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Research Article

An Investigation of Energy Use Efficiency and CO_2 Emissions for Grape Production in Zanjan Province of Iran

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ABSTRACT

Objective: The aims of this study were to determine energy efficiency and CO_2 use pattern of grape production in Zanjan province, Iran by a non-parametric method of data envelopment analysis (DEA). **Methods:** Initial data were collected using a face to face questionnaire from 42 orchards in Abhar city of Zanjan province which is one of the most important centers of grape production in Iran. The DEA method was applied based on seven inputs including human labor, machinery, diesel fuel, fertilizers (nitrogen, phosphate, potassium and farmyard manure), chemicals (pesticides and fungicides), water for irrigation, electricity and with the single output of grape yield. **Results:** The results indicated that based on variable returns to scale (BCC) model, 23.8% of the grape orchards were efficient. While based on constant returns to scale (CCR) model, it was 16.6%. The technical, pure technical and scale efficiency were found to be 0.668, 0.857 and 0.797, respectively. Energy use efficiency, energy productivity and net energy were found to be 4.14, 0.35 and 64178 MJ ha^{-1}respectively. The results of CO_2 analysis showed that the total CO_2 emissions of grape production were found to be 1207.37 $kgCO_{2eq.}$ ha^{-1}.

INTRODUCTION

Grape production is very important for Iran in terms of both export and domestic consumption Vine (*Vitis Venifera L.*) is a fruit from *vitaceae* family. This family has 10 different geniuses which only vitis genus is edible (Anon, 2013). Italy with 8.5 million tons production per year is the first grape producer and Iran has the 11th rank in grape production in the world (FAO, 2011). Agriculture is both a producer and consumer of energy. It uses large quantities of locally available non-commercial energies, such as seed, manure and animate energy, commercial energies directly and indirectly in the form of diesel, electricity, fertilizer, plant protection, chemicals, irrigation and machinery. Effective energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resources preservation and air pollution reduction (Nabavi-Pelesaraei et al. 2014a). Due to decreasing of some energy resources and non-renewability of them, finding a solution to reduce energy consumption per production unit seems to be essential to reach the sustainable development (Naderloo et al. 2013). Energy productivity is the key to sustainable energy management; for enhancing the energy efficiency it must be attempted to increase the production yield or to conserve the input energy without affecting the output (Singh et al. 2004). Grape consists of glucose (17.43%),

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water (82%), Fat (0.5%), Na, K, Ca, Mg, Fe and P (0.072%) (Anon, 2013). Ozkan et al. (2004) investigated the energy requirement and economic analysis of citrus production (orange, lemon and mandarin) in turkey. The results showed that lemon production was the most energy intensive among the three fruits investigated. The energy input of chemical fertilizer (49.68%), mainly nitrogen, had the biggest share in the total energy inputs followed by Diesel (30.79%). The energy ratios for orange, mandarin and lemon were estimated to be 1.25, 1.17 and 1.06. Hamedani et al. (2011) determined energy and economic indices for grape production in Hamedan province of Iran. Their results revealed that energy ratio and energy productivity were found to be 4.95 and 0.42 kg MJ^{-1}.

Data envelopment analysis (DEA) is a non-parametric technique of frontier estimation which is used extensively in many settings for measuring efficiency (Malana and Malano, 2006). In the recent years, DEA has gained great popularity in agricultural enterprises. Chauhan et al. (2006) applied DEA approach to determine the efficiency of orchards with regard to energy use in rice production in India. In this study, technical, pure technical and scale efficiency of orchards were found to be 0.83, 0.92 and 0.77 respectively. Mohammadi et al. (2011) investigated energy efficiency and economic indices for kiwifruit production using DEA. Their results indicated that based on variable returns to scale (BCC model), 62.79% growers were efficient, though, based on constant returns to scale (CCR model), it was just 23.26%. The technical, pure technical and scale efficiency were calculated as 0.942, 0.993 and 0.948 respectively. Nabavi-Pelesaraei et al. (2014b) optimized the energy consumption and GHG emissions of rice production in Guilan province of Iran.

Based on the literature, there was not any study on all energy efficiency and CO_2 emissions for grape fruit. Accordingly, the main objectives of this study were to determine the above items in Abhar city of Zanjan province, Iran.

2. MATERIALS AND METHODS

The research was carried out in Abhar city of Zanjan province which is located in the west of Iran: within 35° 59/ and 36° 45/ north latitude and 48° 35/ and 49° 25/ east latitude. The data used in this study were collected from 42 orchards using a face to face questionnaire in the studied area. The Cronbach method was applied to estimate the reliability of a psychometric test for samples (Cronbach, 1951). The Cronbach's alpha of questionnaire was calculated as 0.87 demonstrating adequate construct reliability.

The simple random sampling method was used to determine the survey volume, described by Rafiee et al. (2010):

2.1. Sampling design

$$n = \frac{N(s \times t)^2}{(N-1)d^2 + (s \times t)^2} \quad (1)$$

Where n is the required sample size; s is the standard deviation; t is the value at 95% confidence limit (1.96); N is the number of holding in target population and d is the acceptable error (permissible error 5%). The calculated sample size in this study was found to be 42.

2.2. Energy Analysis

A standard procedure was used to convert each agricultural input and output into energy equivalents (Table 1). Inputs in grape production included: human labor, machinery, diesel fuel, farmyard manure, chemical fertilizer, chemicals and electricity. The output was considered grape. The energy equivalents given in Table 1 were used to calculate the input amounts.

(Table 1)

The input and output were calculated per hectare and then, these input and output data were multiplied by the coefficient of energy equivalents. Following the calculation of energy input and output values, the energy use efficiency, energy productivity and specific energy were determined (Mohammadi et al., 2008):

$$\text{Energy use efficiency} = \frac{\text{Energy output (MJ ha}^{-1})}{\text{Energy input (MJ ha}^{-1})} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{Grape output (kg ha}^{-1})}{\text{Energy input (MJ ha}^{-1})} \quad (3)$$

$$\text{Specific energy} = \frac{\text{Energy output (MJ ha}^{-1})}{\text{Grape output (kg ha}^{-1})} \quad (4)$$

$$\text{Net energy} = \text{Energy output (MJ ha}^{-1}) - \text{Energy input (MJ ha}^{-1}) \quad (5)$$

The energy use efficiency is the ratio between the output products and the total sequestered energy in the production inputs. The energy use efficiency gives an indication of how much energy was produced per unit of energy utilized. The energy productivity provides quantitative data on how much grape is obtained per unit of input energy. The specific energy provides quantitative data on how much input energy is consumed per unit of grape yield.

2.3. DEA method

DEA method has been wildly used to determine the relative efficiency of a number of producer units. The

CCR and BCC models are two models for applying DEA. The CCR model is based on CRS (Constant Returns to Scale) model; while, the BCC model is based on VRS (Variable Returns to Scale) model. In this study, the DEA method with both models mentioned were applied to identify efficient and inefficient producers from energy point of view.

Decision Making Units (DMUs) are a collections or teams of producers who used identical inputs in grape production process. In this study DMU, refers to each grape orchard (1 orchard = 1 DMU) (Nabavi-Pelesaraei et al., 2014a). Technical efficiency is basically a measure by which DMUs are evaluated for their performance relative to the performance of other DMUs in consideration. The TE can be defined as follows (Mohammadi et al., 2013):

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \ldots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \ldots + v_m x_{mj}} = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \quad (6)$$

Where, ur, is the weight given to output n; yr, is the amount of output n; vs, is the weight given to input n; xs, is the amount of input n; r, is number of outputs (r = 1, 2, n); s, is number of inputs (s = 1, 2... m) and j, represents jth of DMUs (j = 1, 2, k).

To solve Eq. (1), following Linear Programming (LP) was formulated:

$$\text{Maximize} \quad \theta = \sum_{r=1}^{n} u_r y_{rj}$$

$$\text{Subjected to} \quad \sum_{r=1}^{n} u_r y_{rj} - \sum_{s=1}^{m} v_s x_{sj} \le 0 \quad (7)$$

$$\sum_{s=1}^{m} v_s x_{sj} = 1$$

$$u_r \ge 0, \ v_s \ge 0, \quad \text{and (i and j= 1, 2, 3, ..., k)}$$

Where θ is the technical efficiency, Eq. (7) is known as the input oriented CCR DEA model assumes constant returns to scale (CRS) (Avkiran, 2001).

The Pure Technical Efficiency (PTE) measures how a DMU utilizes the resources under exogenous environments; a low PTE implies that the DMU inefficiently manages its resources. In another word, PTE is the technical efficiency of BCC model. On the other hand BCC model decomposes the technical efficiency into pure technical efficiency for management factors and scale efficiency for scale factors. Thus, pure technical efficiency is the technical efficiency that has the effect of scale efficiency removed (Khoshnevisan et al., 2014).

The dual model is derived by construction from the standard inequality form of linear programming. Mousavi-Avval et al. (2011) expressed it by Dual Linear Program (DLP) as follows:

$$\text{Maximize} \quad z = uy_i - u_i$$

$$\text{Subjected to} \quad vx_i = 1 \quad (8)$$

$$-vX + uY - u_o e \le 0$$

$$v \ge 0, \ u \ge 0 \ \text{ and } \ u_o \ \text{free in sing}$$

where z and u0 are scalar and free in sign; u and v are output and input weight matrixes, and Y and X are the corresponding output and input matrixes, respectively. The letters xi and yi refer to the inputs and output of ith DMU.

The quantitative information of scale characteristics can be obtain from Scale efficiency; Also, scale efficiency is the potential productivity gain from achieving optimal size of a DMU (Reyhani-Farashah et al., 2013). If a DMU is fully efficient in both the technical and pure technical efficiency scores, it is operating at the most productive scale size. If a DMU has the full pure technical efficiency score, but a low technical efficiency score, then it is locally efficient but not globally efficient due to its scale size. Thus, it is reasonable to characterize the scale efficiency of a DMU by the ratio of the two scores (Mobtaker et al., 2012). The relationship between technical and pure technical efficiency scores can be described by Mousavi-Avval et al. (2012):

$$\text{Scale efficiency} = \frac{\text{Technical efficiency}}{\text{Pure technical efficiency}} \quad (9)$$

Using scale efficiency helps farmers to find the effect of farm size on efficiency of production. Simply, it indicates that some part of inefficiency refers to inappropriate size of DMU, and if DMU moved toward the best size the overall efficiency (technical) can be improved at the same level of technologies (inputs) (Nassiri and Singh, 2009). If a farm is fully efficient in both the technical and pure technical efficiency scores, it is operating at the most productive scale size. On the other hand if a farm has the high pure technical efficiency score, but a low technical efficiency score, then it is locally efficient but not globally efficient due to its scale size. Thus, it is reasonable to characterize the scale efficiency of a DMU by the ratio of the two scores (Nabavi-Pelesaraei et al., 2014a).

2.4. CO_2 emissions

Application of these inputs leads to emission of CO_2. Thus, an understanding of the emissions expressed in kg CE (kilograms of carbon equivalent) for different agricultural operations is essential to identify C-efficient alternatives such as bio fuels and renewable energy sources (Lal, 2004; Khoshnevisan et al. 2014). The CO_2 emissions of grape production were computed by the standard coefficients of CO_2 emissions for each input (Table 2).

4. Results and Discussion

3-1- Analysis of input-output energy use in grape production

The inputs used in grape production, units, quantity per unit area, total energy equivalent and the percentage of each input are shown in Table 3. The results illustrated that around 319.14 hours of human labor and 31.55 hours of machinery power per hectare were used in this studied area. Fertilizers including (Nitrogen, Phosphate, Farmyard manure and Potassium) with 12695.87 MJ ha^{-1} and 60.49% of total inputs had the highest share in grape production. After that diesel fuel with 5161.75 MJ ha^{-1} and 24.7% of total inputs had the highest share. The total energy input for various processes in grape production was calculated to be 20894.38 MJ ha^{-1} (Table3). Chemicals including (pesticides and fungicides) with 203.6 MJ ha^{-1} and 0.98% of total inputs and electricity with .003MJha^{-1} had the least shares. Hamedani et al. (2011) concluded that the total energy input for grape production in Hamedan province of Iran was found to be 45213.66 MJ ha^{-1}. Water for irrigation with 229.59 MJ ha^{-1} and 1.1% of total inputs had a little share in the production. Also, they reported that the grape production consumed 550.4 MJ ha^{-1} of chemicals, (1.2% of total inputs). The average yield of grape production was obtained to be 7209.52 kg ha^{-1} (Table 3).

3.2. Identifying efficient and inefficient orchards

The results of BCC and CCR are models are illustrated in Fig 2. The results showed that from 42 orchards, considered for the analysis, 7 units (16.6% of total units) and 10 units (23.8% of total units) had the technical and pure technical efficiency score of 1 and they are recognized as technically and pure technically efficient farmers, respectively: so, they have no reduction potential on energy use. From efficient farmers 8 ones had a scale efficiency of unity. From inefficient farmers 4 (0.09%) and 21 (50%) ones had technical and pure technical efficiency scores 0.8 to 0.99.

The summarized statistics for the three estimated measures of efficiency based on technical, pure technical and scale efficiency are presented in Table 5. The results revealed that the average values of technical (global), pure technical (local) and scale efficiency scores were 0.668, 0.857 and 0.797, respectively. The minimum amount of technical efficiency was found to be 0.44. The wide range in the technical efficiency of farmers shows that all the farmers were not aware of the on time usage of the inputs and did not apply them at the proper amount (Mohammadi et al. 2013). In another study on alfalfa production, TE, PTE and SE of farmers were calculated as 0.84, 0.97 and 0.89, respectively (Mobtaker et al. 2012) as it can be seen; the difference between the best (max) and the worst (min) units was very high for both technical and pure technical methods. These results demonstrated that the energy use pattern in the studied area wasn't normative. Because, the orchardists had different levels of education and some of them used old methods for grape production.

3.3. Analysis of CO_2 emissions

CO_2 producer inputs used in grape production are shown in Table 6. Accordingly chemicals including (pesticides and fungicides) with 584.01 had the highest share. Fertilizers including (Nitrogen, Phosphate and Potassium) with 229.94 kg$CO_{2eq.}$ ha^{-1} and machinery with 140.44 kg$CO_{2eq.}$ ha^{-1} had the 3rd and 4th place in CO_2 emissions, respectively. Electricity with 0.00015 kg$CO_{2eq.}$ ha^{-1} had the least share because the amount of electricity used for grape production in this area was little. So, it can be said that the energy consumption had a direct relationship with CO_2 emissions.

Conclusion

In this study the non-parametric method of DEA was used to analyze the efficiency of grape orchards in Iran. Moreover CO2 emissions pattern of grape production was investigated for this studied area. Based on the results of the investigations, the following conclusions are drawn:

1- Total energy input and output for grape production were found to be 20894.38 and 85072.38 MJ ha^{-1}, respectively.

2- From 42 orchards considered for the analysis, 23.8% and 16.6% of orchardists were found to be pure technical and technically efficient, respectively.

3- The technical, pure technical and scale efficiency were found to be 0.668, 0.857 and 0.797 respectively.

4- The energy use efficiency, energy productivity and specific energy were found to be 4.14, 0.35 and 2.90, respectively.

5- The total CO2 emissions were estimated to be 1207.37 kgCO2eq. ha^{-1}. Chemicals including (pesticides and fungicides) and diesel fuel had the highest share in emitting CO2.

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Table 1

Energy equivalent of inputs and output in agricultural production

Inputs (unit)	Unit	Energy equivalent (MJ unit^{-1})	Reference
A. Inputs			
1. Human labor	h	1.96	(Mobtaker et al., 2012)
2. Machinery	h	62.70	(Nabavi-Pelesaraei et al., 2013)
3. Diesel fuel	L	56.31	(Barber, 2003)
4. Total fertilizers	kg		
(a) Nitrogen		66.14	(Mousavi-Avval et al., 2011)
(b) Phosphate		12.44	(Unakitan et al., 2010)
(c) Potassium		11.15	(Pahlavan et al., 2011)
(d) Farmyard manure	kg	0.3	(Nabavi-Pelesaraei et al., 2014a)
5. Chemicals	kg		
(a) Pesticide		199	(Nabavi-Pelesaraei et al., 2014a)
(b) Fungicide		92	(Ozkan et al., 2004)
6. Water for irrigation	m^3	1.02	(Hamedani et al., 2011)
7. Electricity	kWh	11.93	(Nabavi-Pelesaraei et al., 2014a)
B. Output			
grape	kg	11.8	(Hamedani et al., 2011)

Table 2
GHG emissions coefficients of agricultural inputs

Input	Unit	CO_2 Coefficient (kg $CO_{2eq.}$ $unit^{-1}$)	Reference
1. Machinery	MJ	0.071	(Nabavi-Pelesaraei et al., 2014c)
2. Diesel fuel	L	2.76	(Khoshnevisan et al., 2014)
3. Total fertilizers	kg		
(a) Nitrogen		1.3	(Nabavi-Pelesaraei et al., 2014c)
(b) Phosphate		0.2	(Pishgar-Komleh et al., 2012)
(c) Potassium		0.2	(Khoshnevisan et al., 2014)
4. Chemicals	kg		
(a) Pesticides		5.1	(Lal, 2004)
(b) Fungicide		3.9	(Lal, 2004)
5. Electricity	KWh	0.608	(Khoshnevisan et al., 2014)

Table 3:
Amounts of inputs, output and energy inputs and output for grape production in Abhar, Zanjan, Iran

Inputs (unit)	Quantity per unit area (ha)	Total energy equivalent (MJ ha^{-1})	Percentages (%)
A. Inputs			
1. Human labor (h)	319.14	625.52	2.99
2. Machinery (h)	31.55	1978.04	9.47
3. Diesel fuel (L)	91.67	5161.75	24.7
4. Total fertilizers (kg)			
(a) Nitrogen	121.6	8042.3	38.49
(b) Phosphate	110	1368.4	6.55
(c) Potassium	249.29	2779.53	13.03
(d) Farmyard manure	1685.47	505.64	2.42
5. Chemicals (kg)			
(a) Pesticide	83.65	166.47	0.8
(b) Fungicide	40.36	37.13	0.18
6. Water for irrigation	225.08	229.59	1.1
7. Electricity	0.00025	0.003	0.001
The total energy input (MJ)		20894.38	
B. Output			
Grape (kg)	7209.52	85072.38	

Table 4:
Quantity of energy forms and input-output ratio for grape production in Zanjan province, Iran

Items	Unit	Quantity
Total energy consumption	MJ ha^{-1}	20894.38
Direct energy [a]	MJ ha^{-1}	6016.86
Indirect energy [b]	MJ ha^{-1}	14877.52
Renewable energy [c]	MJ ha^{-1}	1360.75
Non-renewable energy [d]	MJ ha^{-1}	19533.63
Energy use efficiency	-	4.14
Energy productivity	kg MJ^{-1}	0.35
Specific energy	MJ kg^{-1}	2.86
Net energy gain	MJ ha^{-1}	64178.00

[a] Includes human labor, diesel fuel.
[b] Includes chemical fertilizers, pesticides, farmyard manure, machinery.
[c] Includes human labor, farmyard manure.
[d] Includes chemical fertilizers, pesticides, diesel fuel, machinery.

Table 5
Some energy parameters in grape production

Parameter	Average	SD	Min	Max
Technical efficiency	0.668	0.19	0.44	1
Pure technical efficiency	0.857	0.16	0.48	1
Scale efficiency	0.797	0.21	0.44	1

Table 6
Greenhouse gas emissions of inputs in grape production.

Input	Quantity per unit area (ha)	CO_2 emissions ($kgCO_{2eq.}$ ha^{-1})
1. Machinery	1978.04	140.44
2. Diesel fuel	91.66	252.98
3. Total fertilizers		
(a) Nitrogen	121.6	158.08
(b) Phosphate	110	22.00
(c) Potassium	249.29	49.86
4. Chemicals		
(a) Pesticide	83.65	426.61
(b) Fungicide	40.36	157.4
5. Electricity	0.00025	0.00015
Total CO_2 emissions	2674.60025	1207.37

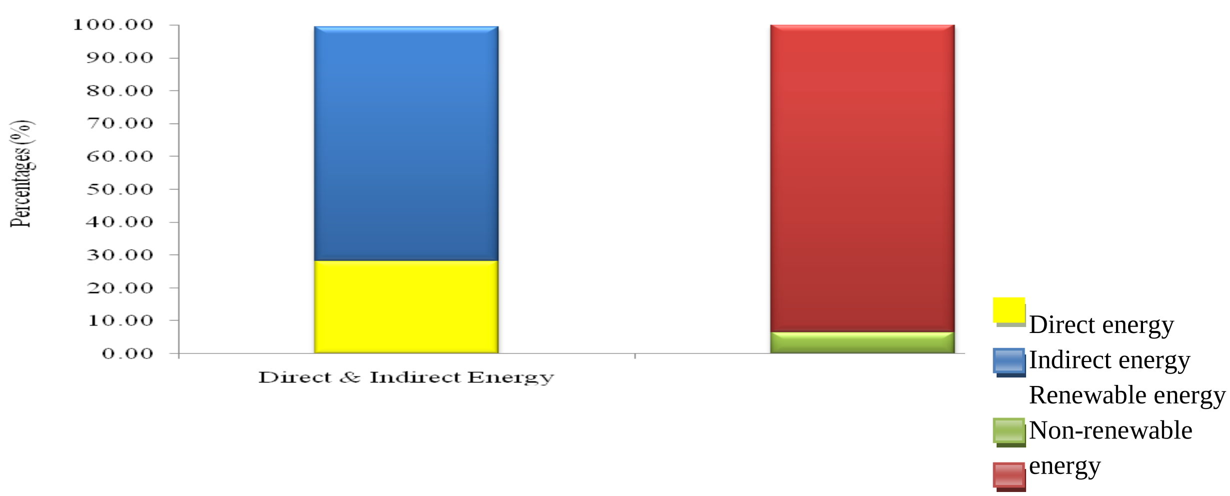

Figure 1:
Share of total mean energy inputs as direct (DE), indirect (IDE), renewable (RE) and non- renewable (NRE) forms

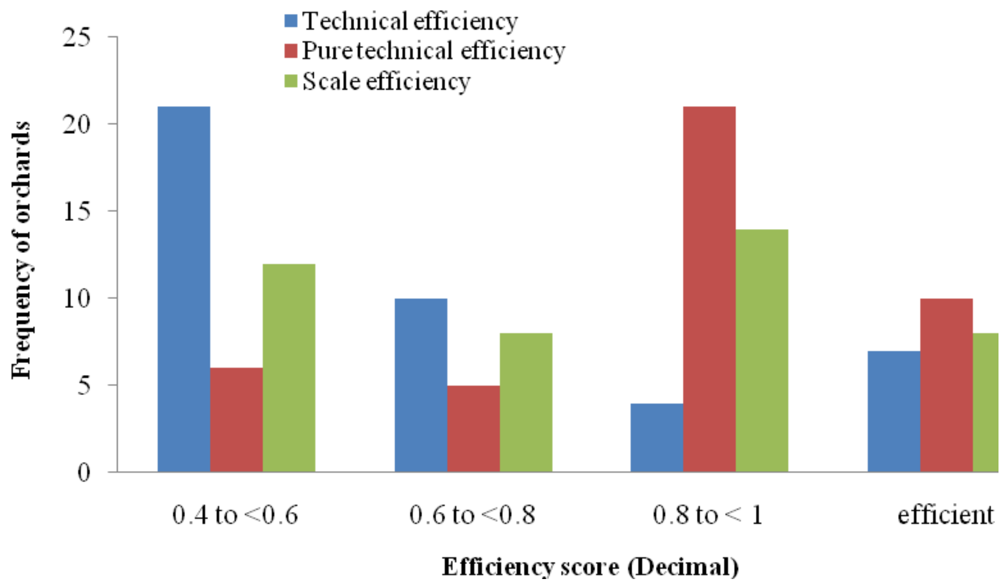

Figure 2:

Efficiency score distribution of grape producers

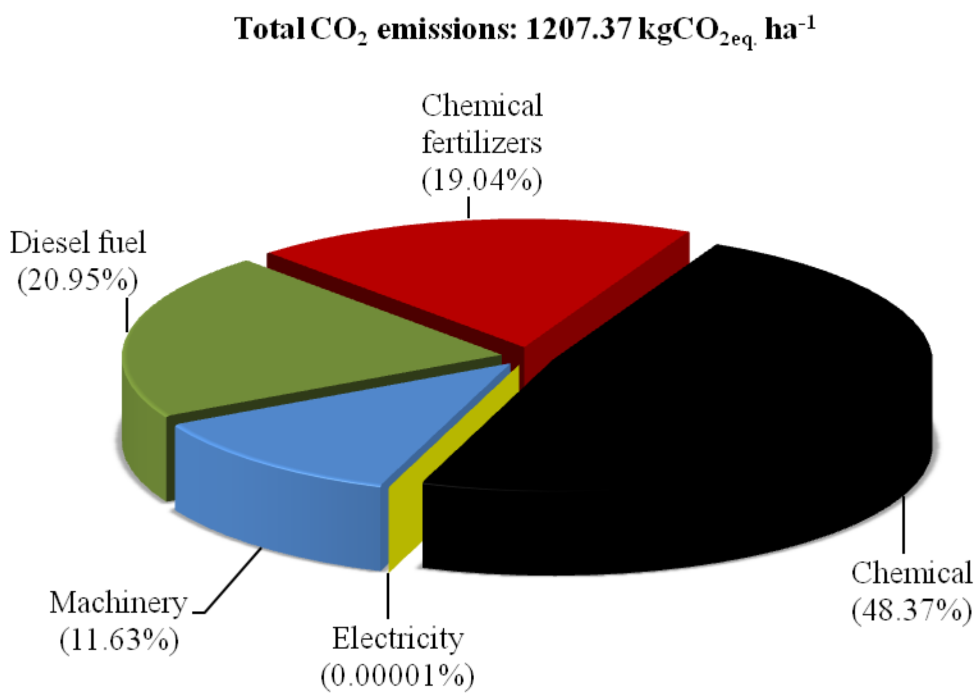

Figure 3:
Share of each input in CO_2 emissions for grape producti