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Improvement of energy efficiency and environmental impacts of rainbow trout in Iran

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ABSTRACT

Combination of Life Cycle Assessment (LCA) and other management tools can help production units to improve economic productivity and environmental protection. In this study, a combination of LCA and Data Envelopment Analysis (DEA) was applied in order to improve the energy efficiency and reduce the environmental burdens of rainbow trout farm in Ardal and Lordegan regions located in Chaharmahal and Bakhtiari Province of Iran. The required data were collected from 60 rainbow trout farms in Ardal region and 38 rainbow trout farms in Lordegan region through face-to-face questionnaire method. In Ardal region, total energy inputs, rainbow trout yield and Energy Ratio (ER) were estimated as 60,483.50 MJ ton^{-1}, 281.78 ton ha^{-1} and 0.40, respectively, while for Lordegan region, these estimates were obtained as 77,183.63 MJ ha^{-1}, 210.50 kg ha^{-1} and 0.33, respectively. The results of LCA revealed that rainbow trout production in Ardal region had lower environmental burdens than Lordegan region in all impact categories. Accordingly, Environmental Emissions Final Score (EEFS) in Ardal and Lordegan regions were 1638.88 and 3484.31 ppt ton^{-1}, respectively. The normalized results also showed that Marine Aquatic Ecotoxicity (MAE) had the highest value among all impact categories in both regions. The DEA results showed that in Ardal and Lordegan regions about 29.28% and 9.59% of the total energy can be saved without reducing the yield, respectively. The highest potential for saving energy was related to feed in both Ardal (24.74%) and Lordegan (9.12%) regions. The results of LCA coupled with DEA also revealed that there is a higher potential for reduction of environmental impacts in Ardal region compare to Lordegan region. Accordingly, the EEFS value in Ardal and Lordegan regions were reduced by 27.34% and 8.85%, respectively. Generally, rainbow trout production in Ardal region had higher energy efficiency, lower environmental burdens and also higher potential to improve energy consumption and reduce the environmental impacts compared to Lordegan region.

1. Introduction

Globally, aquaculture is an important economic activity which plays a role in improving feeding and economic development in developing countries such as Iran (Cacho, 1990). Among aquatic animals, fish provides about 20% of total animal protein and has high quality protein, fat, and high amounts of vitamins and minerals (Bureau et al., 2002). According to reports by FAO (2018), total fisheries and aquaculture production was about 171 million tons in 2016. The shares of fisheries and aquaculture were about 47% (80 million tons) and 53% (91 million tons), respectively. Additionally, FAO (2018) reported Iran as the largest producer of trout fish species, producing 167,830 tons of rainbow trout (Onchorhynchus mykiss). In Iran, about 40% of rainbow trout fish has been produced in Chaharmahal and Bakhtiari (22,803 tons), Lorestan (22,106 tons) and Kohgiluyeh-o-Boyer-Ahmad (19,500 tons) provinces (Anonymous, 2018).

Limitations in fishing and lack of access to the some potential water resources resulted in the maximum utilization of available resources in aquaculture (Aubin et al., 2006). However, higher utilization of non-renewable resources could reduce energy efficiency and lead to further environmental problems. Any measure for managing and reducing energy consumption of inputs such as chemical fertilizers, agricultural machineries, labor, water, electricity and other inputs to improve energy efficiency is the energy saving which is one of the easiest and the

Abbreviations: AC, Acidification; AD, Abiotic Depletion; CRS, Constant Returns to Scale; DEA, Data Envelopment Analysis; DMU, Decision Making Unit; EEFS, Environmental Emissions Final Score; ER, Energy Ratio; EP, Eutrophication Potential; EPr, Energy Productivity; ESTR, Energy saving target ratio; FAE, Fresh water Aquatic Ecotoxicity; FAO, Food and Agriculture Organization; FU, Functional Unit; GHG, Greenhouse Gas; GW, Global Warming; HT, Human Toxicity; ISO, International Standardization Organization; LCA, Life Cycle Assessment; LCI, Life Cycle Inventory; LCIA, Life Cycle Impact Assessment; MAE, Marine Aquatic Ecotoxicity; OLD, Ozone Layer Depletion; PhO, Photochemical oxidation; PTE, Pure Technical Efficiency; SE, Specific Energy; SEf, Scale Efficiency; TE, Terrestrial Ecotoxicity; TEf, Technical Efficiency; VRS, Variable Returns To Scale.

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most cost-effective methods to prevent climate change. Also, improvement of the energy efficiency by energy saving would lead to a reduction in production costs which is very important to consumers. For these reasons, improvement of energy efficiency has been included in the strategy of production (Schnapp, 2012).

Increase in energy efficiency could be achieved by using methods like data envelopment analysis (DEA). The first DEA model was introduced by Charnes et al. (1978). DEA is a nonparametric method and is commonly used to estimate energy efficiency and environmental issues based on decision making units (DMUs) (Zhou et al., 2008). This method is a data-driven frontier analysis technique that considers a piecewise linear surface to rest on top of the observations as efficient frontier (Adler et al., 2002). Unlike the parametric methods, DEA does not require a function to relate inputs to outputs (Seiford and Thrall, 1990). There is difference between DEA and evolutionary algorithms such as genetic algorithm. DEA approach is not capable of calculating global optimum values. In DEA approach, the optimum values are determined on the basis of production units under consideration and in this way global optimum values are not calculated. In the other words, the objective of a DEA study is to select the DMU which is most efficient DMU compared to all DMUs under consideration (Shamshirband et al., 2015). However, genetic algorithm does not always ensure that always an optimal result.

In the other hand, the environmental problems could be assessed by Life Cycle Assessment (LCA) method. LCA is a standard, organized and comprehensive method to assess the environmental impacts related to a product or process throughout its life cycle (ISO 14040, 2006; Shahvarooghi Farahani and Asoodar, 2017). Recently, LCA has been a common tool to evaluate greenhouse gas (GHG) emissions and a wide range of the environmental impacts of agricultural systems (Goglio et al., 2015). Therefore, combination of LCA and DEA, known as LCA + DEA methodology, has been introduced as a valuable method that avoids concerns related to standard deviation (Iribarren et al., 2010). In recent years, different researchers have indicated that the LCA+DEA methodology led to optimal use of the inputs in agricultural systems in order to reduce energy consumption and environmental impacts without a reduction in output. For instance, Mohseni et al. (2018) conducted a study in Arak county of Iran, in which 58 grape producers were analyzed by LCA + DEA methodology. They reported that a range of 0.25 to 18% reduction among environmental impact categories was observed. Mohammadi et al. (2013) used a combination of LCA and DEA to assess the eco-efficiency of 94 soybean producers in Iran. Their results indicated that LCA + DEA methodology reduced the average global warming by 11%. Nabavi-Pelesaraei et al. (2017) conducted a study using LCA + DEA methodology to assess the levels of operational efficiency of 240 paddy farms. They indicated that global warming could be reduced by 24% only if farmers operate based on the recommended 98 efficient frontier values recommended by LCA + DEA. Increasing energy efficiency and reducing environmental impacts of production systems in order to achieve sustainable development goals is necessary and the combined application of LCA and DEA could be a sensible option to assess production systems and provide suggestions to decrease energy consumption (Khoshnevisan et al., 2015). In the present study, LCA was used as a tool for analyzing environmental burdens and DEA allowed to optimize the inputs and consequently reduce the environmental burdens.

Although, there are several studies in the literature which have investigated environmental impacts of fish farms (Aubin et al. (2006); Bozoglu and Ceyhan (2009); Ayer and Tyedmers (2009); Aubin et al. (2009); Vázquez-Rowe et al. (2011); Samuel-Fitwi et al. (2013); Efole Ewoukem et al. (2012); Chen et al. (2015); Medeiros et al. (2017) that is shown the summary of these researches in Table 1), but there is no

Table 1
Summary of previous researches.

References	Study country (s)	Fish species	Research summery	Energy	LCA	LCA + DEA
Bozoglu & Ceyhan (2009)	Turkey	Rainbow trout (*Oncorhynchus mykiss*)	Current energy balance, energy conversion efficiency, and farm-level efficiency of trout production in the Black Sea, Turkey.	√	×	×
Aubin et al. (2006)	France	Turbot (*Scophthalmus maximus*)	The environmental impacts of a water re-circulating system for fish farming were studied through the case study of an inland turbot farm located in Brittany, France.	×	√	×
Ayer & Tyedmers (2009)	Canada	Salmonid culture systems	Life cycle assessment (LCA) quantify and compare the potential environmental impacts of culturing salmonids in a conventional marine net-pen system.	×	√	×
Aubin et al. (2009)	France-Greece	Rainbow trout (*Oncorhynchus mykiss*) in freshwater raceways in France, sea-bass (*Dicentrarchus labrax*) in sea cages in Greece, and turbot (*Scophtalmus maximus*) in an inland re-circulating system	The LCA method is well suited for evaluating the environmental impacts of finfish production systems: rainbow trout in France, sea-bass in Greece, and turbot in France. Two main characteristics differentiated the three farm systems: feed use and energy use.	×	√	×
Samuel-Fitwi et al. (2013)	Germany	Rainbow trout (Oncorhynchus mykiss)	Consequential life cycle assessment (LCA) is used to analyze the environmental impact of rainbow trout production using extensive system (ES), intensive system (IS) and recirculating aquaculture systems (RAS).	×	√	×
Efole Ewoukem et al. (2012)	Cameroon	Tilapia (*Oreochromis niloticus*)	The study analyzed four farms that integrated fish farming with other agricultural production, and in which fish ponds were fertilized either by pig manure and/or crop by-products, in two regions of the western highlands of Cameroon.	×	√	×
Chen et al. (2015)	France	Rainbow trout (Oncorhynchus mykiss)	Describes a system to classify trout farms based on environmental impacts calculated by life cycle assessment and technical and economic indicators.	×	√	×
V.Mederios	Brazil	Fish tambaqui (*Colossoma macropomum*) and the Amazon River prawn (*Macrobrachium amazonicum*)	Applied LCA to evaluate and compare environmental impacts of Two omnivorous native Brazilian species: the fish tambaqui and the Amazon River prawn.	×	√	×
Vázquez-Rowe et al. (2011)	Spain	Coastal fish	Coupling LCA with DEA to evaluate the environmental impacts of coastal fish production in Spain	×	√	√
Current study	Iran	Rainbow trout (Oncorhynchus mykiss)	A combination of LCA and Data Envelopment Analysis (DEA) was applied in order to improve the energy efficiency and reduce the environmental burdens of rainbow trout farm.	√	√	√

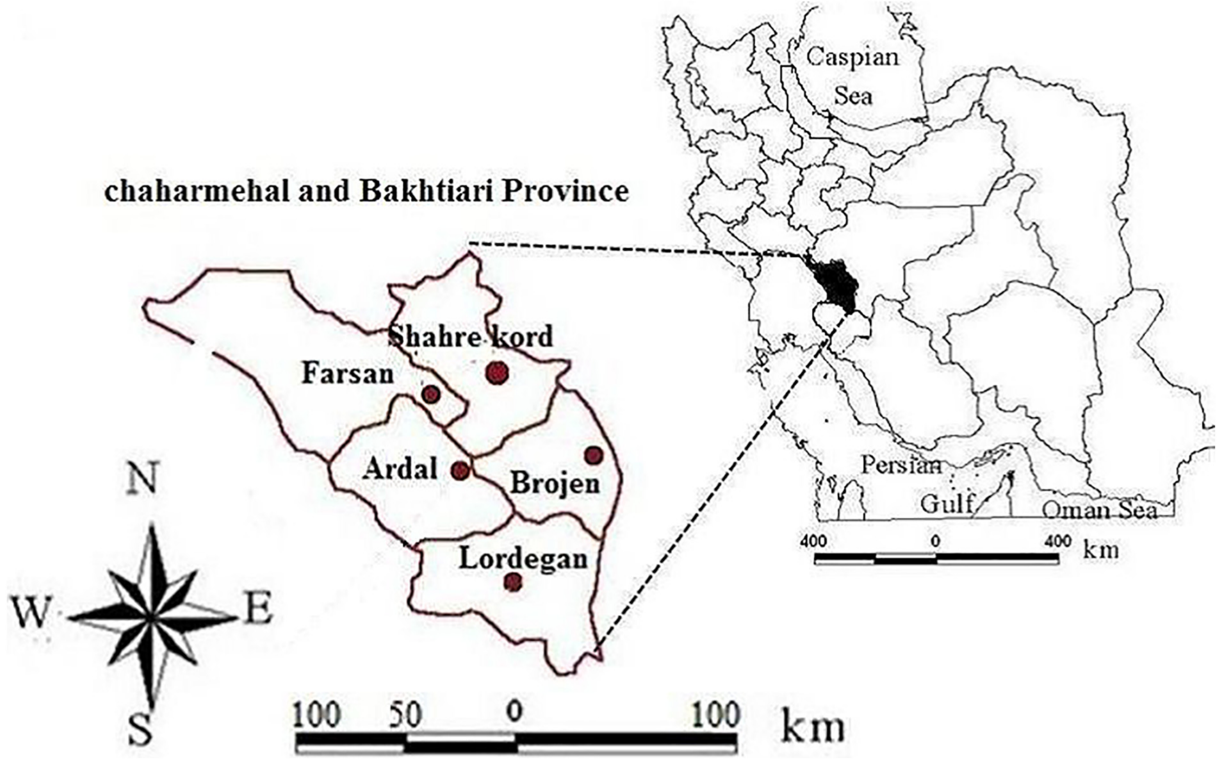

Fig. 1. Geographic location of Chaharmahal and Bakhtiari province in Iran (Anonymous, 2017).

study to improve input energies and consequently reduce environmental impacts of trout farm using a combination of LCA and DEA. On other hand, considering that Chaharmahal and Bakhtiari province ranked first in trout production in Iran, conducting this study seemed to be necessary. The main objectives of this study are as follows:

(1) Energy flow analysis of trout production;
(2) Assessment and analysis of environmental impacts of trout production by LCA;
(3) Evaluation of energy efficiency and identification of inefficiency reasons of the energy in trout farms by DEA;
(4) Provide the improved pattern to reduce energy consumption in trout farms based on efficient units which are introduced by DEA;
(5) A coupled LCA + DEA approach to reduce environmental burdens through the improved energy consumption pattern.

2. Materials and methods

2.1. Site of study and data collection

Area of Chaharmahal and Bakhtiari province area has been estimated as 16,421 km^2, which is 1% of total Iran's area. This province is 2153 m above the sea level located at 31° 9′ to 32° 38′ North latitude and 49° 30′ to 51° 26′East longitude and has the largest share of Iran's water resources (about 10%) (Fig. 1) (Anonymous, 2016). Chaharmahal and Bakhtiari province has 404 trout farms and known as one of the most important region of rainbow trout production in the world. Ardal and Lordegan regions located at Chaharmahal and Bakhtiari province have 113 and 72 trout farms, respectively, the highest share of the province trout farms (45% of total trout breeding of the province) (Anonymous, 2017).

Considering the number of trout farms in Ardal and Lordegan regions, simple random sampling was used and the size of sample was calculated using Cochran's formula (Eq. (1)) (Cochran, 1977).

$$n = \frac{\frac{Z^2pq}{d^2}}{1+\frac{1}{N}\left(\frac{Z^2pq}{d^2}-1\right)} \tag{1}$$

where N is the number of trout farms in each region (113 trout farms in Ardal region and 72 trout farms in Lordegan region), Z is the reliability coefficient (1.96 which denotes 95% reliability), p is the possibility of success for an adjective in the population (equal to 0.5), q is the possibility of failure for an adjective in the population (equal to 0.5), d is the permitted error from the average population (with a value of 0.05) and n stands for the sample size of each region.

Table 2
A brief summary of sample questionnaire.

Questionnaire No: ....
Date: ....
Total area of pond (ha): ....
Duration of the production (day): ....
Type, weight and distance of transportation in various stages (tkm)
Number of fixed labors: ....
Number of variable labors: ....
Amount of water consumed in each period (m^3)
Type and amount of feed consumption (kg)
Total electricity consumption for water pomp and aeration system (kwh)
Total natural gas consumption (m^3)
Number and total weight of Fry (kg)
Total diesel fuel consumption (L)
Total weight of trout (kg):

Table 3
Amounts average of inputs and yield in trout farms of the studied regions.

Inputs/yield (Unit)	Energy equivalent (MJ unit^{-1})	Average consumption (Unit ton^{-1})		References
		Lordegan	Ardal	
- Inputs				
1. Fry (kg)	20.5	57.78	70.30	(Askari Sari and Mohammadi, 2015)
2. Electricity (kwh)	11.93	888.21	1014.96	(Mousavi-Avval et al., 2011a)
3. Diesel fuel (L)	47.8	19.58	57.76	(Elhami et al., 2016)
4. Water (m^3)	1.02	8.82	29.72	(Fathollahi et al., 2018)
5. Natural gas (m^3)	49.5	27.54	26.23	(Khoshnevisan et al., 2014a)
6. Transportation machine (tkm)	1.6	10.03	7.23	(Kitani, 1999)
7. Human labor (h)	1.96	201.55	193.21	(Fathollahi et al., 2018)
8. Feed (kg)				
8.1. Fish meal	15.4	954.24	1744.3	(Hossain et al., 1997)
8.2. Fish oil	18.32	763.39	1067.93	(Hossain et al., 1997)
8.3. Wheat gluten	13	272.64	213.58	(Kitani, 1999)
8.4. Corn gluten	14.7	218.41	177.99	(Houshyar et al., 2012)
8.5. Rapeseed Meal	25	163.58	106.79	(Mousavi-Avval et al., 2011a)
8.6. Soybean Meal	25	190.84	142.39	(Mousavi-Avval et al., 2011b)
8.7. Beans powder	14.9	109.05	71.19	(Koocheki et al., 2011)
8.8. Sweet sorghum	1.2	54.52	35.59	(Kitani, 1999)
- Yield Rainbow trout (ton ha^{-1})	20.5	281.78	210.507	(Askari Sari and Mohammadi, 2015)

According to Cochran's formula, the sample size for Ardal and Lordegan regions were calculated as 60 and 38 farms, respectively. Thus, 60 and 38 trout farms were selected randomly from Ardal and Lordegan regions, respectively. The required data were collected based on one ton rainbow trout using face-to-face questionnaire method. This method is conducted by an interviewer asking questions of a respondent in person. Also, this tool was found useful to gather contextual insights, especially when key organization representatives were interviewed (e.g. farmers union, local authorities and community groups). The required data includes fry, electricity, diesel fuel, natural gas, water, fish feed (fish meal, fish oil, wheat gluten, corn gluten, rapeseed meal, soybean meal, sweat sorghum and bean powder), labor and transportation. A brief summary of sample questionnaire is provided in Table 2.

2.2. Energy balance evaluation

To analyze energy flow and optimize energy consumption in a production system, it is necessary to calculate the input–output energies in the first step. Then, energy equivalents are used for transforming all inputs and outputs to their energy equivalent (Mousavi-Avval et al., 2011a). The average of the consumed inputs (per ton of trout) and the yield for the two studied regions is shown in Table 3. The input and output energies were calculated by multiplying the quantities of the inputs and output by their energy equivalents. According to the input energy, the quantity of the yield and the output energy, the energy indices were calculated using the following equations (Elhami et al., 2016; Fathollahi et al., 2018):

$$\text{Energy Ratio (ER)} = \frac{\text{Output Energy}\left(\text{MJ ha}^{-1}\right)}{\text{Input Energy}\left(\text{MJha}^{-1}\right)} \tag{2}$$

$$\text{Energy Productivity (EPr)} = \frac{\text{Trout output}\left(\text{ton ha}^{-1}\right)}{\text{Input Energy}\left(\text{MJ ha}^{-1}\right)} \tag{3}$$

$$\text{Specific Energy (SE)} = \frac{\text{input Energy }\left(\text{MJ ha}^{-1}\right)}{\text{Trout output}\left(\text{ton ha}^{-1}\right)} \tag{4}$$

Energy indices help to assess the status of a system according to the total energy input and the yield (or energy output). However, it cannot help to find out how the system would be improved. For instance, Energy Ratio (ER) of a system could be improved by 2 times more yield and 1.5 times more energy input. In spite of more ER, more energy

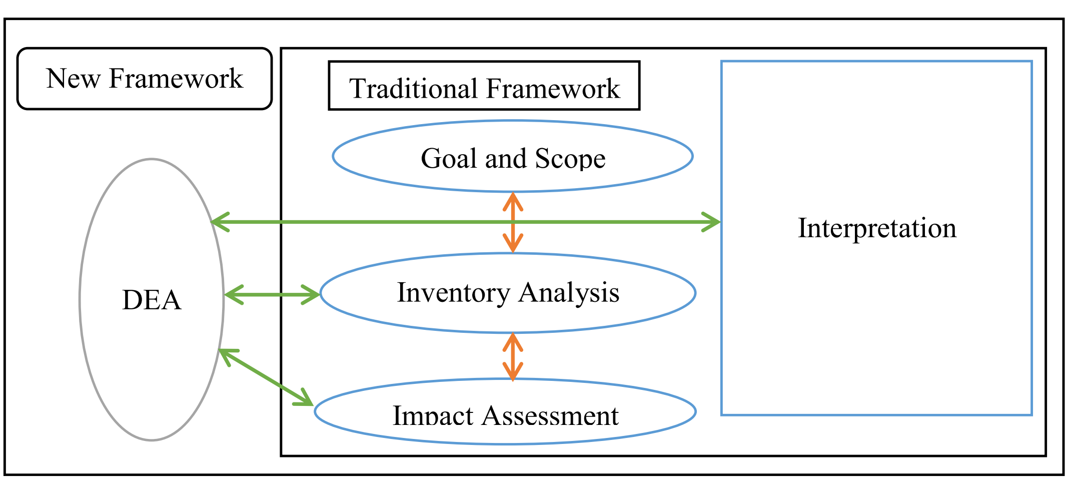

Fig. 2. LCA framework with regard to DEA technique (indeed, inventory and impacts of LCA, Interpreted by DEA) (Adapted from Khoshnevisan et al. (2015)).

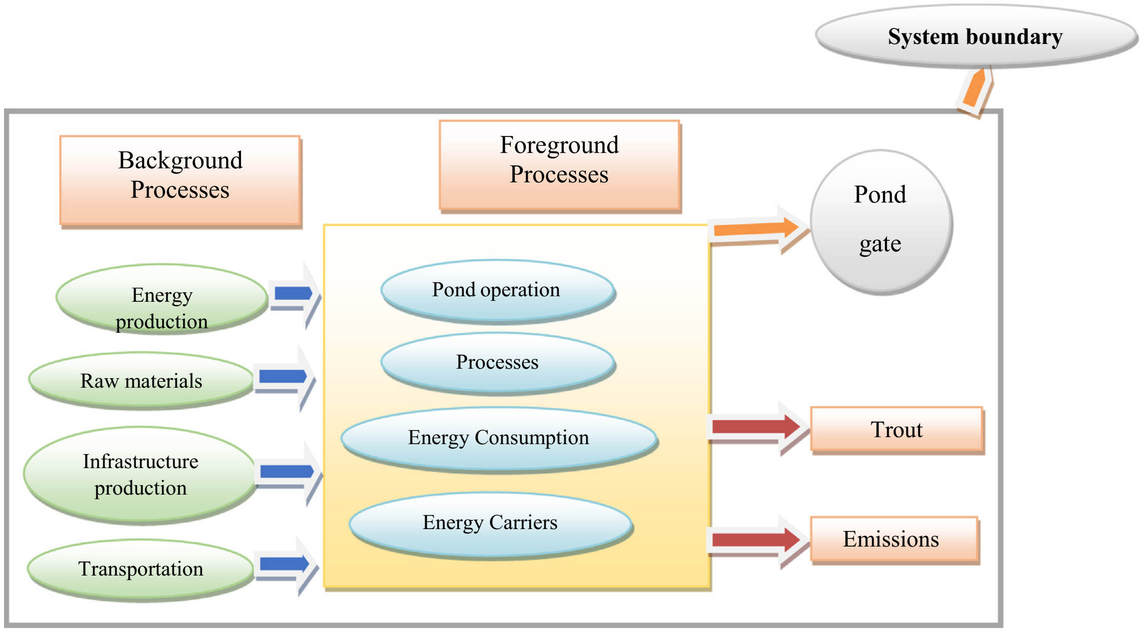

Fig. 3. System boundaries of rainbow trout farms.

input would result in lower sustainability. Therefore, it seems to be necessary to use other scientific methods such as DEA to evaluate the efficiency and sustainability of the systems (Houshyar et al., 2012).

2.3. Life cycle assessment

LCA approach follows the instructions provided by ISO 14040 (2006) and ISO 14044 (2006). LCA allows identifying all the energy inputs, natural resources and the environmental burdens related to production, transportation, utilization and disposal of a product (Guinée et al., 2011). A LCA study consists of four main stages including definition of goal and scope (system boundaries, functional unit, final product and assumptions), inventory analysis, impact assessment and interpretation (Fig. 2). Combination of different stages of LCA and DEA is explained in the following sections.

2.3.1. Goal and scope definition

Generally, in a LCA study, explicit expression of study goals represents how a study is carried out. LCA must be defined based on desired applications (ISO 14040, 2006). The aim of this study is to evaluate the actual and improved environmental impacts of trout farms. In the study scope definition, functional unit (FU) and system boundaries should be clearly defined. In this study, the FU which is defined as a brief description of the production process (Rebitzer et al., 2004) considered as one ton of produced trout. LCA is a "cradle to the grave" approach but it is possible to define the system boundaries in a way in which only a part of the production system is considered and the results are reported based on the system boundaries (Khoshnevisan et al., 2013). This study focused on the stages from the cradle (production of the inputs) to the pond gate (trout production) (Fig. 3).

2.3.2. Life cycle inventory (LCI)

The LCI represents a detailed compilation of the inputs (energy and materials) and outputs (product and emissions to water, soil and air). Data related to the foreground system (trout farm practices) were collected using face-to-face questionnaire (Table 3) and data from the background system (production of inputs) were taken from the Ecoinvent database and the previous studies (Table 4) (EPA, 1998; Nemecek and Kagi, 2007; Mousavi-Avval et al., 2017; Bureau et al., 2002). To calculate the emissions from the inputs, the quantities of the inputs and outputs were entered into SimaPro software. The Ecoinvent database consists of the emissions (into water, air and soil) from different production stages of different products and is defined for most countries in the world. This database also could be used for LCA studies in Iran (Khoshnevisan et al., 2014a; Mousavi-Avval et al., 2017). Electricity was used for water pumps and aeration system. Considering that >98% of electricity in Iran generated by natural gas (94.4%) and hydropower (4.9%) and other energy resources generate limited and variable amounts of electricity (Anonymous, 2012), it was assumed that all amounts of electricity is generated by natural gas and hydropower. Inventory data for the production of electricity from natural gas and hydropower at reservoir were taken from Ecoinvent database. Natural gas

Table 4
Emission factors for 1 unit from diesel fuel based on Ecoinvent (Nemecek and Kagi, 2007), human labor (Mousavi-Avval et al., 2017) and natural gas based on EPA (1998).

Direct emissions	Emission factors of diesel fuel (kg MJ^{-1})	Emission factors of natural gas (kg MJ^{-1})	Emission factors of human labor (kg man-h^{-1})
1. Carbon dioxide	7.45E-02	3.87E-02	7.00E-01
2. Sulfur dioxide	2.41E-05	1.93E-07	–
3.Methane	3.08E-06	7.4E-07	–
4. Dinitrogen monoxide	2.86E-06	7.11E-07	–
5.Ammonia	4.77E-07	–	–
6. Hydrocarbons	7.85E-08	–	–
7. Nitrogen oxides	1.06E-03	–	–
8. Carbon monoxide	1.50E-04	–	–
9. Particulates (b2.5μm)	1.07E-04	2.45E-06	–

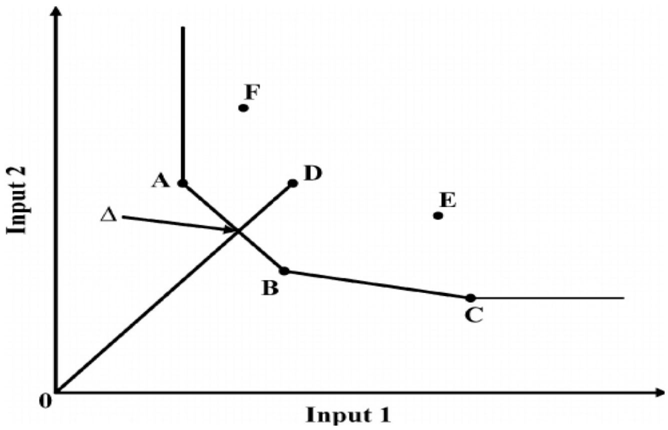

Fig. 4. A scheme of DEA efficient frontier for 2 inputs and 1 output with 6 DMUs.

was used as a fuel for heating system. The emission from diesel fuel combustion, natural gas burning and carbon dioxide emitted during labor activities considered as the direct emissions and their emissions coefficients are shown in Table 4.

Emissions from nutrients to local environments associated with fish growth were estimated by using nutrient-balance modeling (Cho and Kaushik, 1990). This method has been adapted and validated for modeling rainbow trout (Bureau et al., 2002), and it has been previously used for establishing an emissions inventory of rainbow trout (Papatryphon et al., 2004). The N, P and solids emissions was calculated based on the difference between the amount of nutrients provided to trout and the amount assimilated as fish weight-gain. Solid and dissolved fractions of emitted N and P was calculated based on digestibility of the nutrients, fish body-composition, and the non-ingested part of the provided feed (estimated at 5% based on the expert opinion). The nutrients release and theoretical oxygen demand (calculated using the chemical oxygen demand of protein, carbohydrates, lipids, ash and fiber emitted) per ton of trout is shown in section of the results.

2.3.3. Life cycle impact assessment (LCIA)

It is impossible to evaluate and compare the emissions from each the inputs without categorizing the emissions. So, the results from LCI were categorized in the different environmental impact categories (ISO 14040, 2006). There are different methods to define the environmental impact categories. In this study, CML2 baseline 2000 was considered for categorizing. Ten impact categories based on CML2 baseline 2000 include Abiotic Depletion (AD), Acidification (AC), Global Warming (GW), Eutrophication (EU), Ozone Layer Depletion (OLD), Human Toxicity (HT), Freshwater Aquatic Ecotoxicity (FAE), Marine Aquatic Ecotoxicity (MAE), Terrestrial Ecotoxicity (TE) and Photochemical Oxidation (PhO). (Anonymous, 2003). These categories have different units and it is impossible to compare them to each other. Therefore, normalization was used to make the categories non-dimensional (Mousavi-Avval et al., 2017). For this purpose, SimaPro software which has the coefficients for normalization was used.

2.3.4. Interpretation of the results

In interpretation phase, the results obtained from the preceding phases of the LCA are interpreted. Normalization and weighting are optional steps used to solve the incompatibility of units and to simplify the interpretation of the results. Normalization allows to better understanding the contributions of impact categories to the global environmental effects. Therefore, in order to development a relationship between normalization and weighting, Environmental Emissions Final Score (EEFS) was introduced as following eq. 5 (Brentrup et al., 2004):

$$EEFS = \sum N_i \times W_i \tag{5}$$

where N_i stands for the normalized amount of each category and W_i is the weight of the normalized amounts of each category. The coefficients for weighting were taken from Simapro software V.8.0.3.

2.4. Data envelopment analysis

According to Table 3, the amounts of inputs and output in trout farms were different from each other in the both regions and a high standard deviation was observed. This means that there are high potential to improve the inputs, increase the energy efficiency and reduce the environmental impacts by using combination of LCA and DEA. Generally, DEA is a data mining method to estimate productivity of the inputs and rank the production units based on their performance. In DEA, each production unit is known as a decision making

Table 5
Actual, improved and saved (%) energy use in trout farms based on VRS model.

Items	Actual energy average		Improved energy average		ESTR (%)*	
	Ardal	Lordegan	Ardal	Lordegan	Ardal	Lordegan
A. Input energy (MJ ton^{-1})	60,483.50	77,183.63	42,769.71	69,777.69	29.28	9.59
1. Fry	1184.59	1,441.23	894.76	1,194.15	24.46	17.14
2. Electricity	10,596.47	12,108.5	5,598.54	1,145.31	47.16	7.95
3. Diesel fuel	936.18	2,761.4	527.03	2174.42	43.70	21.25
4. Water	8.99	30.32	6.13	24.44	31.78	19.37
5. Natural gas	1,363.51	1,298.77	819.81	1,145.31	39.87	13.39
6. Transportation	16.05	11.57	10.44	9.95	34.92	13.97
7. Human labor	395.04	378.70	309.99	350.03	21.52	7.57
8. Feed	45,982.60	59,177.03	34,602.95	53,754.47	24.74	9.12
8.1. Fish meal	14,695.40	26,886.20	11,058.61	24,410.65	–	–
8.2. Fish oil	13,985.40	1,9564.6	10,524.35	17,779.08	–	–
8.3. Wheat gluten	3,544.33	2,776.64	2667.19	2,523.23	–	–
8.4. Corn gluten	3,206.26	2,616.44	2412.78	2,377.61	–	–
8.5. Rapeseed meal	4,089.62	2,669.84	3077.53	2,426.18	–	–
8.6. Soybean meal	4,771.22	3,559.79	3590.45	3,234.91	–	–
8.7. Beans powder	1624.94	1060.81	1222.80	964.00	–	–
8.8. Sweet sorghum	65.43	42.71	49.24	38.81	–	–
B. Output energy (MJha^{-1})	5,776,149.8	4,315,399.1	–	–	–	–
C. Energy indices						
1. Energy productivity (ton MJ^{-1})	19.72E-06	16.40 E-06	23.38E-06	18.20 E-06	18.56	10.61
2. Specific Energy (MJ ton^{-1})	5,0721.71	60,749.66	4,2769.71	5,4920.59	−15.67	−9.59

* ESTR (Energy Saving Target Ratio) = $\left(\frac{\textit{Actual energy value} - \textit{Improved energy value}}{\textit{Actual energy value}}\right)$.

unit (DMU). The distance between each DMU and the production frontier refers to this fact that there is the possibility for improvement of energy efficiency in that DMU. In Fig. 4, A, B, and C are shown as the efficient frontiers, whereas D, E, F and their combinations are inefficient (Stokes et al., 2007).

In DEA model, an inefficient DMU can become efficient through reducing the quantities of the inputs without a reduction in the output (input-based model), or through increase in the quantity of output while the quantities of the inputs is kept the same as before (output-based model) (Mousavi-Avval et al., 2011a). Considering that the quantities of the inputs are controlled by trout producers and different factors affecting the output, input-based model was selected for this study. DEA based on constant returns to scale (CRS) and variable returns to scale (VRS) models is expressed by technical efficiency (TEf), pure technical efficiency (PTE) and scale efficiency (SEf).

2.4.1. Technical efficiency

Technical efficiency (TEf) is defined as the ratio between the sum of weighted outputs to the sum of weighted inputs that is shown in Eq. (6). The value of TEf varies between zero and one in which the value of one represents that the DMU is a best performer located on the production frontier and has no potential for improvement. A TEf value less than one means that DMU is inefficient (Mousavi-Avval et al., 2011b).

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \ldots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \ldots + v_m x_{mj}} = \frac{\sum_{r=1}^{s} (u_{rk} y_{rk})}{\sum_{i=1}^{m} (v_{ik} x_{ik})} \tag{6}$$

where k is the DMU being evaluated in the set of $j = 1, 2, \ldots, n$; x is the amount of input; y is the output; m and n represent the number of inputs and outputs produced by the DMUs, respectively; u_{rk} and v_{ik} are the matrix of weights assigned to outputs and inputs, respectively. Charnes, Cooper & Rhodes introduced a linear program (Eq. (7)) to solve Eq. (6) (Charnes et al., 1978):

$$\text{Maximize } \theta = \sum_{r=1}^{n} u_{rk} y_{rk} \tag{7}$$

Subject to:

$$\frac{\sum_{r=1}^{s} (u_{rk} y_{rk})}{\sum_{i=1}^{m} (v_{ik} x_{ik})} \le 1; j = 1, \ldots., n u_{rk}, y_{rk} \ge 0; r = 1, \ldots, s; i = 1, \ldots, m \tag{8}$$

where θ is the TEf and i represents ith DMU (it will be fixed in Eq. (6); while j increases in Eq. (8)). The above model is known as the CRS model which is a linear programming model. This model assumes that there is no significant relationship between the scale of production units and efficiency (Avkiran, 2001). Therefore, the large units are considered as efficient as small ones in converting inputs to output.

2.4.2. Pure technical efficiency

When variable returns to scale (VRS) model introduced by Banker, Charnes & Cooper is used, PTE is considered to score and rank DMUs (Banker et al., 1984). In other words, PTE is TEf which is affected by the variation in scale efficiency. PTE compares efficient and inefficient DMUs in the same environment and geographical conditions and it is its advantage in comparison with TEf (Barnes, 2006). This model is calculated on the basis of the following equation (Mohammadi et al., 2013):

$$\text{Max } z = u y_j - u_j \tag{9}$$

Subject to:

$$\begin{array}{l} vX_i = 1; -vX + uY - u_0 e \le 0 \\ v \ge 0, u \ge 0 \text{ and } u_0 \text{ is unconstrained in sign} \end{array} \tag{10}$$

where z and u_0 are scalar and free in sign. u and 'v' are output and input weight matrixes, and Y and X are corresponding output and input matrixes, respectively. The letters x_i and y_j refer to the inputs and output of j^{th} DMU.

2.4.3. Scale efficiency

The small size of trout farms and improper use of the inputs could be considered as the main reasons for inefficiency of DMUs. CRS model calculates TEf and SEf while VRS model only considers PTE. In this study, first, the values for TEf and PTE were calculated for CRS and VRS models, respectively. Then, SEf was calculated using the following equation (Chauhan et al., 2006):

$$\text{SEf} = \frac{\text{TE}}{\text{PTE}} \tag{11}$$

Moreover, PTE is desired efficiency and SEf is the ratio between actual efficiency and desired efficiency. TEf is a combination of both SEf and PTE. In brief, it can be said that SEf is the ratio between the efficiency in CRS and VRS models.

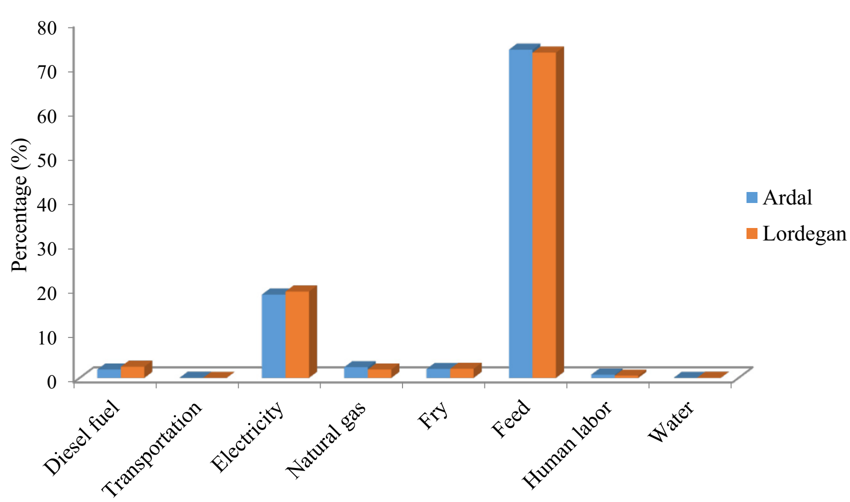

Fig. 5. Share of the inputs within the total energy inputs in the studied regions.

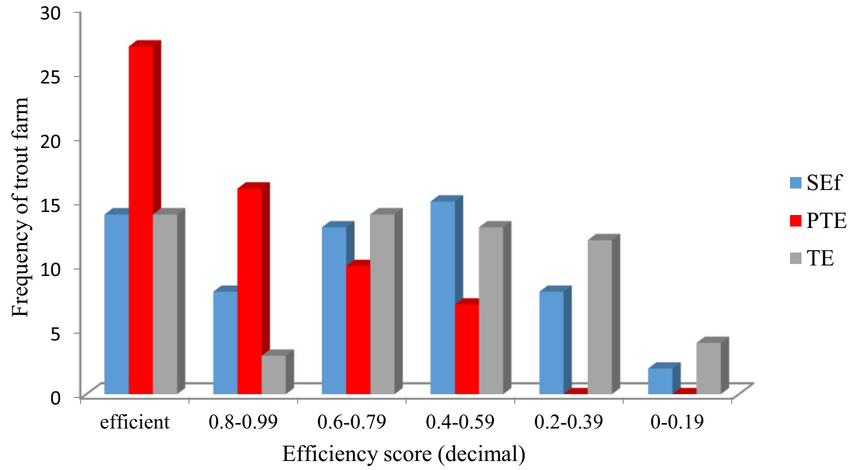

Fig. 6. Distribution of trout farms based on the efficiency score in Ardal region.

In order to detect the most efficient DMUs, they should be ranked according to their importance based on the efficient frontier. The benchmark ranking method as the most common technique in DEA studies was used in the present study. The number of times each efficient DMU is observed in a referent set given by software show how similar the efficient DMUs are in comparison with inefficient DMUs. Efficient DMUs that appear more frequently in the referent set are considered superior and achieve a higher rank (Khoshnevisan et al., 2014b).

2.5. LCA + DEA

In this study, the aim is to improve the inputs to conserve the energy resources and reduce the environmental burdens of trout farms without a significant reduction in the output. To achieve this goal, first, the data was stored into Excel spreadsheets. EMS V1.3 software was used to compute the improvements potential for each input. Hence, the PTE was calculated for each DMU, and all DMUs were benchmarked based on the Eq. (9). Then, SimaPro software was used to evaluate the environmental burdens of the trout farms based on both the actual data and the data modified by DEA (According to Fig. 2). Finally, efficient and inefficient DMUs were specified and the quantities of the input energies and the environmental burdens of the two regions were calculated based on both the actual data and the data modified by DEA.

3. Results and discussions

3.1. Input-output energy analysis

It is necessary in trout farms to know about the importance of each factor in the production process and their influence on the output. Although, there are many unpredictable natural and climate factors affecting the production process and the output, but, the factors like the quantities of the inputs could be controlled by the producers and their quantities could be decided based on their influence on the performance.

The average of the input energies needed for producing one ton of trout in a 8 to 10 months breeding period are brought in Table 5. It should be mentioned that the size of the farms was less than a hectare and differences between the farms size seemed to be negligible. Therefore, it was decided to consider a ton as the FU for calculations. According to Table 5, the total energy inputs in Ardal and Lordegan regions were obtained as 60,438.50 MJ ton^{-1} and 77,183.63 MJ ton^{-1}, respectively. In a previous study, Bozoglu and Ceyhan (2009) reported the total energy use per cubic meter was 46.57 MJ in Turkey's trout farms.

To compare the two regions from an energy efficiency point of view, the energy indices were used. The ER and EPr in Ardal region calculated as 0.40 and 19.72E-06 ton MJ^{-1}, while in Lordegan region,

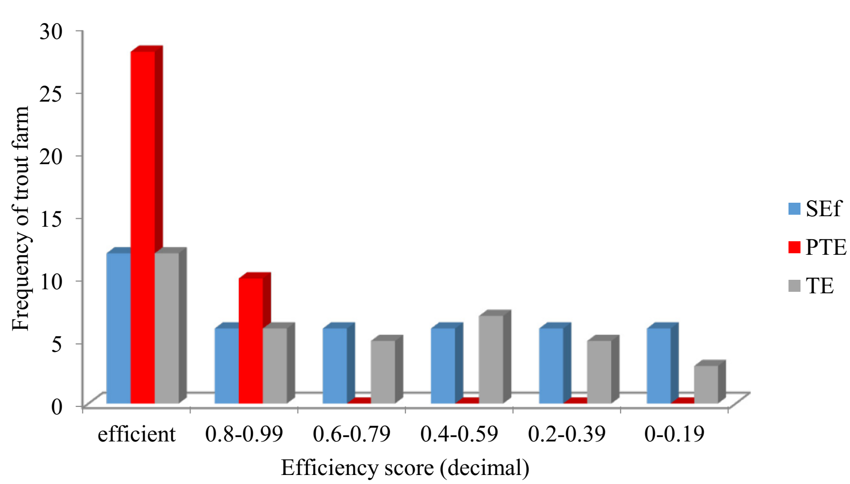

Fig. 7. Distribution of trout farms based on the efficiency score in Lordegan region.

Table 6
Average of efficiency items for trout farms in the studied regions.

Items	Technical efficiency		Pure technical efficiency		Scale efficiency	
	Ardal	Lordegan	Ardal	Lordegan	Ardal	Lordegan
Average	0.59	0.69	0.86	0.98	0.66	0.70
Standard deviation	0.28	0.1	0.16	0.04	0.24	0.29
Minimum	0.07	0.29	0.45	0.84	0.16	0.10
Maximum	1	1	1	1	1	1

the ER and EPr were obtained as 0.33 and 16.40E-06 ton MJ^{-1}, respectively. These indices showed that the energy consumption in Ardal region was more efficient. The SE in Ardal region was 50,721.48 MJ ton^{-1}, while in Lordegan region, the SE was obtained as 60,749.57 MJ ton^{-1}. According to the results, it is clear that Lordegan region needs more attention to improve the total energy needed for trout production. The main reason for difference between the energy consumption results between two studied regions could be attributed to the quantities and the shares of feed consumption. To produce 1 ton trout in Ardal and Lordegan regions, 2727 and 3560 kg of feed were consumed, respectively.

Fig. 5 shows the shares of the inputs from the total energy inputs in the studied regions. The share of feed in both region was about 74% of the total energy inputs. In both regions, feed consisted of fish meal, fish oil, rapeseed meal, wheat gluten, soybean meal, corn gluten, sweet sorghum and bean powders. Fish meal and fish oil as animal sources had the highest share among the feed ingredients in both regions as 63% for Ardal region and 79% for Lordegan region. Therefore, further researches to materialize the use of alternative sources of protein are necessary to replace the standard fishmeal-based feed. This is in agreement with the results of Bozoglu and Ceyhan (2009) who reported that the budget of energy for trout farms strongly depends on the share of consumed feed. Also, electricity had the secondary share of the total energy inputs in both regions with about 19%. The high share of electricity used in trout farms in both regions could be attributed to inefficient aeration systems, worn electro pumps and lack of the producers awareness of the required flow and volume of water. So, it is suggested that worn and old aeration systems and electro pumps be checked and inspected.

3.2. DEA for improving the energy inputs

In DEA, DMU being efficient or inefficient depends on the ratio between the output and the inputs compared to other DMUs. As it is shown in Fig. 6, 27 of 60 DMUs in Ardal region were identified as efficient (PTE value as 1) based on VRS model. Also, based on CRS model, 14 of 60 DMUs were recognized as efficient with TEf and SEf as 1. All 14 efficient DMUs in CRS model are efficient in VRS model, and that is the reason behind the same number of efficient DMUs in TE and SEf. It should be mentioned that 13 DMUs difference between TEf and PTE could be attributed to inappropriate production scale. Also, it worth to mention that TEf scores of 46 DMUs and PTE scores of 33 DMUs were in the range of 0.4 to 0.99.

According to Fig. 7, 28 of 38 DMUs in Lordegan region had PTE score as 1, and 12 DMUs had full TEf and SEf scores. 26 and 10 DMUs had efficiency scores in the ranges of 0.4 to 0.99 for TEf and PTE, respectively. It should be noticed that full PTE score doesn't assure full TEf score.

The average and standard deviation of TEf, PTE and SEf of the DMUs (trout farms) in the two regions are shown in Table 6. The average scores of PTE, TEf and SEf for DMUs in Ardal regions were 0.86, 0.59 and 0.66, respectively. In Lordegan region, the average scores of PTE, TEf and SEf for DMUs were calculated as 0.98, 0.69 and 0.70, respectively. As it can be seen from Table 6, the maximum and minimum scores for TEf, PTE and SEf were calculated. The standard deviation of TEf is higher than PTE which indicates that trout producers have less awareness of the appropriate breeding methods and the optimal amounts of the inputs. In other words, it indicated that the breeders used the energy inputs more that the optimal amounts or applied in an improper time. The scores of SEf in Ardal (0.66) and Lordegan (0.70) regions revealed that the inefficient DMUs in Ardal and Lordegan regions could increase their efficiency by following the suggestions which result in optimal scale efficiency, up to 24 and 20%, respectively. Abedi et al. (2011) conducted a study to optimize the efficiency of trout farms in Fars province, Iran and reported the average of TE, PTE and SEf as 0.93, 0.97 and 0.95, respectively.

The required energy inputs in the optimal condition, the percentage of the saved energy for each input, the energy indices in the optimal condition and the percentage of changes for the energy indices are shown in Table 5. As it can be seen from Table 4, the total required energy inputs in the optimal condition in Ardal and Lordegan regions were obtained as 42,769.71 MJ ton^{-1} (29.28% saved energy) and 69,777.69 MJ ton^{-1} (9.59% saved energy), respectively. It was revealed that DMUs in Ardal region had higher potential to save energy compared to Lordegan region. In Ardal region, electricity (47.16%) and diesel fuel (43.70%) had highest shares of the saved energy, while in Lordegan region, diesel fuel (21.25%) and water (19.35%) showed the highest potential for saving energy. According to Table 4, the EPr in Ardal region after improving the energy inputs increased from 19.72E-06 to 23.38E-06 ton MJ^{-1} (18.56% increase), while in Lordegan region, the EPr increased from 16.40E-06 to 18.20E-06 ton MJ^{-1} (10.61% increase). In other studies that DEA used to improve the energy inputs of crops in Iran, an increase in the EPr was reported for alfalfa from 120.00E-06 to 130.00E-06 (10.6%) (Ghasemi Mobtaker et al., 2012), for kiwi from 800.04E-06 to 920.00E-06 (13.86% increase) (Mohammadi et al., 2011) and for orange from 970.00E-06 to 1110.00E-06 (14.4% increase)

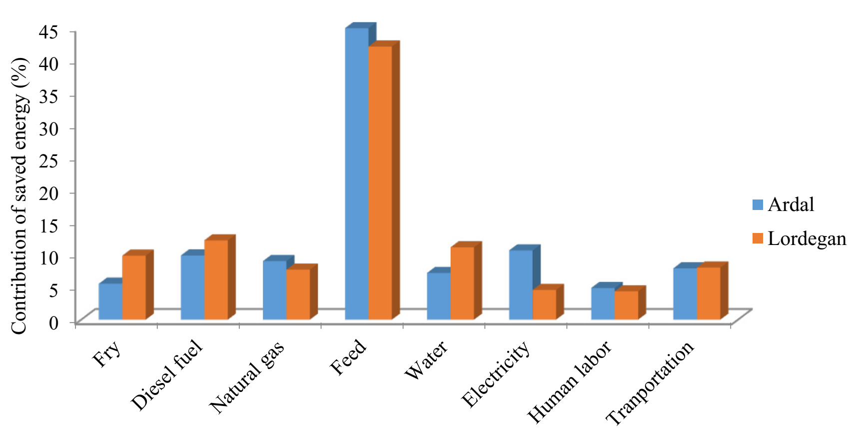

Fig. 8. Contribution of the inputs of the total saved energy in rainbow trout farms in the studied regions.

(Nabavi-Pelesaraei et al., 2014). As it is shown in Fig. 8, in both regions, fish feed had the highest share of the total saved energy with 44.85% (Ardal region) and 42.03% (Lordegan region). The suggestions for improving feed were provided in the previous section.

As it was discussed in the previous section, benchmark ranking method is a valuable method to detect the most appropriate DMUs in the group. The ranking of the 60 DMUs in Ardal region and 38 DMUs in Lordegan region are presented in Table 7 and Table 8. As it is shown in Table 7, the DMU 3 with 19 repetitions (see Table 7; Frequency in referent set) was obtained as the top ranking in Ardal region. It means that this unit in addition to being efficient, is close to input–output levels of the most inefficient units in the group and it was followed by DMU 41 and DMU 57 with 18 and 14 repetitions, respectively. The most important conclusion that can be taken from these results is that, inefficient DMUs can improve their energy use efficiency by following the best practices of the efficient DMUs. It means an inefficient DMU can be efficient by following the some efficient DMUs instead of using a single DMU as a benchmark. For example, DMU 48 as an inefficient unit that had the lowest PTE with 0.45 should follow the practices of DMU 15, 21 and 29 as composite DMU which means that DMU 48 is close to the efficient frontier formed by these efficient DMUs.

As it is shown in Table 8, the DMU 5 with 6 repetitions was obtained as the top ranking in Lordegan region. To clarify benchmarking, consider DMU 16 with PTE calculated as 0.935. To improve efficiency score of DMU 16, it should be changed according to a composite DMU. The composite DMU that represents the best practice is formed by the combination of DMU 5, DMU 7 and DMU 20. The number in the parentheses known as intensity vector indicate that the inputs and output of inefficient DMU 16 is closer to DMU 7 compared to other two farms (DMU 5 and 20). Using intensity vectors and composite DMU, the optimum amount of energy for DMU 16 can be worked out.

Table 7
The source wise actual and optimum energy total for most efficient and inefficient producers in the Ardal region (based on VRS model).

DMU	PTE	Most frequency in referent set	Benchmarks	Actual energy total (MJ ton^{-1})	Optimum energy total (MJ ton^{-1})	ESTR (%)*
A. truly most efficient producers						
3	1	19	–	39,760.41	39,760.41	0
41	1	18	–	32,620.31	32,620.31	0
57	1	14	–	25,054.37	25,054.37	0
40	1	13	–	46,344.37	46,344.37	0
2	1	9	–	52,980.45	52,980.45	0
28	1	7	–	33,713.74	33,713.74	0
12	1	6	–	39,749.13	39,749.13	0
38	1	5	–	38,177.68	38,177.68	0
15	1	5	–	37,694.85	37,694.85	0
17	1	4	–	34,063.33	34,063.33	0
Average of efficient producers	1	–	–	38,015.86	38,015.86	0
B. Inefficient producers						
6	0.574	–	3(0.07)- 12(0.10)- 28(0.59)- 57(0.24)	58,817.89	32,702.17	44.40
8	0.730	–	3(1.00)	32,585.10	39,759.19	36.47
11	0.884	–	3(0.15)- 12(0.33)- 28(0.16)- 38(0.36)	59,097.25	38,210.79	35.34
14	0.904	–	3(0.06)- 13(0.29)- 41(0.05)	61,350.19	45,431.28	25.94
16	0.571	–	1(0.08)- 12(0.53)- 28(0.025)- 57(0.13)	81,506.62	38,683.19	52.53
18	0.750	–	12(0.69)- 28(0.31)	58,224.49	38,887.70	34.96
19	0.622	–	3(0.39)- 4(0.19)- 28(0.01)- 57(0.41)	56,467.93	34,393.79	39.09
20	0.913	–	2(0.10)- 17(0.13)- 28(0.66)- 30(0.02)- 57(0.09)	41,907.17	34,878.47	16.77
22	0.914	–	2(0.15)- 12(0.16)- 38(0.46)- 57(0.23)	58,067.46	37,597.14	35.25
23	0.738	–	3(0.55)- 5(0.04)- 41(0.41)	92,435.56	37,753.07	59.15
24	0.950	–	2(0.04)- 3(0.22)- 15(0.61)- 41(0.13)	45,430.78	38,093.87	16.14
25	0.546	–	2(0.17)- 15(0.06)- 40(0.10)- 41(0.13)- 57(0.53)	64,496.09	33,801.44	47.59
26	0.464	–	3(0.68)- 40(0.30)- 41(0.01)	116,069.40	41,637.82	64.12
27	0.809	–	15(0.09)- 40(0.20)- 41(0.17)- 57(0.44)	44,731.96	33,073.14	26.06
31	0.732	–	3(0.33)- 37(0.42)- 40(0.17)- 41(0.08)	57,266.8	41,433.24	27.64
33	0.880	–	12(0.22)- 41(0.73)- 57(0.05)	48,308.71	33,782.82	30.06
34	0.810	–	3(0.37)- 5(0.60)- 41(0.03)	92,535.66	53,203.7	42.50
35	0.823	–	3(0.94)- 5(0.02)- 41(0.04)	66,400.48	40,005.09	39.75
36	0.994	–	1(0.02)- 2(0.43)- 41(0.55)	45,499.9	42,256.11	7.12
39	0.914	–	3(0.13)- 30(0.04)- 38(0.32)- 40(0.33)- 41(0.10)- 57 (0.09)	42,994.11	39,185.84	8.85
42	0.773	–	3(0.03)- 28(0.02)- 38(0.14)- 57(0.81)	35,779.05	27,530.46	23.05
45	0.872	–	37(0.42)- 40(0.22)- 41(0.36)	46,078.66	39,814.05	13.59
46	0.629	–	3(0.05)- 40(0.19)- 41(0.76)	90,328.73	35,670.75	60.51
47	0.983	–	1(0.01)- 2(0.08)- 40(0.64)- 41(0.29)	45,038.59	42,970.34	4.59
48	0.450	–	15(0.21)- 21(0.15)- 29(0.64)	137,034.00	39,103.91	71.47
49	0.451	–	15(0.32)- 29(0.68)	157,714.20	22,697.02	85.60
50	0.503	–	3(0.11)- 40(0.65)- 41(0.24)	134,281.50	42,321.41	68.48
51	0.915	–	3(0.15)- 5(0.72)- 41(0.13)	106,533.8	55,235.32	48.15
52	0.780	–	3(0.25)- 40(0.31)- 41(0.44)	87,502.99	39,629.93	55.85
53	0.885	–	17(0.19)- 40(0.34)- 57(0.48)	68,917.63	33,910.06	50.79
54	0.752	–	2(0.26)- 17(0.04)- 40(0.22)- 57(0.48)	54,008.86	37,296.69	30.94
56	0.784	–	2(0.18)- 3(0.34)- 17(0.04)- 57(0.44)	45,890.22	35,392.48	22.87
58	0.859	–	38(0.09)- 57(0.91)	41,157.18	26,201.24	36.33
59	0.857	–	2(0.05)- 3(0.23)- 40(0.72)	54,028.24	45,147.25	16.43
Average of Inefficient producers	0.765	–	–	68,484.92	38,167.38	44.26

$$ESTR = \left(\frac{Actual\ energy\ value - Improved\ energy\ value}{Actual\ energy\ value}\right)$$

Table 8
The source wise actual and optimum energy total for most efficient and inefficient producers in the Lordegan region (based on VRS model).

DMU	PTE	Most frequency in referent set	Benchmarks	Actual energy total (MJ ton^{-1})	Optimum energy total (MJ ton^{-1})	ESTR (%)*
A. truly most efficient producers						
5	1	6	–	50,916.93	50,916.93	0
14	1	5	–	120,935.10	120,935.10	0
26	1	5	–	94,216.31	76,166.01	0
36	1	5	–	48,194.38	48,194.38	0
1	1	4	–	47,649.48	47,649.48	0
7	1	4	–	45,624.76	45,624.76	0
2	1	3	–	48,217.61	48,217.61	0
18	1	2	–	53,947.56	53,947.56	0
Average of efficient producers	1	–	–	63,712,70	63,712,70	0
B. Inefficient producers						
6	0.932	–	1(0.40)- 5(0.57)- 26(0.01)- 36(0.01)	58,503.25	51,233.58	12.42
11	0.9819	–	1(0. 56)- 2(0.24)- 5(0.08)- 14(0.12)	60,623.76	58,768.24	3.06
13	0.9724	–	5(0.77)- 9(0.05)- 12(0.02)- 14(0.16)	59,730.94	55,991.23	6.26
15	0.982	–	5(0.08)- 9(0.31)- 14(0.33)- 26(0.14)- 29 (0.14)	104,786.40	82,899.05	20.88
16	0.935	–	5(0.22)- 7(0.69)- 20(0.09)	61,372.38	48,572.89	20.85
17	0.850	–	2(0.10)- 14(0.14)- 26(0.41)- 36(0.35)	69,933.55	58,188.69	16.79
19	0.894	–	1(0.03)- 7(0.02)- 20(0.31)-36(0.47)- 38(0.16)	50,841.98	44,433.39	12.60
22	0.951	–	1(0.28)- 5(0.40)- 7(0.18)- 18(0.06)- 36(0.08)	52,020.50	48,565.09	6.64
23	0.841	–	2(0.14)- 8(0.01)- 18(0.02)- 26(0.13)- 36(0.71)	56,058.04	46,024.37	17.89
25	0.982	–	3(0.01)- 7(0.06)- 14(0.84)- 26(0.08)	116,056.20	96,202.24	17.10
Average of Inefficient producers		–	–	68,992.70	59,087.88	13.44

$$ESTR = \left(\frac{Actual\ energy\ value - Improved\ energy\ value}{Actual\ energy\ value}\right)$$

The PTE, actual and optimum amount of required energy from different energy sources, for most efficient and inefficient units in Ardal and Lordegan regions are shown in Tables 7 and 8, respectively. Using the obtained information, it is possible to help a producer by providing suggestions regarding the better operating practices by following his target energy requirement from different inputs to reduce the input energy levels to the target values without reduction in its output. So, dissemination of these results would be helpful to improve efficiency in rainbow trout farms in the surveyed regions. For example, in the last column of Table 7, the Energy Saving Target Ratio (ESTR) percentage for 33 inefficient farms in Ardal region are presented. As it can be seen, for inefficient DMUs, ESTR was varied in the range between 4.59% (DMU 47) to 85.60% (DMU 49), with the average of 44.26% that indicate between inefficient DMUs, DMU 47 was the best, and DMU 49 was the most inefficient unit.

3.3. LCA results

The contributions of the inputs to each impact category for trout production in the regions are shown in Figs. 9 and 10. The emissions from electricity generation in power plants had a contribution of 29% on the MAE in both regions. In Ardal region, the fish meal had the share of 75%, 72%, 72%, 63% and 42% on the AD, AC, GW, Pho and EP, respectively, while in Lordegan region, the fish meal had the share of 82%, 81%, 78%, 44% and 55% on the AD, AC, GW, Pho and EP, respectively. Also, fish oil in Ardal region had a contribution of 73%, 62% and 60%, on the HT, FAE

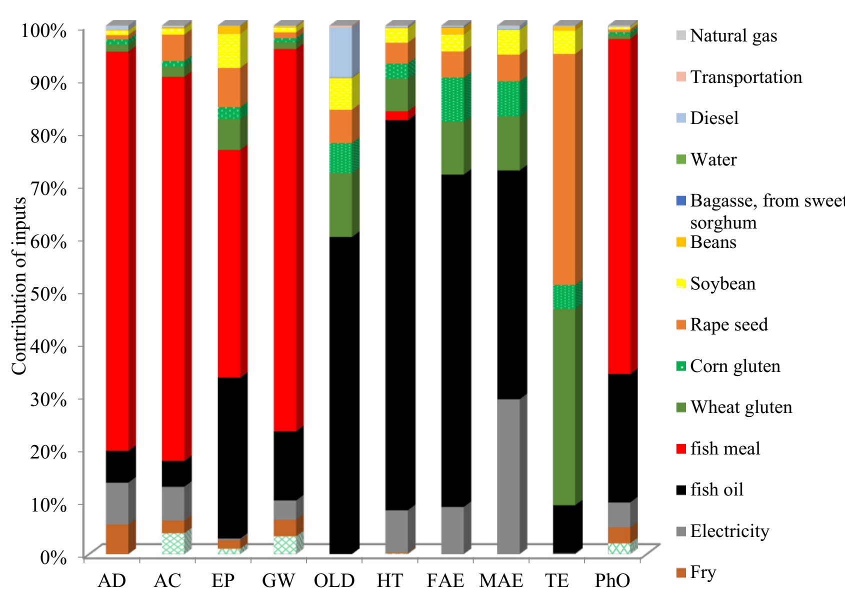

Fig. 9. Contribution of the inputs in environmental impact categories of trout farms in Ardal region.

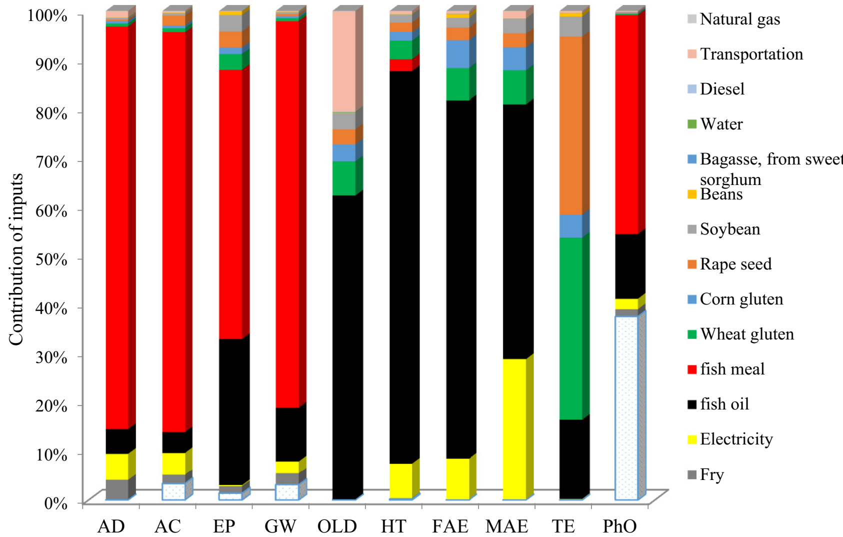

Fig. 10. Contribution of the inputs in environmental impact categories of trout farms in Lordegan region.

and OLD, respectively, while in Lordegan region, fish oil had the share of 80, 73% and 62% on the HT, FAE and OLD, respectively. Also, in Ardal region, wheat gluten and rapeseed meal had the share of 37% and 43% of total contribution to TE, respectively, while in Lordegan region, these two inputs had the share of 16% and 36% of total contribution to TE, respectively. Finally, In Lordegan region, the direct emissions from feed consumption, diesel fuel, natural gas and labor had the share of 24% of total contribution to PhO.

Considering that about 7 million tons fish meal and 1 million tons fish oil are produced per year (International fish meal and fish oil organization (FAO, 2006)), the increase in production of aquaculture products makes an important challenge for diversification of protein and lipid sources. Using feeds containing high levels of wild-fish protein in raising carnivorous fish is greatly under debate in aquaculture, particularly when it comes to comparison of fish farming with commercial fishing (Ellingsen and Aanondsen, 2006). In a study conducted in Greece, it was reported that feed in trout farms had 73% and 68% of total contribution to GW and AC, respectively (Aubin et al., 2009). Researches focused on identifying plant-based alternatives to fish meal and oil (FAO, 2006), and there is optimistic outlook to find high-quality inputs to replace them. The use of fish by-products as a complementary the nutritional inputs to plant-based diets seems an interesting way. In this way, dependence on the stocks which are needed for producing fish meal and the environmental burdens associated with the fish feed can be decreased (Papatryphon et al., 2004). However, the availability of these by-products is a problem and they are available only in certain markets, which does not make them a global solution. Considering that most of electricity in Iran is generated from fossil fuels and has a significant emissions, it is clear that using more efficient electro pumps and awareness about the amount of water needed in the different production phases would cause a considerable reduction in the environmental burdens.

The values of characterization, normalization and weighting of the impact categories for a ton produced trout in the regions are shown in Table 9. These values consist of the direct (the emission during trout production) and indirect emissions (the inputs production). The GW as the most important category in Ardal and Lordegan region were calculated as 617.61 and 1379.89 kg CO_2 per ton of trout, respectively. The main reason for this difference is higher direct emissions in Lordegan region. In similar studies, the value of GW per a ton of trout produced in Germany, Greece and Canada were reported as 2239 kg CO_2 (Samuel-Fitwi et al., 2013), 2753 kg CO_2 (Aubin et al., 2009) and 2073 kg CO_2 (Ayer and Tyedmers, 2009), respectively. Samuel-Fitwi et al. (2013) conducted a LCA study to evaluate different production systems including extensive, intensive and recirculating aquaculture systems in rainbow trout production and reported that recirculating aquaculture systems had the largest impact on GW and AC, while its impact on EP was the lowest compared to two other systems. Also, the emissions from feed production had the highest contribution to the GW as 96% and 46% in extensive and intensive system, respectively, while, their contributions to AC were 97% and 73%, respectively. In another study in Canada, LCA approach was used to quantify and compare the potential environmental impacts of culturing salmonids in a conventional marine net-pen system with those of three reportedly environmentally-friendly alternatives; a marine floating bag system; a land-based saltwater flow through system; and a land-based freshwater recirculating

Table 9
The values of characterization, normalization and weighting of the impact categories per ton of trout in the studied regions.

Impact categories	Units	Characterization (units)		Normalization		Weighting (pPt)	
		Ardal	Lordegan	Ardal	Lordegan	Ardal	Lordegan
AD	kg Sb $_{eq.}$	2.342	5.643	1.417E-09	3.183E-09	141.784	317.968
AC	kg $SO_{2\ eq.}$	3.348	7.856	5.186E-09	1.135E-08	518.683	1127.58
EU	kg $PO^{-3}{}_{4\ eq.}$	0. 954	1.183	1.904E-09	3.649E-09	190.481	364.369
GW	kg $CO_{2\ eq.}$	617.61	1379.898	2.443E-09	5.463E-09	244.394	546.473
OLD	kg CFC11 $_{eq.}$	5.12 E-06	9.25 E-06	5.222E-12	9.433E-12	0.522	0.943
HT	kg 1,4-DB $_{eq.}$	77.660	134.600	4.137E-10	7.136E-10	41.370	71.288
FAE	kg 1,4-DB $_{eq.}$	24.680	39.891	3.301E-9	5.315E-09	108.964	175.208
MAE	kg 1,4-DB $_{eq.}$	27,660.551	43,030.852	8.686E-9	1.351E-08	286.645	445.882
TE	kg 1,4-DB $_{eq.}$	1.404	1.709	1.139E-9	1.204E-09	37.594	39.540
PhO	kg $C_2H_{4\ eq.}$	0.205	0.714	1.134E-9	3.932E-09	113.439	393.052
Total weighting (EES)						1683.882	3484.310

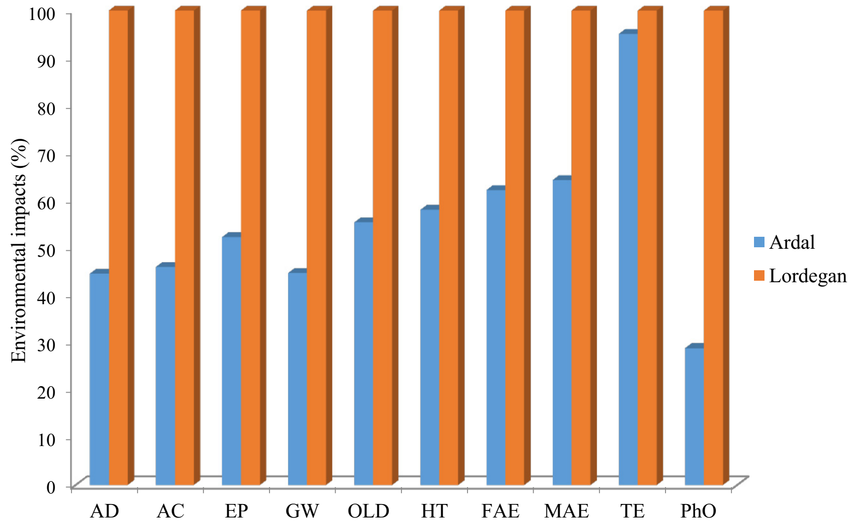

Fig. 11. The comparative normalization results of trout farms in the studied regions.

system. Their results showed that while the use of these closed-containment systems may reduce the local ecological impacts typically associated with net-pen salmon farming, the increase in material and energy demands may result in a significantly increase in several environmental impacts of global concern, including GW, AD and AC (Ayer and Tyedmers, 2009).

The normalization values were calculated by SimaPro software which contains the special coefficients for each category. The normalization values of MAE, AC and FAE were higher than other impact categories. The all normalized impact categories related to Lordegan region were higher in comparison with Ardal region (Fig. 11). More uses of the inputs are the main reason for this difference between the regions.

In the final section of the environmental impacts analysis, EEFS was calculated by summing up the values of the weighting column. The EEFS values for a ton of trout produced in Ardal and Lordegan regions were calculated as 1683.88 PPt and 3484.31 PPt, respectively. As it was expected, fish meal had the highest contribution to EEFS in Ardal and Lordegan regions with 48% and 57%, respectively.

The direct emissions for a ton of trout are presented in Table 10. The direct emissions from diesel fuel, natural gas and human labor were calculated based on Table 4. The direct emissions from the feed were estimated using nutrient-balance modeling (Cho and Kaushik, 1990). As it can be seen from Table 10, diesel fuel had the highest contribution to the direct emissions into air. Fish feed, although, had no direct emissions into air but was the only input that had the direct emissions to water.

3.4. LCA + DEA results

Based on the PTE scores for the inefficient DMUs calculated by EMS software, the improved inputs was obtained and new LCA analysis conducted with the new modified LCI. The ten impact categories computed through SimaPro software based on the optimal condition and compared to the impact categories computed based on the actual data (Table 11). According to the LCA + DEA results, in Ardal region, despite the lower environmental impacts, there were more potential to reduce the environmental impacts compared to Lordegan region. Also, there were more potential to reduce the energy inputs in Ardal region compared to Lordegan region. The optimal uses of the inputs in Ardal region had the highest potential to reduction of AD and TE as 45.47% and 44.14%, while in Lordegan region, the results showed that TE had the highest reduction potential as 38.49%. The LCA + DEA results showed that improvements of fish meal and wheat gluten had the highest contribution to AD and TE, respectively. Moreover, based on LCA + DEA, GW was reduced as 26.43% (454.36 kg CO_2 eq per ton of trout) in Ardal region, while in Lordegan region, the reduction of GW was calculated as 8.78% (1258.65 kg CO_2 eq. per ton of trout). Finally, the LCA

Table 10
Direct emissions from diesel combustion, natural gas, human labor and feed consumption for 1 ton trout fish.

Direct emissions (kg ton^{-1})	Diesel fuel		Natural gas		Human labor		Feed consumption	
	Ardal	Lordegan	Ardal	Lordegan	Ardal	Lordegan	Ardal	Lordegan
A. Emissions to air								
1. Carbon dioxide	690.745	2050.724	31.316	42.967	15.11E-03	13.63E-03	–	–
2. Sulfur dioxide	22.56E-03	66.54E-03	1.56E-03	2.14E-03	–	–	–	–
3.Methane	28.83E-03	85.05E-03	6.07E-03	8.32E-03	–	–	–	–
4. Dinitrogen monoxide	26.77E-03	78.97E-03	5.82E-03	7.79E-03	–	–	–	–
5.Ammonia	44. 6E-04	10.37E-03	–	–	–	–	–	–
6. Hydrocarbons	73.00 E-05	21.67E-04	–	–	–	–	–	–
7. Nitrogen oxides	99.23E-01	29.27 E-00	–	–	–	–	–	–
8. Carbon monoxide	14.04E-01	41. 42E-01	–	–	–	–	–	–
9. Particulates	10.01E-01	350.237	2.01E-02	2.76E-02	–	–	–	– (b2.5 μm)
B. Emissions to water								
10. Dissolved N	–	–	–	–	–	–	46.56	69.84
11. Dissolved P	–	–	–	–	–	–	3.12	4.78
12. Solid N waste	–	–	–	–	–	–	8.65	12.97
13. Solid P waste	–	–	–	–	–	–	5.50	9.25
14. Theoretical O_2 demand	–	–	–	–	–	–	110.35	155.45

Table 11
The values of the impacts categories per a ton trout based on the inputs optimized by DEA in the studied regions.

Impact categories	Units	Calculated with LCA + DEA		Values of improvement		Reduction percentage (%)	
		Ardal	Lordegan	Ardal	Lordegan	Ardal	Lordegan
AD	(kg Sb $_{eq}$)	1.277	4.593	1.065	1.105	45.47	18.60
AC	(kg $SO_{2\ eq}$)	2.353	6.288	0.995	1.568	29.71	19.95
EP	(kg $PO^{-3}{}_{4\ eq}$)	0.715	1.166	0.239	0.017	25.05	1.43
GW	(kg $CO_{2\ eq}$)	454.368	1258.652	163.242	121.246	26.43	8.78
OLD	(kg CFC 11 $_{eq}$)	3.76E-06	8.59E-06	1.36E-06	6.64E-07	26.55	7.18
HT	(kg 1,4-DB $_{eq}$)	57.804	124.443	19.856	10.157	25.56	7.54
FAE	(kg 1,4-DB $_{eq}$)	18.616	37.637	6.064	2.254	24.57	5.65
MAE	(kg 1,4-DB $_{eq}$)	18,954.89	40,698.55	8705.66	2332.03	31.47	5.41
TE	(kg 1,4-DB $_{eq}$)	0.782	1.101	0.618	0.689	44.14	38.49
PhO	(kg $C_2H_{4\ eq}$)	0.152	0.616	0.053	0.098	25.85	13.72
EES	pPt	1223.500	3173.909	460.374	308.400	27.340	8.856

+ DEA results showed that the EEFS value in Ardal and Lordegan regions was reduced by 27.34% and 8.85%, respectively. Vázquez-Rowe et al. (2011) coupled LCA with DEA to evaluate the environmental impacts of coastal fish production in Spain. Their results showed that using LCA coupled with DEA led to a reduction in diesel fuel consumption which had the largest contribution to all impact categories. They reported that using LCA coupled with DEA resulted in an increase in operational efficiency, reducing input costs and the environmental burdens.

4. Conclusions

The main aim of this study was to improve the energy efficiency and consequently reduce the environmental impacts in rainbow trout farms in Ardal and Lordegan regions located at Chaharmahal and Bakhtiari Province of Iran. For this purpose, the required data were collected from rainbow trout farms in Ardal and Lordegan regions. Based on the DEA results, the total required energy inputs in Ardal and Lordegan regions were calculated as 42,769.71 MJ ton^{-1} (29.28% saved energy) and 69,777.69 MJ ha^{-1} (9.59% saved energy), respectively. Also, LCA tool was used to assess the environmental impacts of rainbow trout farms. The LCA results revealed that fish meal, fish oil and electricity in production stage were the major contributors to the impact categories in the studied regions. Based on LCA + DEA, GW was reduced by 26.43% and 8.78% in Ardal and Lordegan regions, respectively.

Finally, it can be said that DEA is used to show the hot spots in crop production meaning that the producers are informed that for which input there is a higher potential for better management in terms of energy and environmental performance. Then they focus on those inputs with higher potential. In other words, we were not meant to practically reduce energy consumption but we were aimed at finding the sources of energy with higher energy saving potential. When a system is optimized, we do not force the production system to reduce all application rates but we are meant to combine different application of inputs in order to reduction of production costs as direct (reduction in the cost of the inputs) and indirect (reduction in the environmental cost). Considering the high feed costs, government could help trout producers by controlling the feed costs especially through providing alternative sources of protein that are necessary to replace the standard fishmeal-based feed and identification of plant-based alternatives to fish meal and oil. Leveling pond bottom and creating a uniform slope could lead to a considerable reduction in water use and electricity. The electricity generation in fossil-based power plants has significant environmental problems. Considering solar potential in Iran, it is suggested that some study be conducted to evaluate the potentials for developing solar power plants and generate more environmentally friendly electricity. Moreover, government measures to use clean energies would also encourage farmers to use more clean energy technologies. Consequently, quantify the environmental impacts associated with the different production phases using LCA method can help to identify potential improvement options that could significantly reduce environmental impacts and enhance environmental efficiency of a production system or a product. Also, it could help to identify the underlying problems of the different impacts which is important in finding solutions for achieving sustainability in aquaculture.

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