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Energy, economic and GHG emissions analysis of potato production

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Abstract

Potatoes (*Solanum tuberosum L.*) are among the foremost vital international food crops. In this study cross-sectional data were collected from potato growers by employing a face to face survey in East-Azerbaijan Province of Iran. The data collected was analyzed for the energy, GHG emissions and economics of potato production. According to the results, total average energy inputs consumption and GHG emissions were 131608.14 $MJ\ ha^{-1}$ and 4542 $kg\ CO_2eq.ha^{-1}$, respectively. Electricity, chemical fertilizers and diesel fuel were the most influential factors in energy consumption with quantity of 46.3, 34.7 and 24.6 $GJ\ ha^{-1}$. Energy use efficiency, net energy and energy intensiveness were 0.97, -4292 $MJ\ ha^{-1}$ and 21.73 $MJ\ \$^{-1}$, respectively. Among the energy inputs, the contribution of DE was more than that of IDE energy and also the proportion of NRE was more than RE resources. Electricity with a share of 52% played the most important role on GHG emissions, followed by diesel fuel (31%) and chemical fertilizer (12%). The results of economic analysis showed that the benefit to cost ratio was 1.1 and the economic productivity was 5.84 $kg\ \$^{-1}$. Economic analysis showed that the potato production could be a profitable business in East-Azerbaijan Province. Encouraging farm energy consumers to use less electricity is indispensable for sustainable use of energy and a key element of GHGs emission reduction.

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Introduction

Potatoes (*Solanum tuberosum L.*) is the world's third most important food crop next to rice and wheat in terms of human consumption and subsequently a exigent crop in terms of food security (Chetty *et al.* 2015). Iran with annual production of nearly 4.82 million tons is the thirteenth country in world potato production (FAO, 2013). East-Azerbaijan province with cultivated field of 9602 ha was among the most important potato producers in 2012. The production of this province was 315464 tons with average yield of 32.85 tons per hectare (Anonymous, 2012).

Agricultural sustainability is a substantial global issue. Its importance has raised from the increasing awareness of the necessity for conservation of resources and environment for future use (Islam *et al.*, 2003). It can be expected that effective energy use in agriculture would be essential not only for sustainable agricultural production, but also for providing fossil resources conservation, financial savings and air pollution diminution (Uhlin, 1998). Energy analysis of agricultural ecosystems looks to be a promising approach to investigate and assess environmental issues and also their linkages to various instances of sustainability (Schroll, 1994). Various studies on energy input and output have been concentrated mainly on worldwide production of field crops but on potato Mohammadi *et al.* (2008) estimated the energy input and output per hectare so as to extend the energy ratio by decreasing the amount of energy consumption for potato production. Zangeneh *et al.* (2010) studied the energy consumption of potato production in several levels of farming technology in Iran to reduce energy consumption of this crop. Rajabi Hamedani *et al.* (2011) determined the energy consumption and also the relationship between energy input and yield of potato production in Hamadan province. All these studies showed a high dependency on fossil energy and non-renewable energies. Some problems in agricultural production are primarily because of the high levels of reliance on fossil energies such as serious environmental issues of which global warming and greenhouse gas (GHG) emissions are counted as important ones. Agricultural greenhouse gas (GHG) emissions account 10–12% of all manmade GHG emissions (Brown *et al.*, 1998). As energy inputs in agriculture rapidly raised and accumulated many benefits to farmers, these also adversely influence the environment by deteriorating water and natural resources, and lead contributing to worldwide warming substantially through increased GHGs (Soni *et al.*, 2013). Pishgar-Komleh *et al.* (2012) examined the energy consumption and CO_2 emission of potato production in Esfahan province of Iran. Also, Khoshnevisan *et al.* (2014) were investigated the input and output energy in potato production and estimated GHG emissions.

No studies have been published on the energy evaluation, economic analysis and GHG emission examination of potato production in East-Azerbaijan province of Iran. Thus, the aim of the present study is to investigate the energy input and output per hectare for the production of potato in East-Azerbaijan province, Iran, and to make a cost and economic analysis. Moreover, determination of GHG emissions related to the potato production is another goal of this research.

Methodology

Data collection

This study was carried out in East-Azerbaijan province that placed in north-west of Iran, within 36° 45' and 39° 26' north latitude and 45° 5' and 48° 22' east longitude (Anonymous, 2012). Data were gathered from 62 potato farms by employing a face to face questionnaire in September 2014. The sample size was determined using a stratified random sampling technique (Yamane, 1967) as is shown below:

$$n = \frac{(\sum N_h S_h)^2}{N^2 D^2 + \sum N_h S_h^2} \qquad (1)$$

where n is the needed sample size; N is the number of holdings in target population; N_h is the number of the population within the h stratification; S_h is the standard deviation within the h stratification, S_h^2 is the variance of h stratification; d is the precision wherever ($\bar{x}-\bar{X}$); z is the reliability constant (1.96 that represents the 95% reliability); D^2 is equal to d^2/z^2. For the calculation of sample size, criteria of 5% deviation from population mean and 95% confidence level were used.

Energy calculation method

The energy coefficient of various inputs and output was used for the conversion of physical inputs and output into energy terms (Table 1). Indeed, for each and every biophysical input and output, a specific conversion factors will be used. Inputs in potato production process were seed, human labor, machinery, water for irrigation, chemical fertilizers, farmyard manure (FYM), chemicals, diesel fuel, electricity, and output was potato (Table 1).

Table 1. Energy coefficients of different inputs and outputs used in agriculture production.

Inputs/Output	Unit	Energy coefficients (*MJ unit⁻¹*)
A. Inputs		
1) Human labor	*h*	1.96 [Ozkan *et al.* (2004)]
2) Machinery	*h*	62.7 [Erdal *et al.* (2007)]
3) Diesel fuel	*L*	47.8 [Kitani (1999)]
4) Electricity	*kWh*	12 [Kitani (1999)]
5) Chemical fertilizers	*kg*	
a) Nitrogen (N)		78.1 [Kitani (1999)]
b) Phosphate (P_2O_5)		17.4 [Kitani (1999)]
c) Potassium (K_2O)		13.7 [Kitani (1999)]
6) Water for irrigation	m^3	1.02 [Erdal *et al.* (2007)]
7) FYM	*kg*	0.3 [Ozkan *et al.* (2004)]
8) Chemicals	*kg*	120 [Mandal *et al.* (2002)]
9) Seed	*kg*	3.6 [Ozkan *et al.* (2004)]
B. Output		
1) Potato	*kg*	3.6 [Ozkan *et al.* (2004)]

Following the calculation of energy input and output terms, the energy use efficiency (energy ratio) (Eq. 2), specific energy (Eq. 3), net energy (Eq. 4), energy productivity (Eq. 5) and energy intensiveness (Eq. 6) were computed (Mandal *et al.*, 2002).

$$Energy\ use\ efficiency = \frac{Energy\ output\ (MJ/ha)}{Energy\ input\ (MJ/ha)} \quad (2)$$

$$Specific\ energy = \frac{Energy\ input\ (MJ/ha)}{Yield\ (kg/ha)} \quad (3)$$

$$Net\ energy = Energy\ output\ (MJ/ha) - Energy\ input\ (MJ/ha) \quad (4)$$

$$Energy\ productivity = \frac{Yield\ (kg/ha)}{Energy\ input\ (MJ/ha)} \quad (5)$$

$$Energy\ intensiveness = \frac{Energy\ input\ (MJ/ha)}{Cost\ of\ cultivation\ (\$/ha)} \quad (6)$$

For more investigation, input energy was divided into direct (DE), indirect (IDE), renewable (RE) and non-renewable (NRE) species. The DE includes energy incorporated in diesel fuel, human labor, water for irrigation and electricity whereas the DE covers seed, fertilizer, FYM, chemicals, machinery employed in the potato production. The RE includes human labor, seeds, water for irrigation and FYM, and therefore the NRE consists of diesel fuel, electricity, chemicals, fertilizers and machinery.

GHG emission calculation method

Production processes, formulization, transportation facilities, storage operations, distribution and application of crop production inputs with farming machinery lead to burning fossil fuels and consumption energy from superseded resources, which additionally emit CO_2 and other GHGs into the atmosphere (Lal, 2004). Standard coefficient of GHG emission utilized for each and every input to calculated GHG emission in potato production. Table 2 summarizes GHG emission coefficients for agricultural inputs.

Economic indexes calculation method

The economic analysis of potato production was investigated. Total income, net and gross profit, economic productivity and benefit to cost ratio were computed using the Eqs. 7 to 11 as reported by Demircan *et al.* (2006) and Zangeneh *et al.*, (2010).

Table 2. GHGs emission coefficients of agricultural inputs.

Inputs	Unit	GHG Coefficient (*kg* $CO_{2eq.}$ *unit*$^{-1}$)	Reference
1. Machinery	*MJ*	0.071	Dyer and Desjardins, 2006
2. Diesel fuel	*L*	2.76	Dyer and Desjardins, 2006
3. Electricity	*kWh*	0.608	Khodi and Mousavi, 2009
4. Chemical fertilizers			
a) Nitrogen (N)	*kg*	1.3	Lal, 2004
b) Phosphate (P_2O_5)	*kg*	0.2	Lal, 2004
c) Potassium (K_2O)	*kg*	0.15	Lal, 2004
5. FYM	*tone*	0.005	Meisterling *et al.* 2009
6. Biocides			
a) Herbicide	*kg*	6.3	Lal, 2004
b) Insecticide	*kg*	5.1	Lal, 2004
c) Fungicide	*kg*	3.9	Lal, 2004

$$Total\ income = Yield\ of\ potato\ (kg/ha) \times Price\ of\ potato\ (\$/kg) \quad (7)$$

$$Net\ return = Total\ income\ (\$/ha) - Total\ poroduction\ cost\ (\$/ha) \quad (8)$$

$$Gross\ return = Total\ income\ (\$/ha) - Variable\ cost\ of\ poroduction\ (\$/ha) \quad (9)$$

$$Econimic\ productivity = Yield\ of\ potato\ (kg/ha) / Total\ poroduction\ cost\ (\$/ha) \quad (10)$$

$$Benefit/cost\ ratio = Total\ income\ (\$/ha) / Total\ poroduction\ cost\ (\$/ha) \quad (11)$$

All analysis of data was performed into Excel 2013 spreadsheets and SPSS 22.0 software programs. The results are tabulated and presented as tables.

Results and discussion

Energy analysis

The energy consumption and its physical quantity sources for potato production are reported in Table 3. The last column in Table 3 shows the percentage of each and every input of the Total Energy Input (TEI). The results disclosed that, total energy consumption during the production period of potato was 131608.14 *MJ ha*$^{-1}$ whereas the Total Energy Output (TEO) was about 127315.8 *MJ ha*$^{-1}$. Electricity input with average of 46281.96 *MJ ha*$^{-1}$ was the greatest energy consumer (with share of 35.17%). Chemical fertilizers were second high energy consuming inputs of the various operations. Furthermore, nitrogen had the highest portion (22.43%) among the fertilizers with the application rate of 378 *kg ha*$^{-1}$, as a result of its high energy values.

Table 3. Inputs and outputs expressed as quantity per unit area, total energy equivalent and percentage share.

Inputs/Output	Quantity per unit area (*ha*)	Total energy equivalent (*MJ ha*$^{-1}$)	Percentage (%)
A. Inputs			
1) Human labor	494.28	968.79	0.74
2) Machinery	45.34	2842.81	2.16
3) Diesel fuel	515.12	24622.74	18.71
4) Electricity	3856.83	46281.96	35.17
5) Chemical fertilizers			
a) Nitrogen (N)	378	29521.8	22.43
b) Phosphate (P_2O_5)	228.5	3975.9	3.02
c) Potassium (K_2O)	85	1164.5	0.88
6) Water for irrigation	6423.47	6551.94	4.98
7) FYM	8740	2622	1.99
8) Chemicals	4.75	570	0.43
9) Seed	3468.25	12485.7	9.49
TEI	-	131608.14	100
B. Output			
1) Potato	35365.5	127315.8	

The total energy equivalent of diesel fuel consumption placed third among the energy inputs and accepted 18.71% of the TEI. Chemicals for potato plant protection had the lowest proportion among the inputs (0.43%). The share of input energies within the total input energy is shown in Fig. 1.

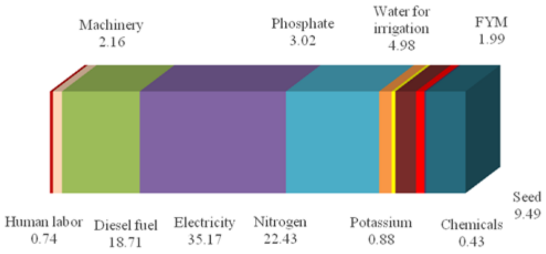

Fig. 1. Share of energy inputs for potato production.

To review the literature disclosed that some researchers investigated input–output energy flow in potato production, in Iran. The examined literature showed total input energy was a region-specific parameter. Mohammadi *et al.* (2008) presented that the total input energy was estimated at 81624 *MJ ha⁻¹* in potato production in Ardabil province. They highlighted that chemical fertilizer consumed 40% of TEIs followed by diesel energy 16% throughout production period. In another study done by Rajabi Hamedani *et al.* (2011), the TEI was calculated as 92296.3 *MJ ha⁻¹*. They stated that chemical fertilizers (47%) and diesel fuel (21%) were the foremost contributors to the total input energy followed by seeds (15%). The TEI of potato production in Pishgar-Komleh *et al.* (2012) was 47000 *MJ ha⁻¹*. They found that chemical fertilizers constituted 49% of the TEI followed by seed with 24%. Mohammadi *et al.* (2008), Rajabi Hamedani *et al.* (2011) and Pishgar-Komleh *et al.* (2012) did not take into account the energy of electricity and this could affected TEI. Khoshnevisan *et al.* (2014) asserted that total means input energy of potato production were 83723 *MJ ha⁻¹* in Fereydoonshahr region, Iran. They revealed that electricity (37%) and chemical fertilizer (34%) had the most considerable result on the energy consumption followed by seed with 14% of the TEI. In the same investigation Zangeneh *et al.* (2010) expressed that the total input energy expended in potato farms with high level of agricultural technology was around 153071.40 *MJ ha⁻¹*. They reported that electricity consumed 36.6% of the TEI followed by chemical fertilizers (24.79%) throughout production period. These studies were conducted in dissimilar climatic conditions and regions with different soil types, therefore, the difference in application rate of chemical fertilizers and water for irrigation was inevitable.

Energy indexes

Direct, indirect, renewable and non-renewable energy forms utilized in potato production are investigated (Table 4). The results show that the share of direct input energy was 59.59% within the TEI compared to 40.41% for the indirect energy. On the other hand, renewable and non-renewable energy contributed to 17.19% and 82.81% of the TEI, respectively. It is clear that the proportion of NRE use in surveyed farms holdings is extremely high. This result indicates the requirement for a revolution in non-renewable energy consumption behavior in potato production. The results on potato are in agreement with the results of other authors (Khoshnevisan *et al.* 2014; Mohammadi *et al.* 2008; Pishgar-Komleh *et al.* 2012; Zangeneh *et al.* 2010) that showed a range 64–84% of energy input comes from non-renewable energy. Regarding the direct and indirect energy, results are founded by Zangeneh *et al.* (2010) that showed that the ratio of DE is more than that of IDE.

Table 4. Energy indices and different form of energy in potato production.

Inputs/Output	Quantity	Percentage (%)
Energy use efficiency	0.97	-
Specific energy (*MJ kg⁻¹*)	3.72	-
Net energy (*MJ ha⁻¹*)	-4292.34	-
Energy productivity (*kg MJ⁻¹*)	0.27	-
Energy intensiveness (*MJ $⁻¹*)	21.73	-
Direct energy (*MJ ha⁻¹*)	78425.42	59.59
Indirect energy (*MJ ha⁻¹*)	53182.72	40.41
Renewable energy (*MJ ha⁻¹*)	22628.43	17.19
Non-renewable energy (*MJ ha⁻¹*)	108979.71	82.81
TEI (*MJ ha⁻¹*)	131608.14	100
TEO (*MJ ha⁻¹*)	127315.8	-

The energy use efficiency, specific energy, net energy and energy productivity of potato production were calculated using Eqs. 2 to 6 and the results are tabulated in Table 4. Energy use efficiency or energy ratio was calculated as 0.97. It is concluded that the energy ratio will be increased by raising the yield and/or by decreasing energy inputs consumption. The calculated energy use efficiency was virtually less than 1.25 reported by Mohammadi *et al.* (2008), 1.71 by Pishgar-Komleh *et al.* (2012), 1.1 by Rajabi Hamedani *et al.* (2011) and 1.03 by Khoshnevisan *et al.* (2014) on potato production. Although it was agreed closely with the value (0.95) that Zangeneh *et al.* (2010) obtained for non-owner of machinery and low level of farming technology potato growers. Also, specific energy (energy intensity) was accounted as 3.72 $MJ\ kg^{-1}$. Negative net energy (-4292.34 $MJ\ ha^{-1}$) can be concluded that energy is being lost in potato production, particularly by practicing traditional technique of irrigation and losing chemical fertilizers. Similar with this study, Khoshnevisan *et al.* (2014) and Zangeneh *et al.* (2010) found a negative value for the net energy of potato production. The energy productivity and energy intensiveness were 0.27 $kg\ MJ^{-1}$ and 21.73 $MJ\ \$^{-1}$, respectively. Zangeneh *et al.* (2010) reported higher energy intensiveness for potato production in Hamedan province.

GHG emissions analysis

Results of GHG emission of potato production process are reported in Table 5. The total GHG emission in the studied area was 128.443 $kg\ CO_2eq.$ *per ton* of potato yielded. Consequently, the total emission was 4542.463 $kg\ CO_2eq.ha^{-1}$. As shown in Fig. 2, the most value of GHG emission belonged to electricity with share of 51.623% of total emission and followed by diesel fuel (31.299%), chemical fertilizers (12.105%) and machinery (4.443%). Nitrogen in chemical fertilizer had the first rank in GHG emission. In a similar study conducted by Pishgar-Komleh *et al.* (2012), the amount of GHG emission was reported as 992.88 $CO_2eq.ha^{-1}$. However, they indicated that the share of chemical fertilizer and diesel fuel were 37% and 33% respectively. Pishgar-Komleh *et al.* (2012) did not take into account the GHG emission of electricity. Khoshnevisan *et al.* (2014) reported that the total of GHG emission for potato production process was 116.4 $kg\ CO_2eq.$ *per ton* of potato produced. They found that electricity, chemical fertilizer and diesel fuel with a share of 65%, 20% and 10% respectively, played the important role on GHG emissions.

Table 5. GHG emission of inputs in potato production.

Inputs	GHG emission ($kg\ CO_{2eq.}\ unit^{-1}$)	Percentage of the GHG emission (%)
1)Machinery	201.8401	4.443
2)Diesel fuel	1421.731	31.299
3)Electricity	2344.953	51.623
4)Chemical fertilizers		
a)Nitrogen (N)	491.4	10.818
b)Phosphate (P_2O_5)	45.7	1.006
c)Potassium (K_2O)	12.75	0.281
5)FYM	0.0437	0.001
6)Biocides		
a)Herbicide	7.875	0.173
b)Pesticide	10.71	0.236
c)Fungicide	5.46	0.120
Total GHG emission	4542.463	100

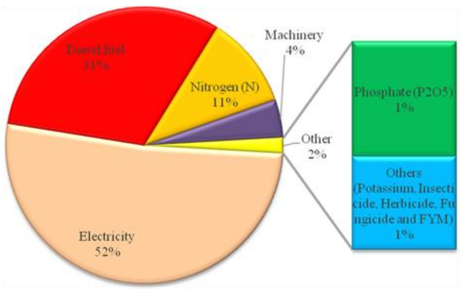

Fig. 2. Contribution of different inputs in the GHG emissions for potato production.

Economic analysis

The main economic indexes of potato production calculated using the Eqs. 7 to 11 and can be observed in Table 6. In the surveyed area, the potato sale price and cost of production were found 0.19 $\$\ kg^{-1}$ and

0.17 *$ kg^{-1}*, respectively. Average fixed cost of potato cultivation was 1558.68 *$ ha^{-1}* and about 74% of the total production costs were variable costs. The economic productivity demonstrates 5.84 *kg* potato was yielded per each dollar expending in production process. The net return, gross return and benefit to cost ratio were calculated as 662.76 *$ ha^{-1}*, 2221.44 *$ ha^{-1}* and 1.11, respectively. Based on these results, the net return from potato production was at a satisfying level in the studied farms. Also, Mohammadi *et al.* (2008) reported the positive net return but Zangeneh *et al.* (2010) calculated the negative value for potato production. The benefit to cost ratio can be inferred that the net return of 1.11 *$* was obtained per 1 *$* of money invested and was a cost effective business based on the data of the 2013–2014 production season. The benefit–cost ratio result was consistent with finding reported by other research on potato such as 1.88 by Mohammadi *et al.* (2008) and 1.09 by Zangeneh *et al.* (2010).

Table 6. Economic analysis of potato production.

Index	Unit	Quantity
Yield	*kg ha^{-1}*	35365.5
Sale price	*$ kg^{-1}*	0.19
Total income	*$ ha^{-1}*	6719.45
Total cost of production	*$ ha^{-1}*	6056.68
Fixed cost of production	*$ ha^{-1}*	1558.68
Variable cost of production	*$ ha^{-1}*	4498
Total cost of production	*$ kg^{-1}*	0.17
Net return	*$ ha^{-1}*	662.76
Gross return	*$ ha^{-1}*	2221.44
Economic productivity	*kg $$^{-1}$*	5.84
Benefit to cost ratio	-	1.11

Discussion

The main reasons that elevated TEI and raised GHG emissions of potato production were supernumerary use of electricity, diesel fuel and chemical fertilizers. The high proportion of electricity energy was employed in irrigation systems for pumping water from water wells. Effective service and maintenance could keep water well pump acting at peak efficiency. Also replace the defective and outdated water well pumps with new ones is recommendable. Pishgar-Komleh *et al.* (2010) concluded that applying renewable sources in electricity mix (wind, solar, nuclear, biomass and etc.) is the alternative approach to have a life with low non-renewable energy usage and high renewable forms of energy. Diesel fuel was a key factor that significantly contributed to the TEI by 18.71% and GHG emissions by 31.3%. Comprehensive management of farming machinery, choosing proper equipment and replacing time-worn tractors or machines with new and modern alternatives are advisable. Moreover, using wider machinery in extensive farms may improve efficiency in diesel fuel consumption. Dyer and Desjardins (2003) described that high diesel fuel GHG emissions is related to applying worn-out tractors in operations, improper matching of equipment to tractors and performing high energy intensity tillage operation. The potato farms were fertilized both with FYM and chemical fertilizers. The results presented that even though FYM had a high application rate of 8740 *kg ha^{-1}*, its contribution (1.99%) within the TEI was much lower than that of chemical fertilizers (Table 3). This was owing to the lower energy equivalent of FYM (0.30 *MJ kg^{-1}*) in contrast with that of chemical fertilizers (Table 1). Thus, it is advisable to replacing chemical fertilizers with more application of FYM and green manure. Fertilization utilization management and adding legumes into the crop rotation are demanded to reduce the demand for nitrogen fertilizer. Consistent with Demircan *et al.* (2006) appropriate fertilization management, taking the quantity and frequency of fertilization (specially nitrogen) into account, and suitable tractor selection and management of machinery to minimize direct use of diesel fuel are required to save non-renewable energy sources without impairing the yield or profitability to enhance the energy use efficiency of potato production.

Conclusion

For an estimation of potato production energy flow the important components concerning energy input and output in potato farms are identified and energy input and output have been calculated. The total means input and output energy were 131608.14 *MJ ha^{-1}* and 127315.8 *MJ ha^{-1}*, respectively. Electricity (with 35.17%), chemical fertilizer (with 26.33%) and diesel fuel (with 18.71%) were the most influential factors in energy consumption. Also, the energy use efficiency, specific energy, net energy, energy productivity and energy intensiveness were calculated and discussed. The lower value of energy productivity than unity and negative net energy implied that the energy use in potato production is not efficient and harmful to the environment due to immoderate use of inputs. Moreover, about 59.59% of the TEI employed in potato production was DE, while only about 40.41% was IDE. The results disclosed that potato production process in the region signed a high sensitivity on NRE sources which can result in both the environmental deterioration and rapid rate of depletion of these energetic resources. Additionally, GHG emission of potato production was investigated in the surveyed area. The total GHG emission was 128.443 *kg* CO_2*eq. per ton* of potato yielded. Electricity input with a share of 51.623% played the most considerable role on the total GHG emission and it was followed by diesel fuel (31.299%) and chemical fertilizer (12.105%). The economic analysis of potato production was conducted considering total income and total production cost. The positive value of net return and more than unity value of benefit to cost ratio indicating that potato production was a profitable profession based on the data from the 2013–2014 production season. The results derived from this study may be employed by policy makers and other relevant non-governmental organizations (NGOs) for recommendations to farmers in order to use energy and money more efficiently.

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