessment of horticultural crops using ReCiPe2016 and cumulative exergy demand frameworks. *Journal of Cleaner Production*, 278: 123788.
- Mousavi-Avval, S. H., S. Rafiee, A. Jafari, and A. Mohammadi. 2011. Energy flow modeling and sensitivity analysis of inputs for canola production in Iran. *Journal of Cleaner Production*, 19(13): 1464–1470.
- Mousavi-Avval, S. H., S. Rafiee, M. Sharifi, S. Hosseinpour, B. Notarnicola, G. Tassielli, P. A. Renzulli, and M. Khanali. 2017. Use of LCA indicators to assess Iranian rapeseed production systems with different residue management practices. *Ecological Indicators*, 80: 31–39.
- Nabavi-Pelesaraei, A., S. Rafiee, S. S. Mohtasebi, H. Hosseinzadeh-Bandbafha, and K. W. Chau. 2017. Energy consumption enhancement and environmental life cycle assessment in paddy production using optimization techniques. *Journal of Cleaner Production*, 162: 571–586.
- Nabavi-Pelesaraei, A., H. Azadi, S. Van Passel, Z. Saber, F. Hosseini-Fashami, F. Mostashari-Rad, and H. Ghasemi-Mobtaker. 2021. Prospects of solar systems in production chain of sunflower oil using cold press method with concentrating energy and life cycle assessment. *Energy*, 223: 120117.
- Naseri, H., M. G. Parashkoochi, I. Ranjbar, and D. M. Zamani. 2021. Energy-economic and life cycle assessment of sugarcane production in different tillage systems. *Energy*, 217: 119252.
- Nasseri, A. 2019. Energy use and economic analysis for wheat production by conservation tillage along with sprinkler irrigation. *Science of The Total Environment*, 648: 450–459.
- Naujokienė, V., E. Šarauskis, R. Bleizgys, and J. Sasnauskienė. 2019. Soil biotreatment effectiveness for reducing global warming potential from main polluting tillage operations in life cycle assessment phase. *Science of The Total Environment*, 671: 805–817.
- Nisar, S., D. K. Benbi, and A. S. Toor. 2021. Energy budgeting and carbon footprints of three tillage systems in maize-wheat sequence of north-western Indo-Gangetic Plains. *Energy*, 229: 120661.
- Nunes, F. A., M. Seferin, V. G. Maciel, and M. A. Z. Ayub. 2017. Life Cycle Assessment comparison between brown parboiled rice produced under organic and minimal tillage cultivation systems. *Journal of Cleaner Production*, 161: 95–104.
- Olczak, P., A. Żelazna, K. Stecula, D. Matuszewska, and Ł. Lelek. 2022. Environmental and economic analyses of

- different size photovoltaic installation in Poland. *Energy for Sustainable Development*, 70: 160–169.
- Özgöz, E., E. Altuntaş, and M. Asiltürk. 2017. Effects of soil tillage on energy use in potato farming in Central Anatolia of Turkey. *Energy*, 141: 1517–1523.
- Ozkan, B., H. Akcaoz, and C. Fert. 2004. Energy input–output analysis in Turkish agriculture. *Renewable Energy*, 29(1): 39–51.
- Pahlavan, R., M. Omid, S. Rafiee, and S. H. Mousavi-avval. 2012. Optimization of energy consumption for rose production in Iran. *Energy for Sustainable Development*, 16(2): 236–241.
- Parihar, C. M., S. L. Jat, A. K. Singh, B. Kumar, Y. Singh, S. Pradhan, V. Pooniya, A. Dhauja, V. Chaudhary, M. L. Jat, R. K. Jat, and O. P. Yadav. 2016. Conservation agriculture in irrigated intensive maize-based systems of north-western India: Effects on crop yields, water productivity and economic profitability. *Field Crops Research*, 193: 104–116.
- Piastrellini, R., A. P. Arena, and B. Civit. 2017. Energy life-cycle analysis of soybean biodiesel: Effects of tillage and water management. *Energy*, 126: 13–20.
- Rafiee, S., S. H. Mousavi Avval, and A. Mohammadi. 2010. Modeling and sensitivity analysis of energy inputs for apple production in Iran. *Energy*, 35(8): 3301–3306.
- Raheli, H., R. M. Rezaei, M. R. Jadidi, and H. Ghasemi-Mobtaker. 2017. A two-stage DEA model to evaluate sustainability and energy efficiency of tomato production. *Information Processing in Agriculture*, 4(4): 342–350.
- Rebitzer, G., T. Ekvall, R. Frischknecht, D. Hunkeler, G. Norris, T. Rydberg, W. P. Schmidt, S. Suh, B. P. Weidema, and D. W. Pennington. 2004. Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment International*, 30(5): 701–720.
- Roy, P., D. Nei, T. Orikasa, Q. Xu, H. Okadome, N. Nakamura, and T. Shiina. 2009. A review of life cycle assessment (LCA) on some food products. *Journal of Food Engineering*, 90(1): 1–10.
- Saber, Z., M. Esmacili, H. Pirdashti, A. Motevali, and A. Nabavi-Pelesaraei. 2020. Exergoenvironmental-Life cycle cost analysis for conventional, low external input and organic systems of rice paddy production. *Journal of Cleaner Production*, 263: 121529.
- Saldukaitė, L., E. Šarauskis, K. Lekavičienė, and D. Savickas. 2020. Predicting energy efficiency and greenhouse gases reduction potential under different tillage management and farm size scenarios for winter wheat production. *Sustainable Energy Technologies and Assessments*, 42: 100841.
- Salehi, M., R. Ebrahimi, A. Maleki, and H. Ghasemi-Mobtaker. 2014. An assessment of energy modeling and input costs for greenhouse button mushroom production in Iran. *Journal of Cleaner Production*, 64: 377–383.
- Šarauskis, E., K. Romaneckas, A. Jasinskas, R. Kimbirauskienė, and V. Naujokienė. 2020. Improving energy efficiency and environmental mitigation through tillage management in faba bean production. *Energy*, 209: 118453.
- Sarker, J. R., B. P. Singh, A. L. Cowie, Y. Fang, D. Collins, W. J. Dougherty, and B. K. Singh. 2018. Carbon and nutrient mineralisation dynamics in aggregate-size classes from different tillage systems after input of canola and wheat residues. *Soil Biology and Biochemistry*, 116: 22–38.
- Sharma, P., V. Abrol, and R. K. Sharma. 2011. Impact of tillage and mulch management on economics, energy requirement and crop performance in maize–wheat rotation in rainfed subhumid inceptisols, India. *European Journal of Agronomy*, 34(1): 46–51.
- Tabatabaefar, A., H. Emamzadeh, M. Ghasemi-Varnamkhasti, R. Rahimizadeh, and M. Karimi. 2009. Comparison of energy of tillage systems in wheat production. *Energy*, 34(1): 41–45.
- Taki, M., F. Soheili-Fard, A. Rohani, G. Chen, and H. Yildizhan. 2018. Life cycle assessment to compare the environmental impacts of different wheat production systems. *Journal of Cleaner Production*, 197(1): 195–207.
- Wang, X., S. Ledgard, J. Luo, Y. Chen, Y. Tian, Z. Wei, D. Liang, and L. Ma. 2021. Life cycle assessment of alfalfa production and potential environmental improvement measures in Northwest China. *Journal of Cleaner Production*, 304: 127025.
- Zangeneh, M., M. Omid, and A. Akram. 2010. A comparative study on energy use and cost analysis of potato production under different farming technologies in Hamadan province of Iran. *Energy*, 35(7): 2927–2933.

Nomenclature

DE	Direct Energy
EP	Energy Productivity
ER	Energy Ratio
FU	Functional Unit
GHG	Greenhouse Gas
IDE	Indirect Energy
IE	Input Energy
LCA	Life Cycle Assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
NE	Net Energy
NRE	Non-renewable Energy
OE	Output Energy
RE	Renewable Energy
WGY	Wheat Grain Yield
