Iranian Journal of Applied Animal Science

Assessment of Renewable and Non Renewable Energy Use in Dairy Farms with Different Herd Sizes in Iran

Research Article

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Received on: 23 Sep 2018
Revised on: 13 Nov 2018
Accepted on: 15 Nov 2018
Online Published on: Sep 2019

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ABSTRACT

The aim of this study was to compare energy consumption in dairy farms with different sizes. Sources of energy include non renewable sources such as fossil fuel, and electricity and renewable sources such as forage, concentrate, machinery, labor, and water. The required data were collected from 42 dairy farms in Tehran province, Iran and were analyzed to assess energy consumption based on different herd sizes. In this study, the average consumption of non-renewable energy in small, medium, and large dairy farms per kg fat and protein corrected milk were respectively 5.95 MJ kg^{-1}, 3.39 MJ kg^{-1} and 1.71 MJ kg^{-1} ($P<0.0002$). The largest share of energy consumption in all dairy farms was related to feed; 81.49%, 84.37% and 88.62% for small, medium, and large dairy farms, respectively ($P<0.0002$). Also, energy ratio for small, medium, and large dairy farms were calculated as 0.11, 0.16 and 0.23, respectively ($P<0.0001$). Likewise, energy productivity in small, medium, and large dairy farms was 0.033 kg MJ^{-1}, 0.047 kg MJ^{-1} and 0.068 kg MJ^{-1}, respectively ($P<0.0001$). The less non-renewable energy use per kg fat and protein corrected milk in large dairy farms would lead to reduce pollution and protect the environment which in turn cause to a sustainable and more efficient production system.

KEY WORDS dairy farms, energy, energy productivity, herd size, non renewable energy.

INTRODUCTION

Today, responding to the growing need for food for increasing the world's population and providing adequate food is one of the main causes of energy requirements in agriculture operations (Bishop, 1993). In order to meet the food requirements of this population, agricultural activities are highly dependent on energy consumption in different production- agriculture systems; this dependence not only depends on the type of product but also the type of inputs used in the manufacture of that product. The diversity in the type of behavior in different systems of using the inputs and energy sources leads to differences in energy efficiency in the production system so that it can lead cause the unstable agriculture. Sustainable agriculture is defined as supplying the present needs without compromising the ability of future generations to meet consumers' requirements without any trouble (Bishop, 1993; Dovers and Handmer, 1993). Energy can be exploited from different inputs such as human labor, animal, fossil-based fuels, electricity and machinery to perform various operations in dairy production. Implementing more automatic equipment and performing mechanized operations has led to a crisis of environmental deterioration (Kraatz, 2012).

In addition, because of limitation and depletion in energy resources, the outlook of energy consumption needs to be optimized with correct decisions. Therefore, improving the management level of energy usage is crucial to combat the rising energy costs, depletion of natural resources and environmental deterioration (Dovì *et al.* 2009). Energy is one of the basic requirements for the economic and social development of a country or area. The analysis and scientific forecasts of energy consumption are important for the planning strategies and policies of energy usage (Liang *et al.* 2007). Therefore, effective energy usage is one of the key factors for sustainable agricultural production which provides financial savings, fossil resources preservation and air pollution reduction (Uhlin, 1998). On the other hand, livestock production is the poor converter of energy, because it is based on a double energy transformation. First, solar energy and soil nutrients are converted into biomass by green plants. Second, when crops are fed to livestock, a major share of energy intake is spent on keeping up body metabolism and only a small portion is used to produce meat and milk (Frorip *et al.* 2012).

Increased energy efficiency and utilization of non-renewable energy are effective to improve the air quality and also to reduce greenhouse emissions. Of other effects of increased energy efficiency could point to the reduced operating costs as well as the costs arising from agricultural production (Meul *et al.* 2007).

In order to meet the increasing demands of people to animal products, technology and methods need to be adopted to improve the efficiency of animal production; it would increase the production and reduce the environmental impacts (Capper *et al.* 2009).

Moitzi *et al.* (2010) examined the energy used with focus on the concentrate level in dairy farms in Austria. Kraatz *et al.* (2009) examined the effects of different feeds and all inputs (Kraatz, 2012) on the energy indexes in dairy farms.

Recently, Pagani *et al.* (2016) reported that a potential 40% reduction in total energy consumption could be achieved by shifting to organic farming and following some practices in dairy farms.

Uzal (2013) reported that concentrates and forage accounted for the highest percentages (95.93%) in free stall dairy farms. In another study, the highest energy use of electricity was reported as 37% related to milk cooling and heating the water with 31% (Upton *et al.* 2010), respectively. The results of a study in Qazvin province of Iran showed that total energy consumed during one year was 147659.44 MJ calf^{-1} in fattening farms (Hosseinzadeh-Bandbafha *et al.* 2017).

Sefeedpari *et al.* (2012) reported that the annual total energy consumption was 72816.7 MJ cow^{-1} in a dairy farm, where feed was the most energy consumer input (38.089 MJ cow^{-1}); then fuel, electricity and machinery usage were 7824, 1698 and 475 MJ cow^{-1}, respectively. Non-renewable and renewable energy also had 20% and 80% share of total energy consumption. Moreover, many studies (Pagani *et al.* 2016; Nacer *et al.* 2017; Koesling *et al.* 2017; Todde *et al.* 2018) were carried out about the energy consumption in dairy farms worldwide. However, to our knowledge, no research has been carried out so far about the effect of herd size on energy consumption in dairy farms of Iran.

MATERIALS AND METHODS

Selection of case study region and data collection

This study was conducted in Tehran province of Iran. Tehran has located within 35 ˚34' and 35 ˚50' north latitude and 51 ˚02' and 51 ˚36' east longitude (Anonymous, 2010). Required information was collected from dairy farms with face to face questionnaire in the west part of Tehran. The required sample size was calculated using Eq. 1 (Kizilaslan, 2009) and was estimated as 37 units but in order to have less inaccuracy, 45 questionnaires was completed and finally the information of 42 units were analyzed since some information was invalid.

$$n = Nt^2S^2 / Nd2 + t^2S^2$$

Where:

n: required sample size.

N: size of population or number of dairy farms in the study area.

t: t value at 95% confidence limit (1.96), assuming a normal distribution.

s^2: standard deviation.

d: acceptance error.

The studied dairy farms had an average milk yield of 31.94 ± 3.2 kg per day for milking cows and 195.42 ± 10.18 days in milk (Table 1). Since we aimed at comparing energy consumption and energy production among herds of different sizes, dairy farms were categorized to small farms (≤200 cows, N=24 farms), medium size (with 200-450 cows, N=11 farms) and large farms (≥450 cows, N=7 farms) based on the frequencies of each category.

Input and output energy

A number of different sources of input including human labor, machines, fuel, electricity, and feed are required for milk production. Also, energy output sources are considered as milk, meat, and manure. Energy sources can be classified into non-renewable sources such as fuel, and electricity and renewable sources such as forage, concentrate, machines, labor, and water.

Table 1 Specifications of livestock in the studied dairy farms

Variable	Unit	Average	Standard deviation	Range
Total livestock	Head	742.98	1776.76	90-11728
Milking cow	Head	363	774	40-5000
Dry cow	Head	59.49	131.21	12-880
Calves under one year	Head	170.65	528.87	25-3528
Heifer	Head	149.84	353.16	10-2320
Days in milk	Day	195.42	10.18	176-220
Production per head	kg day^{-1}	31.94	3.2	25-40
Farm production	kg day^{-1}	11910	29900	810-195000

To calculate the indirect energy used by machineries such as tractors and stationary machinery, Eq. 2 was used (Kitani, 1999):

$$ME= G \times M_p \times t / T$$

Where:
ME: machinery energy (MJ cow^{-1}).
G: material mass used for manufacturing (kg).
M: production energy of material (MJ kg^{-1}).
t: time that machine used (h cow^{-1}).
T: economic lifetime of machine (h).

Since milk is produced with different qualities in fat and protein content, as the first step, the total milk data was gained from questionnaire and then it was corrected based on fat and protein content using Eq. (3) (IDF, 2010):

Fat and protein corrected milk (kg $Year^{-1}$)= milk production (kg $year^{-1}$) × [0.1226 fat% + 0.0776 true protein% + 0.2534]

The products of a dairy farm consist of milk, meat and manure which were considered as energy outputs and estimated using the energy equivalent coefficients from Table 2.

Energy indices

In order to compare energy efficiency of dairy farms, energy indices (energy ratio (ER), net energy gain (NEG), energy productivity (EP), and specific energy (SE) were used, which are based on the Eqs. (4-7) (Mandal *et al.* 2002):

$$ER= E_{out} / E_{in}$$
$$NEG= E_{out} - E_{in}$$
$$EP=Y / E_{in}$$
$$SE=E_{in} / Y$$

Where:
ER: energy ratio.
NEG: net energy gain (MJ kg $FPCM^{-1}$).
EP: energy productivity (kg FPCM MJ^{-1}).
SE: specific energy (MJ kg $FPCM^{-1}$).
E_{out}: output energy (MJ kg $FPCM^{-1}$).
E_{in}: input energy (MJ kg $FPCM^{-1}$).
Y: kg FPCM production.

Data analysis

Data were analyzed using the general linear model (GLM) procedure of SAS 9.4 (SAS, 2015). When a significant ($P<0.05$) F-test was detected for the dairy farm sizes, the corresponding means were compared by the least significant difference (LSD).

RESULTS AND DISCUSSION

The results of input and output energy analysis are presented in Table 3. All energy calculations were performed on an annual basis. As seen in Table 3, the amount of energy consumed per kg FPCM was significantly greater in small and medium dairy farms than in large dairy farms ($P<0.0001$). The amount of energy consumed in small, medium and large dairy farms were 32.34, 21.94 and 15.30 MJ kg $FPCM^{-1}$, respectively. And, the amount of energy produced in small, medium and large dairy farms were 3.34, 3.35 and 3.9 MJ kg $FPCM^{-1}$, respectively. The results of this study show that the total energy inputs in large farms have produced better efficiency of consumption and energy production than small farms.

For example, feed energy, which has the highest share of energy consumption in all farms of this study, shows a significant difference in large farms compared to small farms ($P<0.0002$). Generally, in large farms due to better and more rigorous management; because of the better feed management and high productive potential of cows hired in large dairy farms and given the smaller part of the feed needed for maintenance energy in high potential cows, efficiency in large farms is higher (Capper *et al.* 2009). The pattern of energy intake usage relates to the energy consumption of machinery, equipment and herd size (De *et al.* 2001). In a study, energy consumption of 60 rural dairy farms (low milk production) was evaluated in India (Divya *et al.* 2012).

Table 2 Energy equivalent coefficients, energy inputs and outputs

Inputs/outputs (unit)	Energy equivalent (MJ unit^{-1})	Reference
A. Inputs		
1. Machinery		
Tractor and self-propelled (kg a*)	9	(Kitani, 1999)
Stationary equipment (kg a*)	8-10	(Kitani, 1999)
2. Human labor (h)	1.96	(Kitani, 1999)
3. Fossil fuels		
Diesel (L)	47.8	(Kitani, 1999)
Gasoline (L)	46.3	(Kitani, 1999)
Kerosene (L)	36.7	(Kitani, 1999)
Natural gas (m^3)	49.5	(Kitani, 1999)
4. Electricity (KWh)	11.93	(Ozkan *et al.* 2004)
5. Feed		
Corn silage (kg DM)	16.4	(Abasi *et al.* 2015)
Alfalfa hay (kg DM)	17.58	(Abasi *et al.* 2015)
Wheat straw (kg DM)	16.64	(Abasi *et al.* 2015)
Barley (kg DM)	17.53	(Abasi *et al.* 2015)
Corn (kg DM)	18.20	(Abasi *et al.* 2015)
Cottonseed (kg DM)	18.02	(Abasi *et al.* 2015)
Cottonseed meal (kg DM)	19.11	(Abasi *et al.* 2015)
Soybean meal (kg DM)	18.60	(Abasi *et al.* 2015)
Corn gluten (kg DM)	18.80	(Abasi *et al.* 2015)
Canola meal (kg DM)	16.88	(Abasi *et al.* 2015)
Wheat bran (kg DM)	17.64	(Abasi *et al.* 2015)
Fish meal (kg DM)	18.86	(Abasi *et al.* 2015)
Beet pulp (kg DM)	17.33	(Abasi *et al.* 2015)
Fat powder (kg DM)	31.39	(Abasi *et al.* 2015)
Linseed (kg DM)	22.10	(Abasi *et al.* 2015)
6. Water (m^3)	1.03	(Mohammadi *et al.* 2010)
B. Outputs		
1. Milk(kg DM)	24.07	(Clark *et al.* 2001)
2. Manure (kg)	0.3	(Singh and Mittal, 1992)
3. Cow meat (kg)	9.22	(Frorip *et al.* 2012)
4. Calf and heifer meat (kg)	6.5	(Frorip *et al.* 2012)

a*: economic life of machine (year).

Table 3 Energy inputs and outputs of dairy farms (MJ kg FPCM^{-1}) (Mean±SE)

Inputs/outputs	Large	Medium	Small	P-value
1. Inputs				
Human labor	0.015±0.0034^b	0.029±0.0027^a	0.035±0.0018^a	0.0001
Water	0.007±0.0008^b	0.009±0.0007^b	0.012±0.0005^a	0.0001
Electricity	0.52±0.26^b	0.90±0.21^b	1.87±0.14^a	0.0001
Fuel	1.19±0.69^b	2.49±0.55^b	4.08±0.37^a	0.0014
Machinery	0.0012±0.00044	0.0019±0.00035	0.0024±0.00024	0.0922
Feed	13.55±2.69^b	18.48±2.15^b	26.43±1.45^a	0.0002
- Forage	7.33±1.59^b	9.27±1.27^b	13.78±0.86^a	0.0009
- Concentrate	6.22±1.45^b	9.21±1.15^b	12.65±0.78^a	0.0007
Total energy input	15.28±2.79^c	21.91±2.23^b	32.43±1.51^a	0.0001
2. Outputs				
Milk	3	3	3	1
Manure	0.16±0.007^b	0.17±0.006^{ab}	0.18±0.004^a	0.0207
Meat	0.13±0.022	0.17±0.018	0.15±0.012	0.3896
Total energy output	3.29±0.023	3.35±0.019	3.34±0.013	0.1632

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SE: standard error.

The research was carried out in dairy farms at three levels of small, medium and large; the average total energy consumed per head in a period of the year was 53024.25 MJ and the highest inputs were related to feed intake with a share of more than 90%, followed by human labor.

This shows that in India, because of the very cheap labor, it is not economical to use the equipment (Divya *et al.* 2012). However, in Iranian dairy farms, the use of equipment is highly logical and cost-effective due to the high salary of the skilled workers.

The results of the study in Qazvin province of Iran showed that total energy consumed during one year was 147659.44 MJ cow^{-1} (Hosseinzadeh-Bandbafha *et al.* 2018). In Tehran province of Iran dairy farms consumes the total energy as 72816.7 MJ cow^{-1} (Sefeedpari, 2012) and in Guilan province of Iran, total energy consumption was calculated to be 52592.81 MJ cow^{-1} (Soltanali *et al.* 2015). In another study, the total energy consumption was reported to be 2.36 MJ kg FPCM^{-1} (Upton *et al.* 2013).

As seen in Table 3, the highest energy consumed was related to feed intake (forage and concentrate) whereby the feed intake energy was significantly higher in small farms (P<0.0002). However, large and medium sized dairy farms had no significant difference (Table 3). More energy has been used in dairy farms in Qazvin province of Iran; the feed energy was calculated 135079.31 MJ cow^{-1} and accounts for 91.5% of the total energy consumed (Hosseinzadeh-Bandbafha *et al.* 2017). In two similar studies in Iran, feed energy consumption was 41549 MJ cow^{-1} (Sefeedpari, 2012) and 42931 MJ cow^{-1} (Soltanali *et al.* 2015) with feed consumption energy as 78% and 82% of total energy consumed, respectively. In Finland, 67-71% of the total energy input was related to feed consumption energy (Frorip *et al.* 2012). In fattening calf farms in Qazvin province of Iran, feed energy consumption was 75% of total energy consumed (Hosseinzadeh Bandbafha *et al.* 2017).

All of these observations were consistent with the results of the current study, meaning that feed has the highest share of energy consumption in dairy farms. Management of feed intake and grouping of animals in dairy farms according to their production and offering the appropriate rations to animals, increases feed efficiency and saves the amount of feed consumed, which in turn saves energy consumption in dairy farms.

The second most important input was fossil fuels, which was used in small farms with a significant difference compared to medium and large farms (P<0.0014), but there was no significant difference between large and medium farms. The results of this study indicate that the number of cows has a direct impact on the consumption of inputs, including fossil fuels. In Qazvin province of Iran, fossil fuels energy was estimated with an average amount of 9405.23 MJ cow^{-1} and is the second most energy-consuming input after feed (Hosseinzadeh-Bandbafha *et al.* 2018).

In Guilan province of Iran, this value for each head was 6799.67 MJ (Soltanali *et al.* 2015); also, in Tehran province of Iran it was calculated as much as 8656 MJ cow^{-1} (Sefeedpari, 2012). The results of these researches, in terms of fossil fuels consumption, are in agreement with the present study, highlighting the need for the optimum use of fossil fuels, and improving or replacing the amortized machinery, equipment, and heating systems on the farm.

The lowest energy consumption was related to the input of the machinery, and equipment, which in small, medium and large farms were 0.0024, 0.0019 and 0.0012 MJ kg FPCM^{-1}, respectively (Table 3). The low consumption of machinery in farms is due to the fact that they were calculated per kg FPCM and also the use of machinery in small farms did not differ significantly from other farms. The third most consumable input was electricity (Table 3). Similar to other inputs, this input is consumed greater in small farms compared to large farms (P<0.0001).

Applying the same logic for abovementioned inputs, the results of this study indicate that the share of water energy consumption in small dairy farms is significantly higher than that of medium and large dairy farms (P<0.0001). The use of human labor in dairy farms is inevitable, even in fully mechanized farms, human labor is one of the main principles. As shown in Table 3, the human labor in small and medium farms is significantly higher than the larger farms. A similar trend of fossil fuels, electricity, and human labor use in the dairy farms was observed while as the number of animals is elevating, the amount of consumption is not ascending and is almost following a step up condition. The share of energy inputs for dairy farms is shown in Figure 1.

The main energy output of dairy farms was milk production (ranging from 89.86% to 91.19%). Hosseinzadeh-Bandbafha *et al.* (2018) reported that 91.36% of energy output was related to milk; and, 5.62% and 3.02% were related to meat and manure, respectively.

According to the results of the current study (Table 4), energy indices (energy ratio and energy productivity) were better in large dairy farms than in medium and small dairy farms (P<0.0001). Energy indices can be improved by increasing the inputs efficiency, by reducing losses of inputs per cow or by optimizing inputs. In large farms, losses of inputs are lower than small farms. Energy productivity for small, medium and large units is calculated as 0.033, 0.477 and 0.068 kg MJ^{-1}, respectively (P<0.0001).

The energy indices obtained in this study also indicates that the large farms had better performance in terms of usage and production. Hosseinzadeh-Bandbafha *et al.* (2018) reported that energy productivity of dairy farms in Qazvin province of Iran was 0.054 kg MJ^{-1}. This amount corresponded to the large and medium farms of the current study in one direction. In another study, the energy productivity was reported to be 0.12 kg MJ^{-1} (Sefeedpari, 2012).

The share of renewable and renewable energy and direct and indirect energy are shown in Figure 2. Non-renewable energy consumption was significantly higher in smaller dairy farms (P<0.0001). Non-renewable energy consumption directly affects environmental pollution and includes fossil fuels and electricity.

Table 4 Energy indices in dairy farms of different sizes (Mean±SE)

Energy indices	Unit	Large	Medium	Small	P-value
Energy ratio	-	0.23±0.012[a]	0.16±0.010[b]	0.11±0.007[c]	0.0001
Energy productivity	kg MJ^{-1}	0.068±0.004[a]	0.047±0.003[b]	0.033±0.002[c]	0.0001
Specific energy	MJ kg^{-1}	15.29±2.79[c]	21.94±2.23[b]	32.44±1.51[a]	0.0001
Net energy	MJ	-12±2.79[a]	-18.59±2.23[b]	-29.1±1.51[c]	0.0001

The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SE: standard error.

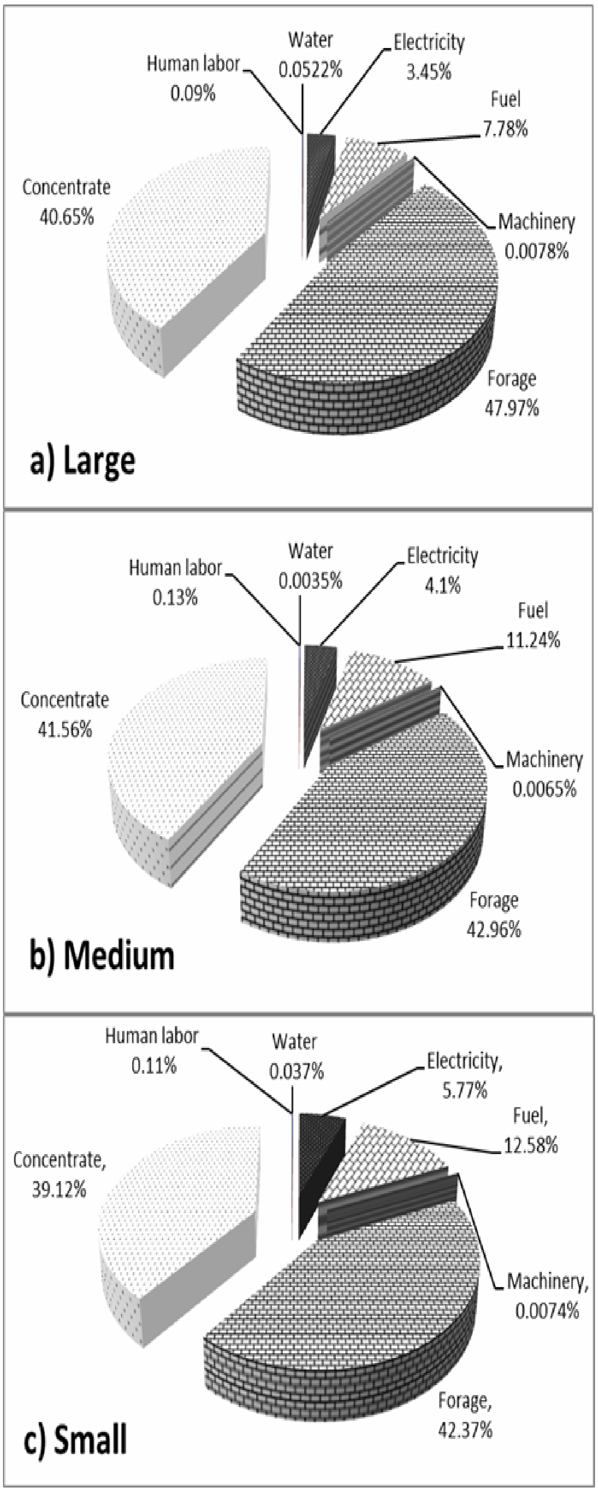

Figure 1 The share of energy inputs in dairy farms of different sizes

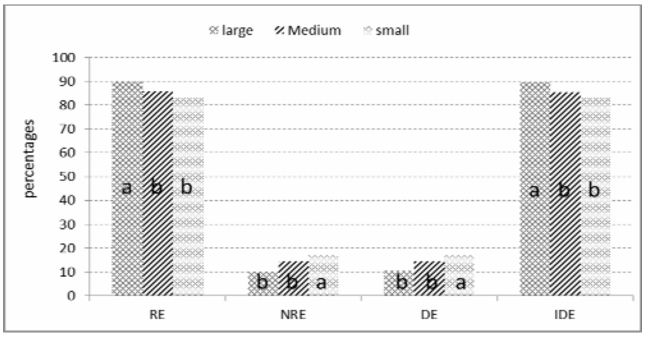

Figure 2 The share of energy inputs in dairy farms of different sizes as direct (DE), indirect (IDE), renewable (RE) and non-renewable (NRE) forms

In this study, non-renewable energy consumption was higher in small farms than large farms, which can be attributed to the high consumption of fossil fuels and electricity in these farms per kg FPCM. In other studies the share of non-renewable energy was reported to be 8.18% (Hosseinzadeh-Bandbafha *et al.* 2018) and 44.89% (Sefeedpari *et al.* 2012). In the present study, the consumption of more non-renewable energy in small and medium-sized farms was related to the inefficient use of fossil fuels for heating systems and machinery such as tractors and equipment, the amount of electricity used to ventilate the animal pens, and milking parlor, the technical performance of the milking machine and the milk cooling system.

CONCLUSION

The results of this study indicate that energy consumption per kg FPCM in large dairy farms is more efficient. Among the inputs fed to the system, energy of feed (forage, and concentrate) accounts for the highest share of energy consumption in dairy farms. The amount of non-renewable energy was lower in large dairy farms, which indicates the impact of herd size on energy consumption. According to the energy indices in small dairy farms, lower energy productivity was observed per kg FPCM. The reason for the higher consumption of inputs in small dairy farms was due to the lower losses occurred in large dairy farms because of better management. In fact, there are other factors in improving the energy consumption per kg FPCM, including farm management, genetic potential of cows, feed quality, grouping cows, feeding management, etc., which has not been included in this study.

REFERENCES

Abasi A., Fazaeli H., Zahedifar M., Mirhadi A., Gerami A., Teymournejhad N. and Alavi M. (2015). Iran's Chemical Composition Tables of Livestock and Poultry. Tehran, Iran.

Anonymous. (2010). Annual agricultural statistics. Avaulable at: http://www.maj.ir.

Bishop R.C. (1993). Economic efficiency, sustainability, and biodiversity. *Ambio*. **22(2),** 69-73.

Capper J.L., Cady R. and Bauman D. (2009). The environmental impact of dairy production: 1944 compared with 2007. *J. Anim. Sci.* **87,** 2160-2167.

Clark J., Beede D., Erdman R., Goff J., Grummer R., Linn J., Pell A., Schwab C., Tomkins T. and Varga G. (2001). Nutrient requirements of dairy cattle: National Academies Press, Washington, D.C., USA.

De D., Singh R. and Chandra H. (2001). Technological impact on energy consumption in rainfed soybean cultivation in Madhya Pradesh. *Appl. Energy.* **70,** 193-213.

Divya P., Prabu M., Pandian A.S.S., Senthilkumar G. and Varathan B.J. (2012). Energy use efficiency in dairy farming of Tamilnadu. *Indian J. Energy.* **1,** 50-55.

Dovers S.R. and Handmer J.W. (1993). Contradictions in sustainability. *Environ. Conserv.* **20,** 217-222.

Dovì V.G., Friedler F., Huisingh D. and Klemeš J.J. (2009). Cleaner energy for sustainable future. *J. Clean. Prod.* **17,** 889-895.

Frorip J., Kokin E., Praks J., Poikalainen V., Ruus A., Veermäe I., Lepasalu L., Schäfer W., Mikkola H. and Ahokas J. (2012). Energy consumption in animal production-case farm study. *Agron. Res. Biosys. Engin. Special.* **1,** 39-48.

Hosseinzadeh-Bandbafha H., Safarzadeh D., Ahmadi E. and Nabavi-Pelesaraei A. (2018). Optimization of energy consumption of dairy farms using data envelopment analysis–A case study: Qazvin city of Iran. *J. Saudi Soc. Agric. Sci*. **17,** 217-228.

Hosseinzadeh Bandbafha H., Nabavi Pelesaraei A. and Shamshirband S. (2017). Investigations of energy consumption and greenhouse gas emissions of fattening farms using artificial intelligence methods. *Environ. Prog. Sustain. Energy.* **36,** 1546-1559.

IDF. (2010). Bulletin of the International Dairy Federation, the World Dairy Situation. International Dairy Federation, Brussels, Belgium.

Kitani O. (1999). CIGR Handbook of Agricultural Engineering: Energy and Biomass Engineering. American Society of Agricultural Engineers, Michigan, USA.

Kizilaslan H. (2009). Input–output energy analysis of cherries production in Tokat Province of Turkey. *Appl. Energy.* **86,** 1354-1358.

Koesling M., Hansen S. and Schueler M. (2017). Variations of energy intensities and potential for improvements in energy utilisation on conventional and organic Norwegian dairy farms. *J. Clean. Prod.* **164,** 301-314.

Kraatz S. (2012). Energy intensity in livestock operations–Modeling of dairy farming systems in Germany. *Agric. Syst.* **110,** 90-106.

Kraatz S., Berg W. and Brunsch R. (2009). Factors influencing energy demand in dairy farming. *South African J. Anim. Sci.* **39,** 132-140.

Liang Q.M., Fan Y. and Wei Y.M. (2007). Multi-regional input–output model for regional energy requirements and CO_2 emissions in China. *Energy Policy*. **35,** 1685-1700.

Mandal K., Saha K., Ghosh P., Hati K. and Bandyopadhyay K. (2002). Bioenergy and economic analysis of soybean-based crop production systems in central India. *Biomass Bioenerg.* **23,** 337-345.

Meul M., Nevens F., Reheul D. and Hofman G. (2007). Energy use efficiency of specialised dairy, arable and pig farms in Flanders. *Agric. Ecosyst. Environ.* **119,** 135-144.

Mohammadi A., Rafiee S., Mohtasebi S.S. and Rafiee H. (2010). Energy inputs–yield relationship and cost analysis of kiwifruit production in Iran. *Renew. Energy*. **35,** 1071-1075.

Moitzi G., Damm D., Weingartmann H. and Boxberger J. (2010). Analysis of energy intensity in selected Austrian dairy farms with focus on concentrate level in feeding. *Bull.Univ. Agric. Sci. Vet. Med. Cluj-Napoca. Agric.* **67,** 194-197.

Nacer T., Hamidat A. and Nadjemi O. (2016). A comprehensive method to assess the feasibility of renewable energy on Algerian dairy farms. *J. Clean. Prod.* **112,** 3631-3642.

Ozkan B., Kurklu A. and Akcaoz H. (2004). An input–output energy analysis in greenhouse vegetable production: a case study for Antalya region of Turkey. *Biomass Bioenerg.* **26,** 89-95.

Pagani M., Vittuari M., Johnson T.G. and De Menna F. (2016). An assessment of the energy footprint of dairy farms in Missouri and Emilia-Romagna. *Agric. Syst.* **145,** 116-126.

SAS Institute. (2015). SAS®/STAT Software, Release 9.4. SAS Institute, Inc., Cary, NC. USA.

Sefeedpari P. (2012). Assessment and optimization of energy consumption in dairy farm: energy efficiency. *Iranica J. Energy Environ*. **3,** 213-224.

Sefeedpari P., Rafiee S. and Akram A. (2012). The functional relationship between non-renewable energy use and milk yield in Iran. *J. Livest. Sci*. **3,** 45-51.

Singh S. and Mittal J. (1992). Energy in Production Agriculture. Mittal Publications, New Delhi, India.

Soltanali H., Emadi B., Rouhani A. and Khojastepour M. (2015). Energy consumption modeling and greenhouse gas emissions in dairy farms (case study: Guilan province, Iran). *J. Rumin. Res.* **4,** 175-193.

Todde G., Murgia L., Caria M. and Pazzona A. (2018). A Comprehensive Energy Analysis and Related Carbon Footprint of Dairy Farms, Part 2: Investigation and Modeling of Indirect Energy Requirements. *Energies*. **11(2),** 463.

Uhlin H.E. (1998). Why energy productivity is increasing: An IO analysis of Swedish agriculture. *Agric. Syst.* **56,** 443-465.

Upton J., Humphreys J., Koerkamp P.G., French P., Dillon P. and De Boer I. (2013). Energy demand on dairy farms in Ireland. *J. Dairy Sci.* **96,** 6489-6498.

Upton J., Murphy M., French P. and Dillon P. (2010). Dairy farm energy consumption. Pp. 87-97 in Natl. Dairy Conf., Teagasc, Ireland.

Uzal S. (2013). Comparison of the energy efficiency of dairy production farms using different housing systems. *Environ. Prog. Sustain. Energy*. **32,** 1202-1208.