Study on energy use efficiency for fennel essential oil production in Iran: A case study of Golkaran agro-industrial CO.

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Abstract

In this case study we document the effects of fennel essential oil production in the view of energy efficiency for an agro-industrial company in Iran. This product process was studied both at farm level and factory level to analyse and compare the energy cost of producing 1 kg of fennel crop and accordingly one kg of essential oil. Factory sector due to its complex process was explained largely by a higher energy consumption amount compared to agricultural level that was required to accommodate the new management practices for this sector. This study demonstrates the shares for various energy forms included direct, indirect, renewable and non-renewable energy inputs and highlights the necessity to alternate renewable resources instead of non-renewable ones. In order to make the results comparable to other studies, some energy indices were calculated. Energy use efficiency (EUE) showed the inefficient use of energy in the target processes.

Keywords: Energy use efficiency; Fennel; Essential oil; Renewable resources; Agricultural sector.

1. Introduction

Fennel (*Foeniculum vulgare* Mill.) is known as an annual, biennial or perennial plant depending on the variety, and is belonged to *Apiaceae* family which is native to the Mediterranean area (Piccaglia & Marotti, 2001). Two commercially important fennel types of *Foeniculum vulgare* are bitter fennel, *Foeniculum vulgare* Mill. subsp. *Vulgare* var. *vulgare*, and sweet fennel *Foeniculum vulgare* Mill. subsp. *Vulgare* var. *dulce* (Mill.) Batt (El-Wahab , 2006).

Different forms of fennel including mature fruit and essential oil are used in food industry as flavoring agents for producing liqueurs, bread, pickles, pastries, and cheese. In addition, fennel is an ingredient of cosmetic, pharmaceutical and perfumer industry products (Kandil *et al*., 2002). Studies have shown that herbal drugs and essential oils of fennel have hepatoprotective effect (Ozbek *et al*., 2004), as well as antispasmodic effects. Diuretic, anti-inflammatory, analgesic and antioxidant activities are the other characteristics of this product (Choi & Hwang , 2004).

Energy is a key factor in the recent development of production, transport, and communication processes, as well as economic and social growth (Kofoworola & Gheewala, 2008). Meanwhile, increasing populations, limited supply of arable land and desire for an increasing standard of living has caused the energy intensification in agriculture. Agricultural sector is a consumer of energy exploited from resources in the forms of human labor, electricity, seeds, fertilizers, diesel fuels, etc. (Rafiee *et al*., 2010). Societies have expanded the use of energy inputs for the purpose of maximizing yield and minimizing labor-intensive practices, or both (Esengun *et al*., 2007). On the other hand, consumers should be cautious about adverse impacts of external inputs like massive use of fossil fuels and chemicals, phosphorus or potassium, global warming potential, loss of biodiversity, degradation of soil quality (e.g. by erosion, compaction or loss of organic matter) and pollution of water, soil and air (Nemecek *et al*., 2001). Improving sustainable agriculture is one of the solutions to this issue (Erdal *et al*., 2007). So, the outlook of energy consumption needs optimizing decisions in agricultural production systems (Sefeedpari *et al*., 2014).

Analysis of energy efficiency in food industrial processes has been the subject of many studies as beverage industry (Akinbami *et al*., 2001), sunflower oil expression, palm-kernel oil processing (Jekayinfa & Bamgboye, 2004a), cashew nut processing (Jekayinfa & Bamgboye, 2006b) and cassava-based foods (Jekayinfa & Bamgboye, 2007c). Despite of the literature review, there are relatively less published materials in relation to the entire production process of fennel essential oil.

In this study, attempt has been made to determine the energy use of fennel essential oil production in Golkaran agro-industrial Co., Iran. Also, energy use efficiency, energy productivity, specific energy, and net energy and the share of different forms of energy input, categorized as direct, indirect, renewable and nonrenewable, to fennel essential oil production are investigated.

2. Material and method

Golkaran agro-industrial Co., located in Kashan, Isfahan province, was selected to conduct this study. Kashan city is located in the center of Iran, within 33° 59′ latitude and 51° 27′ longitude (Anonymous) (Fig. 1). Based on the latest statistics in 2012, the total production of herbal and medical plant was 128046 tons in Iran which had 42.3% increase compared to year 2011. The total land area under herbal and medical plant cultivation in Isfahan province was 411 ha with total yield of 4655 tones (Anonymous).

Fig. 1. Location of the study area

The data required for the present study were collected from essential oil production process in September 2014. The above mentioned data were culled during both crop production (agricultural stage) and essential oil production (food processing stage) processes. As demonstrated in Fig. 2, the output of crop production stage (fresh cultivated fennel) was the input to the production process of essential oil.

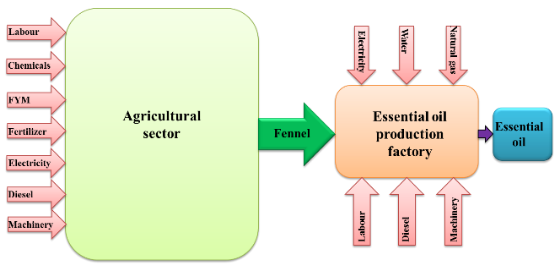

Fig. 2. System description of fennel essential oil production

Inputs to the fennel crop production in the studied region were human labor, machinery, fennel seed, farmyard manure (FYM), fertilizers, chemicals, fuel and electricity while the output was fennel plant. It is worth to note that solar energy, either as radiation or heat, is another input energy source but it is not normally taken into account, as it is considered as a free subsidy in the energetic or economic analysis of agricultural systems. All input and output amounts were measured and then converted into energy units using the energy coefficients reported on Table 3. These coefficients were adapted from several literature sources that best fit the conditions in this study. The amount of inputs used and output produced was reported on the basis of unit per hectare and then, these input data were multiplied with their corresponding energy coefficients. Generally, energy equivalents were estimated using the formula as follows (Eq. (1)):

$$E_{eq} = Q_i \times E_i \qquad (1)$$

Where E_{eq} denotes the energy equivalent of input (or output) (MJ ha^{-1}), Q_i is the input use (or output produced) value (unit ha^{-1}) and E_i represents input (or output) equivalent coefficient (MJ $unit^{-1}$).

At the next stage, fennel plants harvested from the agricultural sector were transferred to the oil essential production factory. There were four essential oil devices in the factory with maximum capacity of 6000 kg. Heating for operating steam distillation devices is provided from the facilities. The distillation process duration for extracting essential oil takes five hours. In this process, different inputs including human labor, machinery, fennel crop, fuel, electricity and water were consumed and the processed output was fennel essential oil.

The fennel seed and fennel crop energy coefficients compounded from protein (15.8 %), fat (14.87%) and carbohydrate (52.29%) and protein (1.24 %), fat (0.20 %) and carbohydrate (7.3%), respectively were calculated according to the work of Moraditochaee *et al*. (Anonymous). These shares and their corresponding energy coefficients are found in Table 1 and 2.

Table 1
Energy equivalents of fennel seed

Item	Unit	Energy coefficients (kJ $unit^{-1}$)	Physical amounts (g ha^{-1})	Energy equivalents (kJ g^{-1})	Energy coefficient References
Protein	g	17.2	158	2717.6	[17]
Total lipid (fat)	g	38.9	148.7	5784.43	[17]
Carbohydrate	g	17.2	522.9	8993.88	[17]

Table 2
Energy equivalents of fennel crop

Item	Unit	Energy coefficients (kJ unit^{-1})	Physical amounts (g ha^{-1})	Energy equivalents (kJ g^{-1})	Energy coefficient References
Protein	g	17.2	12.4	213.28	[17]
Total lipid (fat)	g	38.9	2	77.8	[17]
Carbohydrate	g	17.2	73	1255.6	[17]

In order to highlight the energy use pattern of essential oil production industry in the target company, some energy indices were estimated so that an overall overview of energy consumption was obtained; so that, comparing the results with a similar study was possible. To this end, data should be converted into output and input energy levels using equivalent energy values for each commodity and input (Garavand *et al*., 2010). The formulas used for calculating energy use efficiency (EUE), energy productivity (EP), specific energy (SE) and net energy (NE) are as follows (Rafiee *et al*., 2010) (Eq. (2) – (5)). ER and SE are integrative indices indicating the potential environmental impacts associated with the production of products. The calculated value for EP indicates the yield (kg) of product per 1 MJ of energy consumption. Also, the higher NE shows the more energy is gained from the production system. So, with carrying this analysis out, we believe that the cost of energy input to produce one kilogram of fennel essential oil can be successfully represented.

$$\text{Energy Use Efficiency} = \text{Energy Output (MJ ha}^{-1}) / \text{Energy Input (MJ ha}^{-1}) \quad (2)$$

$$\text{Energy Productivity} = \text{Yield (kg ha}^{-1}) / \text{Energy Input (MJ ha}^{-1}) \quad (3)$$

$$\text{Specific Energy} = \text{Energy Input (MJ ha}^{-1}) / \text{Yield (kg ha}^{-1}) \quad (4)$$

$$\text{Net Energy} = \text{Energy Output (MJ ha}^{-1}) - \text{Energy Input (MJ ha}^{-1}) \quad (5)$$

The energy input demand for the production processes can be divided into different forms as direct, indirect, renewable and non-renewable energies (Rafiee *et al*., 2010). Direct energy (DE) includes human labor, diesel fuel, electricity and natural gas used in the fennel essential oil production while indirect energy (IDE) sources are covered by embodied energy in chemicals, fertilizers, seeds, manure and machinery energy. Renewable energy (RE) consists of two input energies as human labor, FMY and manure whereas non-renewable energy (NRE) sources include diesel, chemical fertilizers, seeds and machinery energy.

In order to reach these aims basic information on energy inputs and yields were entered into Microsoft Excel 2013.

3. Results and discussion

3.1. *Energy analysis of agricultural stage*

The energy consumption and its sources used for essential oil production process in agricultural stage are presented in Table 3. As can be seen, the total energy used in various farm inputs is 30641.25 MJ ha^{-1}. Of all the inputs, the nitrogen fertilizer has the highest contribution in the TEI with about 37.77% share. The electricity energy was in the second rank approximate to 23.32%, mainly used for operating irrigation equipment. Then, fuels energy (9.19) followed by potassium fertilizer energy (9.10% share) were in the next ranks. The embodied energy of machinery is calculated assuming that the energy consumed for the production of the tractors and equipment is depreciated during their economical life time.

Table 3
Energy equivalents of inputs and outputs in fennel production in agricultural sector

Input/output	Unit	Energy coefficient (MJ unit^{-1})	Physical amounts (Unit ha^{-1})	Energy equivalents (MJ ha^{-1})	Percent (%)	Energy coefficient References
Inputs						
Human Labor						
Man	h	1.96	148	290.08	0.95	[19]
Woman	h	1.57	444	697.08	2.27	[19]
Machinery	h	62.7	2.5	156.75	0.51	[19]
Diesel	L	56.31	50	2815.5	9.19	[19]
Electricity	kwh	11.91	600	7146	23.32	[19]
Chemicals	kg					
Insecticides		101.2	6	607.2	1.98	
Herbicides		238	3	714	2.33	[20]
Fungicides		216	2.5	540	1.76	[20]
Fertilizer	kg					
Nitrogen		66.14	175	11574.5	37.77	[21]
Phosphorus		12.44	81	1007.64	3.29	[21]
Potassium		11.15	250	2787.5	9.10	[21]
FYM	kg	0.3	7100	2130	6.95	[20]
Seeds	kg	17.5	10	175		calculated
Output						
Fennel crop	kg	1.55	10000	15500		calculated

Table 4
Energy equivalents of inputs and outputs in fennel essential oil production in factory sector

Input/output	Unit	Energy coefficient (MJ unit^{-1})	Physical amounts (Unit ha^{-1})	Energy equivalents (MJ ha^{-1})	Percent (%)	Energy coefficient References
Inputs						
Human Labor						
Man	h	1.96	54	105.84	0.20	[19]
Machinery	h	62.7	136	8527.2	16.13	[19]
Diesel	L	56.31	135	7601.85	14.38	[19]
Electricity	kWh	11.91	837	9968.67	18.86	[19]
Natural gas	m^3	49.5	225	11137.5	21.07	[22]
Water	m^3	1.02	22.5	22.95	0.04	[20]
Fennel	kg	1.55	10000	15500	29.32	calculated
Output						
Essential oil	kg	200	91.3	18260		[22]

3.2. Energy analysis of factory stage

The same analysis for factory stage was carried out. In this process, fennel input was highly contributed in total energy consumption accounted for nearly 29.23% of TEI. Natural gas and electricity were the next highly contributed inputs to the system (Table 4). Total energy output of this process was equal to 182.6 GJ ha^{-1}.

The important observations in this case study include the comparing of various energy inputs to production process as are shown in Fig. 3. As a result, fertilizers energy should be considered in the center of attentions for its optimized use. Transition to organic and low-input practices on a sample farms is strongly suggested.

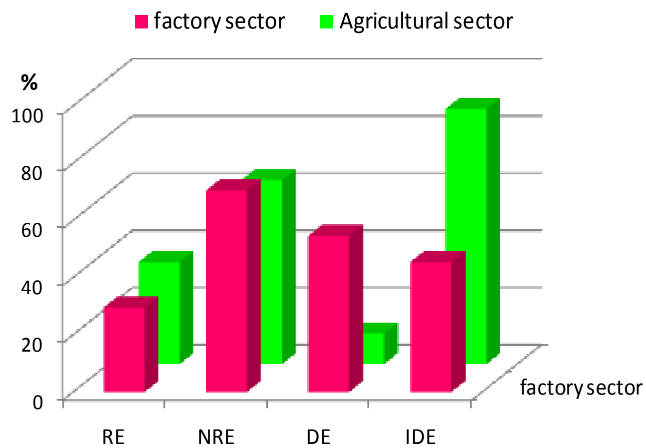

Fig. 3. The share of total mean energy inputs in fennel essential oil production

3.3. Analysis of energy forms

The energy use pattern of different forms of energy at the selected farms was another aim of this study (Fig. 4). The inputs entering the farm as non-renewable energy (machinery, diesel, electricity, natural gas, fertilizers, and chemicals) have increased in comparison to renewable sources (human labour, seeds, water, FYM) in terms of essential oil production practices. Use of direct energy inputs in the form of fuels (diesel, and natural gas and electricity), human labour and water accounted for a much smaller fraction of the total energy input (TEI) in crop production process but this value was slightly higher in factory stage (as a result of natural gas use).

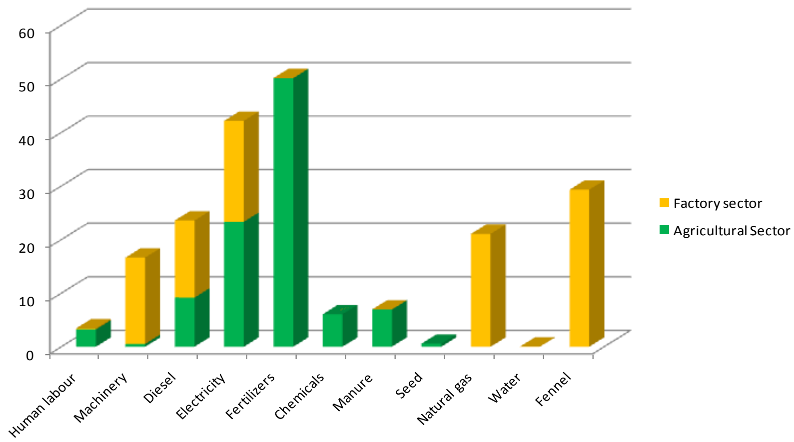

Fig. 4. The distribution of different energy inputs in essential oil production

Energy indices as EUE, EP, SE and NE are presented in Table 5 and 6. The less than unity value of EUE (0.51 and 0.345) shows the inefficient use of energy both on agricultural farms and factory sectors of studied company. This can be promoted via two major guidelines; including using less energy input and increasing the yield. Most of this inefficiency is attributable to the use of chemical fertilizers, fossil fuels and electricity while the transition to organic practices to reduce energy consuming input (inputs with higher indirect energy equivalent) and alternate the use of renewable sources is a specific management suggestion. Energy productivity was calculated as 0.33 and 0.0017 kg MJ^{-1} indicating that using 1 MJ of energy can lead to 0.33 and 0.0017 kg of the yield of fennel crop and essential oil, respectively. These indices are firstly beneficial to compare various production systems in different socio-economic regions and as the second benefit, policy makers and energy consultants are interested in these reports supporting their better decisions. The negative value of NE index was an indicator of high energy input level mainly due to high energy share of studied production process.

Table 5

Energy indices and equivalent of different energy forms in fennel crop production (agricultural sector)

Item	Unit	Quantity
Total energy input	MJ ha^{-1}	30641.25
Total energy output	MJ ha^{-1}	15500
EUE	-	0.51
EP	Kg MJ^{-1}	0.33
SE	MJ kg^{-1}	3.06
NE	MJ ha^{-1}	-15141.25
DE [a]	MJ ha^{-1}	10948.66
IDE [b]	MJ ha^{-1}	19692.6
RE [c]	MJ ha^{-1}	3292.16
NRE [d]	MJ ha^{-1}	27349.1

[a] Include human labor, diesel fuel and electricity
[b] Include machinery, chemicals, fertilizers, FYM and seeds
[c] Include human labor, FYM and seeds
[d] Include machinery, diesel fuel, electricity, chemicals and fertilizers

Table 6

Energy indices and equivalent of different energy forms in fennel essential oil production (factory sector)

Item	Unit	Quantity
Total energy input	MJ ha^{-1}	52864.01
Total energy output	MJ ha^{-1}	18260
EUE	-	0.345
EP	Kg MJ^{-1}	0.0017
SE	MJ kg^{-1}	579.01
NE	MJ ha^{-1}	-34604.01
Direct energy [a]	MJ ha^{-1}	28836.81
Indirect energy [b]	MJ ha^{-1}	24027.2
Renewable energy [c]	MJ ha^{-1}	15628.79
Nonrenewable energy [d]	MJ ha^{-1}	37235.22

[a] Include human labor, diesel fuel, electricity, natural gas and water
[b] Include machinery and fennel
[c] Include human labor, water and fennel
[d] Include machinery, diesel fuel, electricity and natural gas

4. Conclusion

In this study the energy flow of a complete product line of fennel essential oil production process (both at farm and factory levels) was measured and analyzed; so that the energy efficiency of each level was estimated. The farming sector (fennel crop production) was not energy efficient and the factory sector (essential oil production) was not efficient whatsoever. Nitrogen fertilizer and electricity were found as the inputs with much of the effect on TEI at farm level while fennel crop and natural gas were highly contributed to TEI of factory sector. Natural gas was mainly utilized to operate equipment in the factory while electricity was as the main source for factory equipment. DE sources to the farm- including (diesel fuel, human labour, electricity and natural gas) were the least important group of energy consumers in contrast to IDE sources. This was completely inverse for factory sector where DE form was bigger in value than IDE. In both sectors the use of NRE resources was more than RE inputs that highlights the need for less dependency to non-renewable sources. In fact, conducting such studies and comparing their consequences with studies on the effect of renewable inputs on the yield and energy efficiency of similar enterprises is recommended for future works. Moreover, the results of this study is addressed to government agencies and nonprofit organizations as a means of conserving energy, natural resources and reducing on- and off-farm environmental degradation. Efficiency can improve in regard to promote knowledge of farmers due to energy management, energy auditing and optimized use of resources. Moreover, replacing worn and obsolete equipment and machinery with more efficient and state-of-the-art systems is suggested. Due to this, educating farmers and managers via extension programs is essential. To make agriculture and food industry sustainable and friendlier to environment and human health, developing green energy applications such as solar energy, biogas and other renewable energy resources are suggested.

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مطالعه کارایی مصرف انرژی در فرایند اسانس گیری رازیانه : مطالعه موردی کشت‌وصنعت گلکاران

چکیده

در تحقیق حاضر فرایند تولید اسانس رازیانه ازنظر مصرف انرژی در کشت و صنعت در ایران مورد بررسی قرار گرفت. این فرایند شامل دو مرحله کاشت تا برداشت گیاه مورد و اسانس گیری بر حسب ۱ کیلوگرم رازیانه بود. واحد کارخانه اسانس گیری بالاترین مصرف انرژی را داشته است. این مطالعه نشان می دهد که از اشکال مختلف انرژی شامل مستقیم، غیر مستقیم، تجدید پذیر و تجدید ناپذیر، جایگزینی منابع تجدید پذیر به جای منابع تجدیدناپذیر الزامی است. به منظور ایجاد نتایج قابل مقایسه با مطالعات دیگر، بعضی شاخص انرژی محاسبه شد. راندمان مصرف انرژی استفاده ناکارآمد از انرژی در فرآیندها را نشان داد.

واژه‌های کلیدی: اسانس گیاه رازیانه، بخش کشاورزی ، کارایی مصرف انرژی، منابع تجدیدپذیر.