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Multi-criteria sustainability performance assessment of horticultural crops using DEA and ELECTRE IV methods

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Research Paper

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Abstract

This paper presents a novel approach to multi-criteria sustainability performance assessment of horticultural crops. The crops are ranked by the decision-making method ELECTRE IV with environmental, energy and technological criteria. In total eight indicators are taken into consideration and calculated based on primary data collected from over 260 farms in northern Iran. Additionally, Data Envelopment Analysis is used to calculate the technical efficiency and potential for energy saving by different management of the production units. The novel contribution of this study is the comparison of several horticultural products (oranges, kiwis, persimmons and tangerines), when most of the previous studies have focused on one product. Moreover, novel calculations of the carbon footprint are presented for oranges, tangerines and persimmons. This paper also includes the first study on the environmental impact of persimmon fruit's production. The obtained results show that energy efficiency for orange, tangerine, kiwi and persimmon products: 1.1, 0.84, 0.53 and 1.22, respectively. In each hectare of kiwi orchards, the amount of CO_2 emissions of 1219 kg and the ecological footprint of 3.21 hectares have been calculated, which is statistically significant compared to orange, tangerine and persimmon. The chemical and fuel inputs have the greatest potential for reducing energy consumption in the studied products. Results of ELECTRE IV showed that kiwi is the most sustainable selection for the studied region followed by orange, persimmon and tangerine, respectively. Kiwi has also relatively low technical efficiency. This means that this product has the greatest potential for a reduction of energy consumption, while maintaining the same amount of crop. It is recommended to include the development of kiwi orchards in the policies of Guilan, but with more careful management of the production inputs.

Introduction

In recent years, the concept of agricultural sustainability has emerged in response to the challenges of climate change, growing human population and depletion of natural resources in order to improve the quality of the natural environment. Previous studies have indicated that agriculture is one of the most important consumers of energy (Zangeneh *et al.*, 2010). Effective use of energy is pivotal for sustainable production in agriculture in order to achieve cost savings, conservation of fossil resources and reduction of air pollution. Optimized energy consumption in agriculture is essential for selecting appropriate solutions to mitigate negative environmental impacts and it is one of the most important indicators of sustainable development (Uhlin, 1998). The agricultural sector is both consumer and producer of energy. Quantitative analysis of production and optimal use of resources is one of the main elements of agricultural policies in Iran. It aims to increase domestic production through the optimal use of resources and sustainable management of agricultural systems. Measuring the consumption of inputs is a prerequisite for environmental management and pollution reduction. The human ecology balance is cleared by wise choices about population, consumption, technology efficiency and ecosystem protection (Kissinger and Gottlieb, 2012). Ecological footprint analysis in agriculture is a new and evolving subject that determines the amount of productive land needed to compensate for the environmental impacts caused by various agricultural activities. Every human uses the products and services of nature and it affects the earth. The ecological impact of humans equals to the amount of nature that have been occupied to sustain life (Wackernagel *et al.*, 2002). Per capita consumption of materials and energy in agriculture has increased faster than population growth, so the continuation of this process might endanger the sustainability and well-being of society, and causes the destruction of natural resources. Therefore, any exploitation of nature should be done after evaluating the resources and within the framework of the capabilities and capacities of the environment (Yarali *et al.*, 2010b). According to the global statistics, the biological capacity in Iran has been slightly declining since 1961, but the amount of ecological footprint has been increasing. Therefore the ecological footprint of Iran has exceeded the biological capacity and the ecological deficit has been occurring in the country since 1980 (Ewing *et al.*, 2010).

Table 1 presented the previous studies on sustainable citrus production in the north of Iran (Guilan and Mazandaran provinces). Most of them have focused on the calculation and optimization of energy consumption. Some studies, such as Nabavi-Pelesaraei *et al.* (2014) and Nikkhah *et al.* (2015), have also examined greenhouse gas (GHG) emissions for citrus production. According to the authors' knowledge, no studies (in Iran or anywhere else in the world) have been conducted in order to investigate the energy consumption, energy optimization or/and footprints for persimmon fruit's production.

The main contribution of this research is the application of a multi-criteria decision-making method (ELECTRE IV) with sustainability indicators in order to choose the most sustainable horticultural product. In this study, the sustainability of crops is evaluated using field/primary data collected from farmers in the Guilan province.

The proposed approach by the authors allows answering the following research questions:

- Which product (between orange, kiwi, tangerine and persimmon) is better with regards to defined sustainability indicators?
- Which product has the more efficient management of production units and to which extent optimal management of inputs can result in the reduction of energy consumption?

The answer to these questions can help decision-makers to implement more sustainable practices in the horticultural sector. The proposed assessment approach uses a combination of environmental, energy and technical criteria that can be easily used in a wide range of studies on the sustainability of different agricultural products.

The scope of this study focus on Guilan province, that is located beside the Caspian Sea at northern Iran. This region has got excellent conditions for agriculture activities. Due to heavy rainfall (about 2000 mm per year) the groundwater level is very high and followed by high fertility of the soils. Many people living in this region work intensively in agriculture. Therefore, due to high demand, the land is expensive. The predominant agricultural product is rice. In the west of the Guilan province, climate and soil conditions are very favorable for the cultivation and development of orchards, mainly orange, kiwi, tangerine and persimmon. In order to increase production and consequently increase farmers' incomes, the correct and optimal use of inputs of production is needed. Monitoring with the aim of reducing energy consumption and ecological footprints may prove to be very effective for selecting the appropriate cultivation pattern in Guilan province.

Most of the previous studies in energy audition in agriculture have focused on the assessment of just one product, but this paper compares three horticultural products (orange, kiwi, persimmon and tangerine) which are cultivated in a province with regard to environmental, energy and technical criteria. This research implements a practical approach based on the analytical method with a survey strategy. The main aim of this study is to propose and apply multi-criteria assessment approach for horticultural products to be cultivated in a region using sustainable indicators. The novelty of this paper results from:

- Calculation of the carbon footprint for the horticultural products: orange, tangerine, persimmon; as according to authors' knowledge no such studies have been yet conducted;
- Calculation of the environmental impact of persimmon fruit production; as according to authors' knowledge no such studies have been conducted.

Material and methods

The authors propose an original approach (in Fig. 1) for sustainability performance assessment of horticultural crops that combines two multi-criteria decision-making methods: Data Envelopment Analysis and ELECTRA IV.

Table 1. Main orchard crops of Guilan province

Product	Cultivated area (ha)	Methods and indicators used	References
Persimmon	252	–	–
Kiwi	5746	Calculation of energy and economic indicators and regression modeling	Mohammadi *et al.* (2010b)
		Optimization of energy consumption by data envelopment analysis	Mohammadi *et al.* (2010a)
		Calculation of footprints of GHG emissions	Nikkhah *et al.* (2015)
		Calculation of energy consumption and GHG emissions and modeling with artificial neural network	Nabavi-Pelesaraei *et al.* (2016b)
		Audit of energy consumption and calculation of energy indicators	Soltanali *et al.* (2017)
		Investigation of energy consumption and emission of GHGs and optimization by data envelopment analysis method	Mostashari-Rad *et al.* (2019)
Orange	9678	Optimization of energy consumption and GHG emissions by data envelopment analysis	Nabavi-Pelesaraei *et al.* (2014)
		Audit of energy consumption and calculation of energy indicators	Namdari *et al.* (2011a)
Tangerine	631	Energy consumption analysis, regression modeling and sensitivity analysis	Namdari *et al.* (2011b)
		Audit of energy consumption and calculation of energy indicators	Namdari *et al.* (2011a)
		Investigation of energy consumption and emission of GHGs and optimization by data envelopment analysis method	Mostashari-Rad *et al.* (2019)

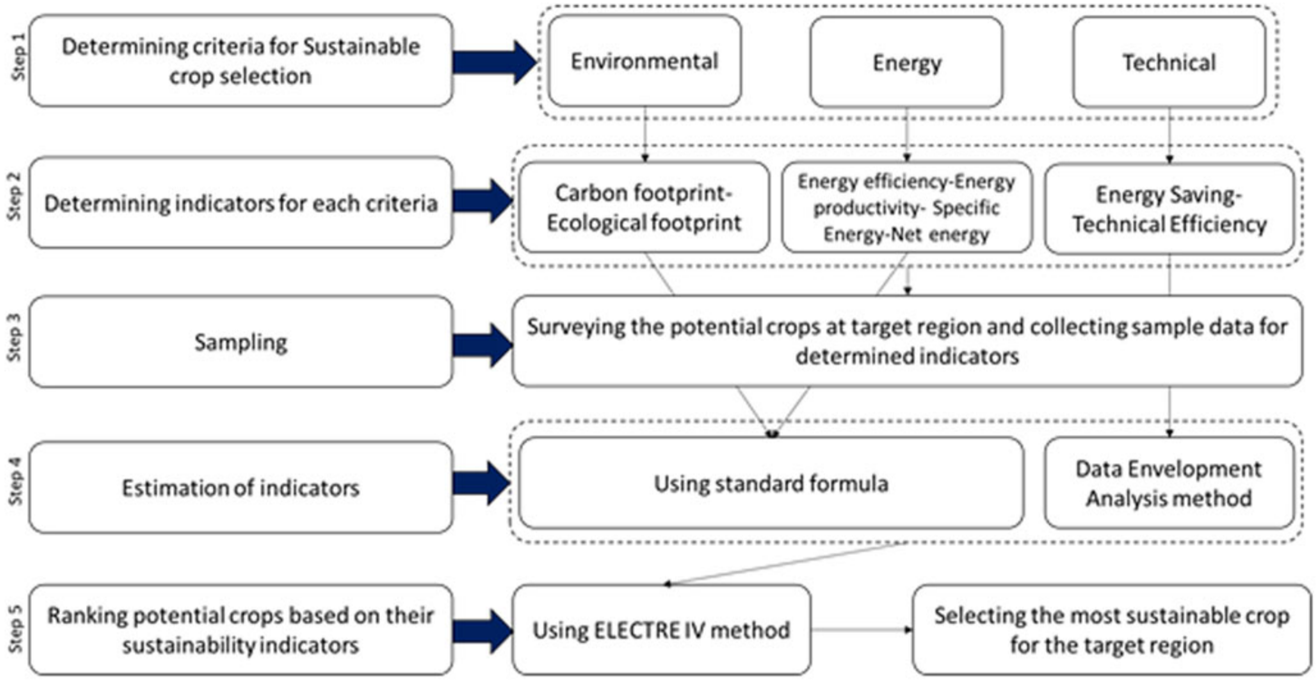

Fig. 1. Research methodology – sustainable crop selection.

The steps of the proposed multi-criteria sustainability assessment approach are described in the subsequent subsections.

Determining criteria and indicators for sustainable crop selection

The criteria for assessment have been identified through literature review and interviews with the experts. According to the experts' opinions, the soil in the Guilan province is characterized by high fertility, therefore any kind of crop that is suitable to grow here is economically feasible. For that reason, the economic criteria have been excluded from further analysis. The criteria for crop assessment have been classified into three categories, namely: environmental, technical and energy-related.

Determining indicators for each criteria

In the next step of this research, we have defined indicators, through which the sustainability of products in terms of that particular criterion can be measured. For the environmental criterion, two indices have been allocated, namely carbon footprint and ecological footprint. For the energy criterion, four indicators have been selected: energy efficiency, energy productivity, specific energy and net energy. For the technical criterion, two indicators have been determined, as energy saving and technical efficiency. The calculation method of each indicator is described in section 2.4.

Sampling

According to the latest statistics of Jihad-e-Agriculture, the main horticultural products in Guilan province are kiwi (5746 ha), persimmon (252 ha), tangerine (631) and orange (9678 ha) (Anonymous, 2017). The data used in this study have been collected in Guilan province in 2019, by a closed-ended questionnaire during face-to-face interviews among farmers of four types of crops: kiwi, orange, tangerine and persimmon.

In order to determine the sample size, Cochran's method (Equation 1) has been used. A simple random sampling method has been applied (Zangeneh *et al.*, 2010), as result the following numbers of orchards were selected: 83 for kiwi's production, 51 for tangerines' production, 86 for oranges and 43 for persimmons. In order to determine the validity of the questionnaire, a panel of five university professors of agricultural systems analysis at the University of Guilan was consulted. Pre-test and post-test methods were used to confirm the research validity.

$$n = \frac{Nt^2s^2}{Nd^2 + t^2s^2} \qquad (1)$$

where n is the required sample size, N is the number of orchards in the target population, t is the reliability coefficient (1.96 which represents 95% confidence), t is confidence value (at 95% confidence limit is 1.96), s is the standard deviation of pre-tested data, and d is the precision or acceptance error which was defined to be 5% for a confidence level of 95%.

A table of all inputs was prepared and used during interviews with farmers. Farmers usually have got very accurate information about the consumption of their inputs because they grow the product every year, and therefore the information collected from them is very accurate. The data was collected on key inputs, as follows: Labor (h); Machinery (h); Diesel fuel (L); Fertilizers (kg) including: Nitrogen, Phosphate, Potassium, Micro; Farmyard Manure (kg); Chemicals (kg) including: Herbicide; Pesticide; Fungicide; Insecticide, Water (m3) and Electricity (kWh). Additionally, the information was collected on the outputs (kg) according to the product type. The responses were used to calculate the average values of inputs and outputs for

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the analyzed crops and they were applied for further estimation of indicators.

Estimation of indicators

Environmental indicators

Carbon footprint: The production, transportation, storage, distribution and application of agricultural inputs with the help of agricultural machinery, lead to the combustion of fossil fuels and the use of a variety of energy sources that emit carbon dioxide and GHGs into the atmosphere. Nitrogen oxides are among the other GHGs that are released into the atmosphere by various agricultural operations.

The carbon footprint calculation is based on life-cycle assessment principles. A carbon footprint is the total set of GHG emissions caused directly and indirectly by an individual, organization, event or product. In this paper, the carbon footprint is calculated by the multiplication of related coefficients and the amount of inputs used. CO_2 equivalents are presented in Table 2. The total emissions of GHG are determined, as in Equation 2 (Yousefi *et al.*, 2014):

$$Greenhouse\ effect = \sum^{G} WP_i \times m_i \qquad (2)$$

where m_i is the mass of the emission gas (kg) and the score is expressed in terms of CO_2 equivalents.

Ecological footprints: The ecological footprint determines the amount of human needs and effects. It suggests factors that improve the sustainable use of natural resources. The average hectare of productive land on Earth is biodegradable per person (Ewing *et al.*, 2010). The ecological footprint model for assessing agricultural environmental sustainability is provided by Kissinger and Gottlieb (2012) and Solís-Guzmán *et al.* (2013). In this study, the ecological footprint is calculated (Equations 3 to 5) based on the energy consumption and place-oriented approach in order to compare persimmon, kiwi, orange and tangerine crops.

$$EF_t = \sum_{i=1}^{n} EF_i = \left(\frac{E_i \times T}{C_0}\right) \qquad (3)$$

$$E_i = F_i \times EQF \times 1000 \qquad (4)$$

$$T = \left(\frac{P_c}{E_c \times O_C \times K}\right) \qquad (5)$$

Where: EF_t is the ecological footprint index (gha), E_c is the capability of energy generation by one gram of coal (20 kJ), E_i is the energy of the ith factor (kJ), C_0 is the capability of one hectare farm for carbon absorption (ton) [1.8 ton for Iran (Gharakhlou *et al.*, 2009)], F_i is the energy of ith factor, EQF is the equivalence factor of ith factor for converting productive land to global hectare (Anielski and Wilson, 2010), P_c is percent of the carbon in coal (gr) (0.85%), O_C is the percent of coal derived from plants (gr) (0.314%), K is the constant coefficient for converting gram to tone (1000000) (Solís-Guzmán *et al.*, 2013).

Energy indicators

Energy consumption: The previous studies on the energy use in the agricultural sector have commonly applied the energy indicators, as follows: Energy Use Efficiency, Energy Productivity, Specific Energy and Net Energy (Mohammadi *et al.*, 2008; Shahin *et al.*, 2008; Ziaei *et al.*, 2015). This study also includes them in the assessment of the energy criterion.

First, the consumption of inputs in each horticultural product was estimated according to the average data obtained from the questionnaires. Then, the energy consumption was calculated by considering the energy equivalents for each input according to Table 3.

The amounts of input were calculated per hectare and then, these values were multiplied by the coefficient of energy equivalent. The total input equivalent results from adding up the energy components of all inputs in mega joule (MJ) (Banaeian *et al.*, 2011). Then the Energy Use Efficiency, Energy Productivity, Specific Energy and Net Energy have been calculated (Equations 5–8) according to the study of the Avval *et al.* (2011).

$$Energy\ Use\ Efficiency = \frac{Energy\ Output\ (MJ\ ha^{-1})}{Energy\ Input\ (MJ\ ha^{-1})}. \qquad (6)$$

$$Specific\ Energy = \frac{Energy\ Input\ (MJ\ ha^{-1})}{Output\ (kg\ ha^{-1})} \qquad (7)$$

Table 2. Emission ratio of inputs

Input	**Unit**	Emission ratio (**kg CO_2-eq Unit^{-1}**)	Reference
1. Machinery	h	0.071	**Nabavi-Pelesaraei *et al.* (2016a)**
2. Chemical fertilizers			**Khoshnevisan *et al.* (2013)**
I. Nitrogen	kg	1.3	
II. Phosphate	kg	0.2	
III. Potassium	kg	0.2	
IV. Sulfur	kg	7.3	
3. Chemicals	kg	5.1	**Yarali *et al.* (2010a)**
4. Fuel	L	2.761	**Mohammadi *et al.* (2014)**
5. Electricity	kWh	0.608	**Solís-Guzmán *et al.* (2013)**
6. Farmyard manure	kg	0.0126	**Nikkhah *et al.* (2015)**

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Table 3. Energy equivalents of inputs and outputs

Input/output	Unit	Energy equivalent (MJ Unit^{-1})	Reference
A. Inputs			
Human labor	h	1.96	**Hosseinzadeh-Bandbafha *et al.* (2018)**
Machinery	kg	64.8	**Banaeian *et al.* (2011)**
Farmyard manure	kg	0.3	**Salehi *et al.* (2016)**
Chemical fertilizers			
I. Nitrogen	kg	66.14	**Banaeian *et al.* (2011)**
II. Phosphate	kg	12.44	**Banaeian *et al.* (2011)**
III. Potassium	kg	11.15	**Banaeian *et al.* (2011)**
IV. Sulfur	kg	1.12	**Nabavi-Pelesaraei *et al.* (2014)**
Micro	kg	10.00	**Salehi *et al.* (2016)**
Chemicals	kg	199.00	**Khoshnevisan *et al.* (2013)**
Fuel	L	47.8	**Banaeian *et al.* (2011)**
Electricity	kWh	11.93	**Banaeian *et al.* (2011)**
Water	m^3	1.02	**Banaeian *et al.* (2011)**
B. Outputs			
Kiwi	kg	1.9	**Mohammadi *et al.* (2010b)**
Orange	kg	1.9	**Nabavi-Pelesaraei *et al.* (2014)**
Tangerine	kg	1.9	**Namdari *et al.* (2011b)**
Persimmon	kg	1.9	**Ozkan *et al.* (2004)**

$$Net\ Energy = Energy\ Output\ (MJ\ ha^{-1}) - Energy\ Input\ (MJ\ ha^{-1}) \quad (8)$$

Technical indicators

e values of the indicators from the technical criterion have been calculated using Data Envelopment Analysis (DEA). DEA method measures the relative efficiency of a group of DMUs (Decision Making Units = farms in this study) with regard to different inputs and outputs (Pahlavan *et al*., 2011). The application of DEA benefits from the ease and clarity of the non-parametric method, as well as the lack of need for assuming the effect of discrete variables (Banaeian and Namdari, 2011). The in-depth studies on DEA can be found in Liu *et al.* (2013).

DEA has been accepted as one of the major techniques for benchmarking energy in different sectors in many countries (Pahlavan *et al*., 2011). This method has been also applied previously to investigate the efficiency of agricultural production units in Iran (Avval *et al*., 2011; Mohammadi *et al*., 2014; Hosseinzadeh-Bandbafha *et al*., 2018). The efficiency index that includes one input (x) and one output (y) is the ratio of output to input (y/x), but if there are multiple inputs and multiple outputs, it is necessary to allocate coefficients for inputs and outputs. The most common definition of performance used in DEA models is presented by Equation 9 (Banaeian *et al*., 2012):

$$Technical\ Efficiency = \frac{u_1 y_1^{j^*} + u_2 y_2^{j^*} + \ldots + u_N y_N^{j^*}}{v_1 x_1^{j^*} + v_2 x_2^{j^*} + \ldots + v_M x_M^{j^*}} \quad (9)$$

Where, u_1,, … are the weight given to output n (n = 1,2, … , N); , ,…, are the amount of output n (n = 1,2, … , N) of DMU j^*; v_1, v_2, … are the weight given to input m (m = 1,2, … , M); x_1^{j*}, x_2^{j*}, x_M^{j*} are the amount of input m (m = 1,2, … , M) to DMU j^*; and j^* is the DMU under consideration. In the present study, the efficiency of production systems in orange, tangerine, kiwi and persimmon products using the non-parametric method of data envelopment analysis, input-driven model (minimizing production factors with constant output) with eight inputs (input energy) and output (product yield) have been performed.

The technical efficiency is applied in order to determine the current energy efficiency of analyzed horticultural products, and then to identify the energy inputs to be reduced (if necessary). DEA method divides all studied orchards into efficient and inefficient groups. Applications of DEA allow for identification of inefficiency reasons and levels (Hosseinzadeh-Bandbafha *et al*., 2018). For each inefficient farm, target input and output levels are prescribed. These targets are the results of respective slack values added to outputs. The amount of energy saving from different sources (if recommendations are followed) can be calculated. It is possible to advise an inefficient farmer on better operating practices in order to reduce the input energy level up to the target values indicated in the analysis while maintaining the same output (Banaeian &Namdari, 2011).

Ranking crops with regard to the sustainability indicators using ELECTRE IV method

When the eight indicators have been calculated then the ELECTRE IV method can be applied for ranking of horticultural crops with regards to their sustainability.

ELECTRE IV method allows ranking a finite set of alternatives evaluated by a family of criteria, and based on the preferential information submitted by the decision maker. The preferential

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information is defined in the form of the indifference – q, preference – p and veto – v thresholds (Żak and Kruszyński, 2015). ELECTRE IV is based on the use of multiple non-fuzzy relations to determine the degree of superiority of alternatives. The main difference between the third and fourth editions of ELECTRE is that in the fourth edition, the weight of the criteria has no numerical effect, the decision maker affects the importance of the criteria in other parameters of the algorithm. ELECTRE IV is suitable for studies on problems where the importance of criteria cannot be determined numerically. The problem-solving approach in ELECTRE IV, like other editions, is based on a pairwise comparison of alternatives in the criteria. In this paper are ranked eight indicators (in three criteria) for four alternatives including kiwi, orange, persimmon and tangerine (Fig. 2).

Results and discussion

The ratio of energy input to output in orchard products of Guilan

Based on the data from interviewed horticultural farms in Guilan province, the energy consumption for persimmon, kiwi, orange and tangerine has been calculated respectively, as: 56.6, 42.7, 53.5 and 61.6 GJ ha^{-1}, respectively. Energy efficiency for persimmon, kiwi, orange and tangerine crops was calculated (Table 4) to be 0.53, 1.22, 1.01 and 0.84, respectively. In previous studies Bhunia *et al.* (2021) showed using optimized energy input values, an average of 4027 MJ ha^{-1} (9.21%) energy could be saved for rice–wheat–green gram cropping system. Nabavi-Pelesaraei *et al.* (2014) reported that the energy efficiency of the orange crop was 1.83, and the total energy in the orange crop was calculated to be 25.582 GJ ha^{-1}. Mohammadi *et al.* (2010a) reported energy consumption and energy efficiency of kiwi in Mazandaran province as about 30 GJ ha^{-1} and 1.54. Soltanali *et al.* (2017) calculated the energy efficiency of kiwifruit in Guilan province as 0.48. Nabavi-Pelesaraei *et al.* (2016b) reported the energy efficiency of kiwifruit in Guilan as 1.16. In this study for kiwi, the energy efficiency is about 1.226 and energy productivity 0.645, which is better than other analyzed products in the province and at the same time, it consumes less energy per unit area. Energy efficiency and productivity for persimmon products are the lowest. Since no study has been conducted to investigate the energy consumption of persimmons, it is not possible to compare with similar studies.

In the test of comparing the average stability indicators of these four main horticultural products in Guilan province, the statistical benchmark of the least significant difference was used. The results of the comparison test showed that there was no significant difference between the three products of tangerine, orange and persimmon; while for kiwi, the average input energy of total (total energy consumption) was significantly better than other products. This means that it has been statistically proven that kiwifruit in Guilan province consumes less energy than the other three products.

Carbon footprint of products

The carbon dioxide emissions per hectare were estimated at 3745 kg for persimmon, 2620 kg for kiwi, 3987 kg for orange and 4626 kg for tangerine orchards (Table 5). Overall results of carbon footprint analysis showed a considerable amount of carbon dioxide emissions. Litskas *et al.* (2020) highlight that the carbon footprint of agricultural products can be reduced by lowering inputs (e.g., fertilizers, fuel) for production, using varieties well adapted to the local environment, increasing carbon storage in soil and minimizing transportation distance to the markets.

Duncan test results showed that there was no significant difference between the three products of tangerine, orange and persimmon, while there was a significant difference between the average of kiwi product and other products. No carbon footprint of persimmons, tangerines and oranges has been reported in previous studies. Nikkhah *et al.* (2015) studied the emissions of GHGs in three products: Their findings show that GHG emissions are higher in kiwifruit (4518 kg of carbon dioxide) and tea, respectively, and are lower in peanuts. Nabavi-Pelesaraei *et al.* (2016b) reported an average of 1310 kg ha^{-1} of carbon dioxide emissions in kiwifruit. They indicated the management of electricity consumption in the input as a reason for the declining spread compared to the similar study mentioned earlier (Nikkhah *et al.*, 2015). The study also showed that there was no significant difference between small, medium and large orchards in carbon dioxide emissions.

Figure 3 shows the contribution of each input to carbon dioxide emissions in four horticultural products. In the oranges, persimmons and tangerines, livestock manure had the largest share, and then chemical fertilizer and fuel (gasoline), respectively. In the kiwi, which had the lowest carbon dioxide emissions, the share of electricity and chemical fertilizers increased, while the share of livestock manure decreased.

The ecological footprint of products

Table 6 shows the ecological footprint of persimmon, kiwi, orange and tangerine. Tangerine production has the highest ecological footprint at 4.63 hectares on a global scale, and the lowest

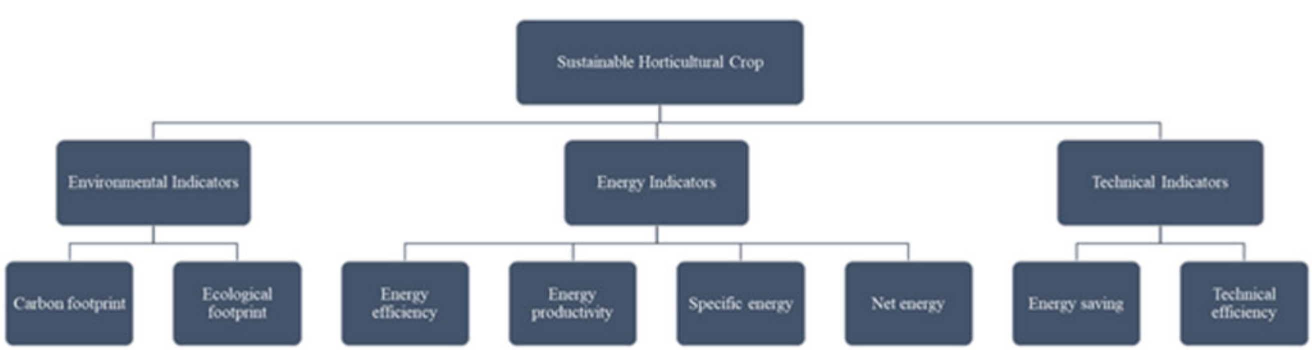

Fig. 2. Criteria to select the sustainable horticultural crop.

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Table 4. The amount of different characteristics and forms of energy in orchard products of Guilan province

Indicators	Unit	Persimmon	Kiwi	Orange	Tangerine
Energy efficiency	–	0.5391	1.2258	1.0106	0.8427
Energy productivity	kg MJ^{-1}	0.2837	0.6451	0.5107	0.4435
Specific energy	MJ kg^{-1}	3.5241	1.5499	1.88	2.2545
Net energy	MJ ha^{-1}	− 26,112.6	9660.4	568.78	−9689
Direct energy	MJ ha^{-1}	15,514.5	11,397	17,119.3	20,590.2
Indirect energy	MJ ha^{-1}	41,146.2	31,382.5	36,385.8	41,020.1
Renewable energy	MJ ha^{-1}	16,435.2	9558.2	14,970.8	18,731.8
Nonrenewable energy	MJ ha^{-1}	40,225.6	33,221.2	38,534.4	42,878.4
***Total energy input**	MJ ha^{-1}	$56{,}660.81^{b}$	42780^{a}	53505^{b}	61610^{b}

*Different letters indicate a significant difference at the level of 5%.

Table 5. Carbon dioxide emissions and carbon footprint (kg CO_2).

Input	Persimmon	Kiwi	**Orange**	**Tangerine**
Electricity	236.76	598.27	393.98	474.24
Fuel	726.33	325.8	759.27	902.85
Fertilizers	1196.94	1298.24	1173.5	1223.6
Chemicals	196.19	42.33	60.18	77.77
Machinery	3.4	3.09	4.12	5.11
Farmyard manure	1386	352.8	1596.4	1942.9
***Total**	3745.6^{a}	2620.54^{b}	3987.47^{a}	4626.5^{a}

*Different letters indicate a significant difference at the level of 5%.

ecological footprint production is related to kiwifruit production (3.217 hectares on a global scale). Similar studies on the ecological footprint of horticultural products were not found. Also, the results of the mean comparison test (Duncan test) showed that there was no significant difference between the three products of tangerine, orange and persimmon, while there was a significant difference between the kiwi product and other products. The contribution of each input to the ecological footprint is shown in Figure 4. Chemical fertilizers have the greatest impact on all four crops. The difference between kiwifruit and other crops in this index is the decrease in the share of chemical fertilizers, water, fertilizers and gasoline, while the share of labor and electricity has increased.

Technical efficiency and energy saving

Table 7 shows the technical efficiency and potential of each product to save the amount of energy input. According to the optimization analysis in the variable scale return model, the optimal energy results for persimmon, kiwi, orange and tangerine products were calculated to be 48.7564, 45.36001, 45.1396 and 6.31610 MJ ha^{-1}, respectively. In a similar study, Mostashari-Rad *et al.* (2019) estimated the optimal energy value for kiwi and tangerine at 179.2007 and 24477.24 MJ ha^{-1}, respectively. Efficiency analyses have shown that although the energy ratio in tangerine is low, technical efficiency in tangerine orchards has been significantly higher than the other crops. The technical management in the production of this crop is better than other products and has the least potential to reduce energy consumption. Tangerine orchards can achieve the same amount of crop with about one percent reduction in input consumption, which is not a significant amount of savings. Kiwi, orange and persimmon orchards are far from the optimal energy consumption and can save the most energy (15.84, 14.94 and 14.14%, respectively) with the same amount of output.

The contribution of each input to the energy saving is given in Figure 5. Fuel inputs and chemical fertilizers have the greatest potential for better management and reduced energy consumption. Iriarte *et al.* (2011) showed that use of mineral fertilizers has the greatest energy demand, with a contribution of over 75%. In previous studies on the orange production in Guilan province, Mostashari-Rad *et al.* (2019) showed similar results, which indicated that chemical fertilizer inputs have got the greatest potential for reduction in the management of orange production inputs. They also showed that for kiwifruit production the nitrogen and fertilizer inputs have a potential of 42.8 and 22.82% of energy consumption reduction, respectively. In the present study, the greatest potential for reducing energy consumption in tangerine production was related to chemical and fertilizers (29.9 and 24.6%, respectively), while in the same study for tangerine product, inputs were reported by nitrogen fertilizers and fungicides (39.47 and 18.94%).

ELECTRE IV method results

Finally, after the values for each indictor have been calculated the ranking of crops' sustainability can be performed by application

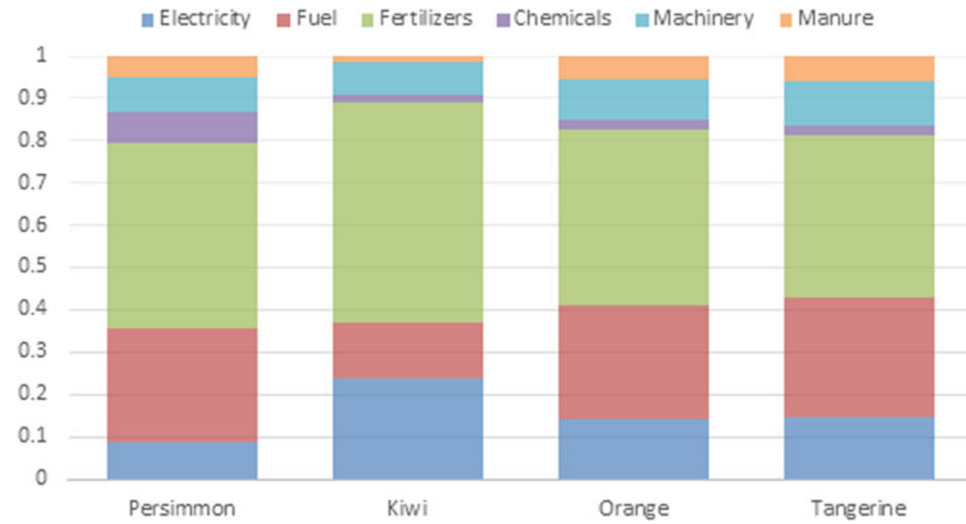

Fig. 3. The share (percentage) of each input in the carbon footprint.

Table 6. Ecological footprint (gha)

Inputs	Persimmon	Kiwi	Orange	Tangerine
Human labor	0.1453	0.1798	0.1544	0.1986
Electricity	0.1054	0.2663	0.1754	0.2111
Fuel	0.9158	0.4108	0.9574	1.1384
Fertilizers	1.4224	1.5335	1.3756	1.3862
Farmyard manure	0.2481	0.0631	0.2858	0.3478
Chemicals	0.3471	0.0748	0.1064	0.1376
Machinery	0.2338	0.2124	0.2826	0.3508
Water	0.8423	0.4757	0.6854	08620
***Total**	4.2605[a]	3.2167[b]	4.0233[a]	4.6327[a]

*Different letters indicate a significant difference at the level of 5%.

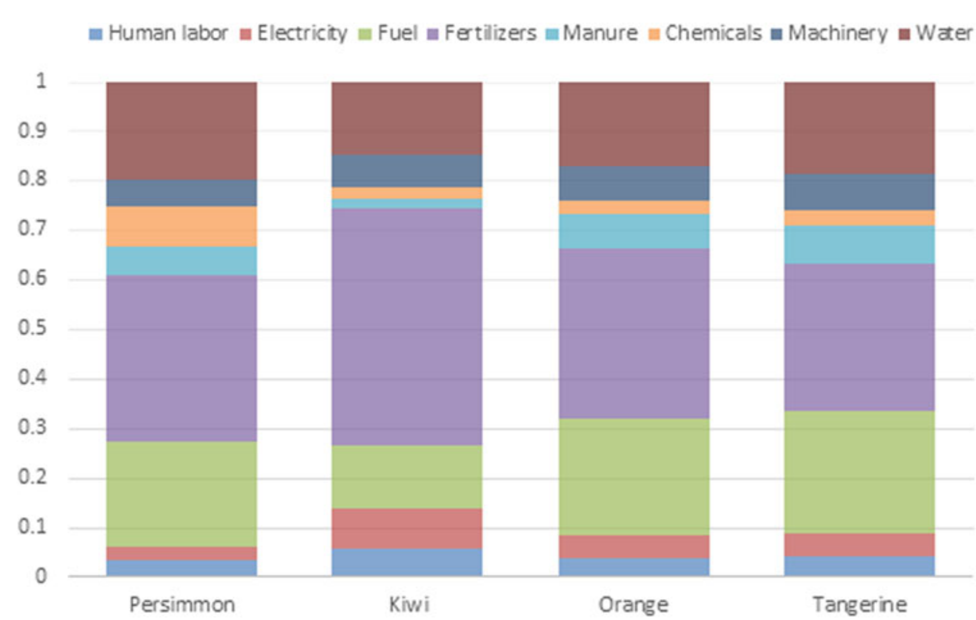

Fig. 4. The share (percentage) of each input in the ecological footprint.

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Table 7. Technical efficiency and energy saving

Item	Unit	Persimmon	Kiwi	Orange	Tangerine
Real energy consumption	MJ ha^{-1}	56,660.81	42,779.53	53,505.22	61,610.32
Optimal energy consumption	MJ ha^{-1}	48,664.75	36,001.45	45,962.13	60,996.01
Energy saving	MJ ha^{-1}	7996.06	6778.08	7543.09	614.3
Energy saving percentage	%	14.11	15.84	14.09	0.99
***Technical efficiency**	%	89[a]	86[a]	87[a]	94[b]

*Different letters indicate a significant difference at the level of 5%.

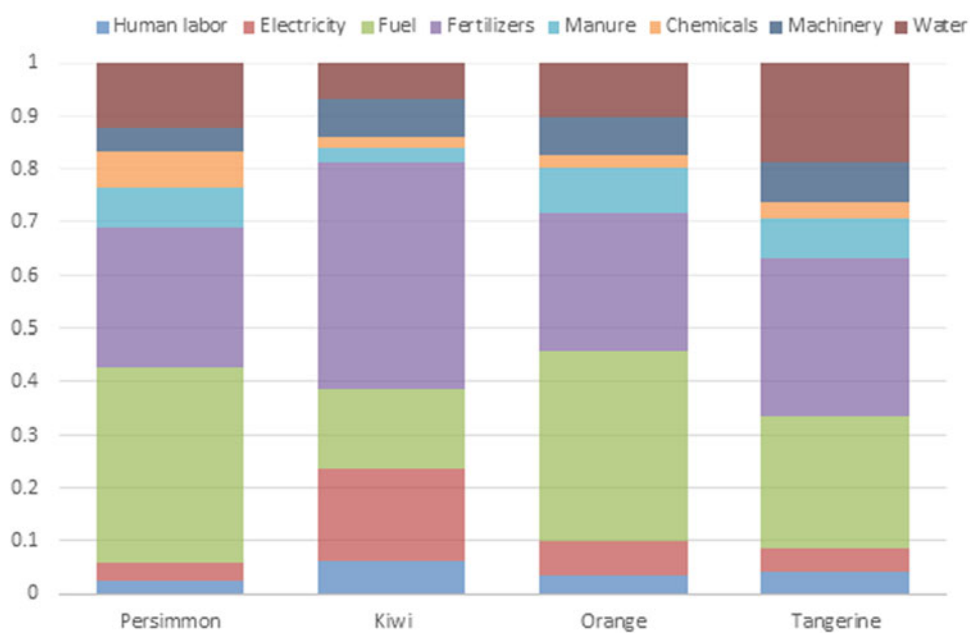

Fig. 5. The contribution of each input in reducing the energy consumption.

Table 8. Selection criteria values for ELECTRE IV

	Environmental Indicators		Energy Indicators				Technical Indicators	
Item	**Carbon footprint**	**Ecological footprint**	**Energy efficiency**	**Energy productivity**	**Specific energy**	**Net energy**	**Energy saving**	**Technical efficiency**
Q*	3000	3.5	1.1	0.6	1.6	9000	7600	0.9
P**	4000	4	0.8	0.5	2	500	7000	0.88
V***	4500	4.5	0.6	0.3	3	0	6500	0.87
Kiwi	2620.54	3.2167	1.2258	0.6451	1.5499	9660.4	6778.08	0.86
Orange	3987.47	4.0233	1.0106	0.5107	1.88	568.78	7543.09	0.87
Tangerine	4626.5	4.6327	0.8427	0.4435	2.2545	−9689	614.3	0.94
Persimmon	3745.6	4.2605	0.5391	0.2837	3.5241	− 26,112.6	7996.06	0.89

Q*, indifference; P**, preference; V***, veto (thresholds).

of the ELECTRE IV method (Table 8). The results showed that the kiwi has the highest rank among the four products according to the considered indicators, followed by orange, persimmon and tangerine, respectively.

This research was the first to study the environmental indicators of persimmon in Iran. Also, the use of multi-criteria methods to select the most sustainable horticultural product for development in a region is the main novelty of this study that can be

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very effective in the sustainable development of agriculture in very fertile areas of northern Iran. This methodology can also be used in other products and regions. The main advantage of this decision model is that it offers the most sustainable crop using the actual conditions of crops grown in one area and considering its various aspects, while in many methods based on expert opinions, quantitative data not used in decision process such as energy consumption or environmental indicators.

Conclusions

According to this study, energy efficiency, CO_2 emission and ecological footprint in per hectare of kiwi were significantly different from other main orchard products (tangerine, orange and persimmon) in Guilan. Calculating the technical efficiency of orchards confirmed that the usage of chemical fertilizers and fuel have the greatest potential to reduce energy consumption. Overall result showed good position of kiwi fruit with regard to sustainability, but it has a relatively low technical (managerial) efficiency. Therefore, kiwi has the greatest potential for reduction of energy consumption while producing the same amount of crop.

Currently, there are 11,500 farmers growing kiwifruit in Guilan province, and about 40 percent of the province's kiwifruit is exported annually to the Caspian and Central Asian countries, indicating that province's good potential for growing first-class kiwi. This product can play a greater role in rural employment and value creation and increase sustainability in Guilan province, due to the superiority of kiwi in the sustainability indicators over three other products (orange, tangerine and persimmon). In addition, the reduction of the use of chemical and livestock fertilizers, fuel (gasoline) and water should be considered as important factors for further reduction of carbon footprint and ecological footprint in the province. The results provide a valuable insight for the decision-makers for further sustainable agriculture policy in the province.

The benefit of this study is the real data-based assessment of the sustainability of several horticultural crops by comparison of their environmental, energy-related and technical indicators. The proposed mulita-criteria assessment approach which can be applied anywhere in the world allows for selecting which product is most sustainable among others with regards to energy consumption, carbon footprint and ecological footprint. Also DEA application for efficiency analysis helps decision makers to find out to what extent more optimal management of inputs can be effective in reducing energy consumption.

The proposed Multi-criteria assessment approach uses a combination of environmental, energy and technical criteria that can be easily used in a wide range of other fields. The limitation of this study results from the fact that due to the fertility of the studied area economic criteria have been not included. If this method is to be used in different geographical areas, it might be beneficial to consider the economic indicators in the assessment process.

The further research will consider applying the proposed multi-criteria assessment approach for the development of sustainable production of different agricultural products. The authors also plan to extend the method by adding economic and social criterion and related indicators.

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