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Energy Assessment in Product Chain of Pasteurized milk: Agronomy, Animal Farm and Processing Plant

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ABSTRACT The objectives for this study were first to understand and estimate energy consumption in each stage of production and processing of milk using regional data and second, suggesting improvement opportunities. A cradle to gate assessment of market milk was performed by separating the system into three stages: agronomy, animal farm and processing plant. Data were collected from multiple sources e.g. questionnaire, published papers, national and international databases, and the processing plant database. Throughout the study, ISO framework and International Dairy Federation guideline on life cycle assessment were used. The functional unit (FU) was one liter of pasteurized milk packaged in plastic pouch at the processing plant gate. The average energy demand for producing 1 kg of fat-protein corrected milk at farm-gate was 10.8 MJ, although for the final packaged milk, it was 12.5MJ. Main stages in overall energy use of FU were agronomy 68 %, animal farm 19 % and processing plant 13%. The average energy use for raw milk production was 2-5 times higher than previous European reports. To enhance efficiency in this sector, we need to assess other regions' potentials for feed and milk production and then to focus on agronomy stage for lower energy use by optimization of irrigation, or even importing energy intensive feed such as barley and alfalfa from other countries.

Key words: *Dairy industry, Energy efficiency, Iran, Life Cycle Assessment (LCA), Packaged milk*

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1 INTRODUCTION

Food production affects the environment in numerous ways and energy use and pollution occur at many stages in a food product's life cycle. Thus, intensifying the agricultural practices more, without occupying the remained natural ecosystems, is a recommended way to increase yield and satisfy the increasing demand of food in the world (Tilman *et al.*, 2011). As yields and the inputs needed to support those yields increase, agriculture as well as the food industry is becoming more dependent

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on energy sources (e.g. fossil fuels), either directly for plowing and industrial processes, or through the application of energy-intensive inputs such as synthetic fertilizer and packaging materials. Thus, the need exists to address these contributions more holistically and in an integrated product-oriented manner, and to succeed in that, the responsibility of food industry should be expanded from the production site to the whole product chain.

Energy is considered the driving engine for economic development and an important input determining the production cost however, Iranian government planned to remove the energy subsidies gradually. By implementation of the first phase in 2010, the energy expenditures of industries have raised sharply, which caused the industries to seek after the energy efficiency by policies and green technologies.

Iran dairy sector produces about 1.4% of the world's cow milk that corresponds to 8.405 million tons per year and from that 54% is produced in industrial animal farms, and is delivered to dairy processing plants (IDF 2011). The Iranian agriculture is heavily dependent on the non-renewable energy sources by 87% and the results of one study in Iran showed that irrigation (40.0%) and fertilizer (28.4%) had the highest share in energy consumption (Beheshti Tabar *et al.*, 2010). Normally, complex and interdependent factors affect the amount of energy used per unit of food produced including climate, soil condition, cultivation practices, fertilizer use, transportation and efficiency of equipment. In view of climatic differences, animal farm systems in Iran are often different from animal farms of the Europe, where animals may graze in green pastures for most of the year. The dairy industry in Iran usually comprises three distinct stages, namely agronomy, animal farm and processing plant.

Several studies have examined the energy requirements in the dairy sector (Thomassen *et al.*, 2008; Upton *et al.*, 2013; Wells 2001), but the focus were mainly on the European dairy systems and there is, however, a lack of research with respect to the energy performance of dairy food systems in the developing countries, or the regions with different climate. In a survey of 150 farms, Wells (2001) reported the energy usage on an average dairy farm as 1.84 Mega Joule (MJ) per kilogram (kg) raw milk with a range of 0.9-5.6 MJ kg^{-1} raw milk found in their survey data. The author recognized that farms that utilized irrigation had substantially different energy demands and the average was 1.79 MJ kg^{-1} raw milk for non-irrigated farms in comparison with 2.79 MJ kg^{-1} raw milk for irrigated farms. Moreover, regarding the data of 119 farms, Thomassen *et al.* (2008) reported 5.3 MJ kg^{-1} of raw milk, which from that 56 % was only for cultivation and transport of purchased feed. In dairy processing stage, a study has found that the average energy use of various dairy products exhibited significant large variations, ranging from 0.2 to 12.6 MJ kg^{-1} fluid-milk product across plants in different countries, which may imply significant opportunities in energy savings in the fluid- milk-processing sector (Xu and Flapper, 2009).

One of the scientifically valid methods that allow for comparisons between products is the Life Cycle Assessment (LCA). The LCA has become the most widely used methodological platform for the implementation of energy analyses of food systems from a supply chain perspective (Pelletier *et al.*, 2011). The energy demand of a product represents the direct and indirect energy use in units of Mega Joule (MJ) throughout the life cycle and it may compose of the fossil energy demand and the energies from nuclear, water, wind and solar energy in the life cycle. In a product chain, many industrial processes use the same resource for different products and co-products. Whether it is feed, fuel or even raw milk, in the absence of process-specific data, allocation of resources between main products and co-products is necessary. The

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allocation methods applied can change the results considerably.

Energy analysis studies in agri-food sectors of developing countries are essential because they need benchmarks to monitor their progress towards more efficient products. Thus, the objectives of this investigation were to quantify the energy use in life cycle of pasteurized milk and then to identify the processes that are the largest energy user in the product system, and finally opportunities for overall energy use reduction. However, researchers and policy-makers must remember that the energy use is only one factor in the production process, and there are indicators like carbon and water footprint that if all combined, may present a more complete profile of the product’s environmental performance.

2 METHOD

2.1 Life cycle assessment

The life cycle energy assessment was performed in compliance with ISO 14040: 2006. The included stages of LCA methodology were goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation of results (ISO 2006). This study was a cradle-to-factory-gate attributional life cycle abiotic energy assessment for a one-year period between 2011 and 2012. Forms of energy we accounted for were all non-renewable fossil and nuclear energy plus renewable wind, solar, geothermal and hydropower energy. Biomass energy (i.e. feed gross energy) input to the system was excluded from the calculations. To manage data and for graphical illustrations in this work, Simapro v7.3 and Ms. Excel were used depending on the needs.

2.2 Goal and scope

The primary goal was to study and understand the energy consumption pattern along the production chain of pasteurized milk in Tehran and second, to set a benchmark for future studies on energy efficiency of the dairy sector. The scope includes three separate stages. First, the agronomy stage where feeds are produced for cows. The second stage is animal farms, where milk is produced, which also included the needed transportation of feed from the local suppliers into the system. Third, processing plant where various dairy products are produced and packaged. The system under study is illustrated in Figure 1.

2.3 Functional units (FU)

The FU describes the primary function of a product system. As there are a number of studies about the energy need for raw milk production at farm-gate, we decided to report the results for both raw milk and the packaged milk, because it could provide us with the opportunity to compare our results with other studies. The raw milk at farm-gate was 1 kg of Fat-Protein Corrected Milk (FPCM) with 3.3 % protein and 4 % fat or standard milk. Milk from different animal farms with various fat and protein contents were converted to FPCM by the formula proposed by IDF (2010a) (Formula 1):

$$\text{FPCM (kg)} = \text{raw milk (kg)} * (0.337 + 0.116 * \text{fat content (\%)} + 0.06 * \text{protein content (\%)}) \quad (1)$$

The FU however, was one liter of medium-fat (2.5 % fat; 11 % milk solids) pasteurized milk, packaged in a 3-layer low-density polyethylene (LDPE) pouch, ready for use by customers at the dairy processing gate.

2.4 Description of system

Tehran region, consisting of Tehran and Alborz provinces, produces about 7.5% of the country's cow milk, and agricultural sector in this region consumed 7.8% of the national electricity needed by agriculture in 2011 (SCI 2012).

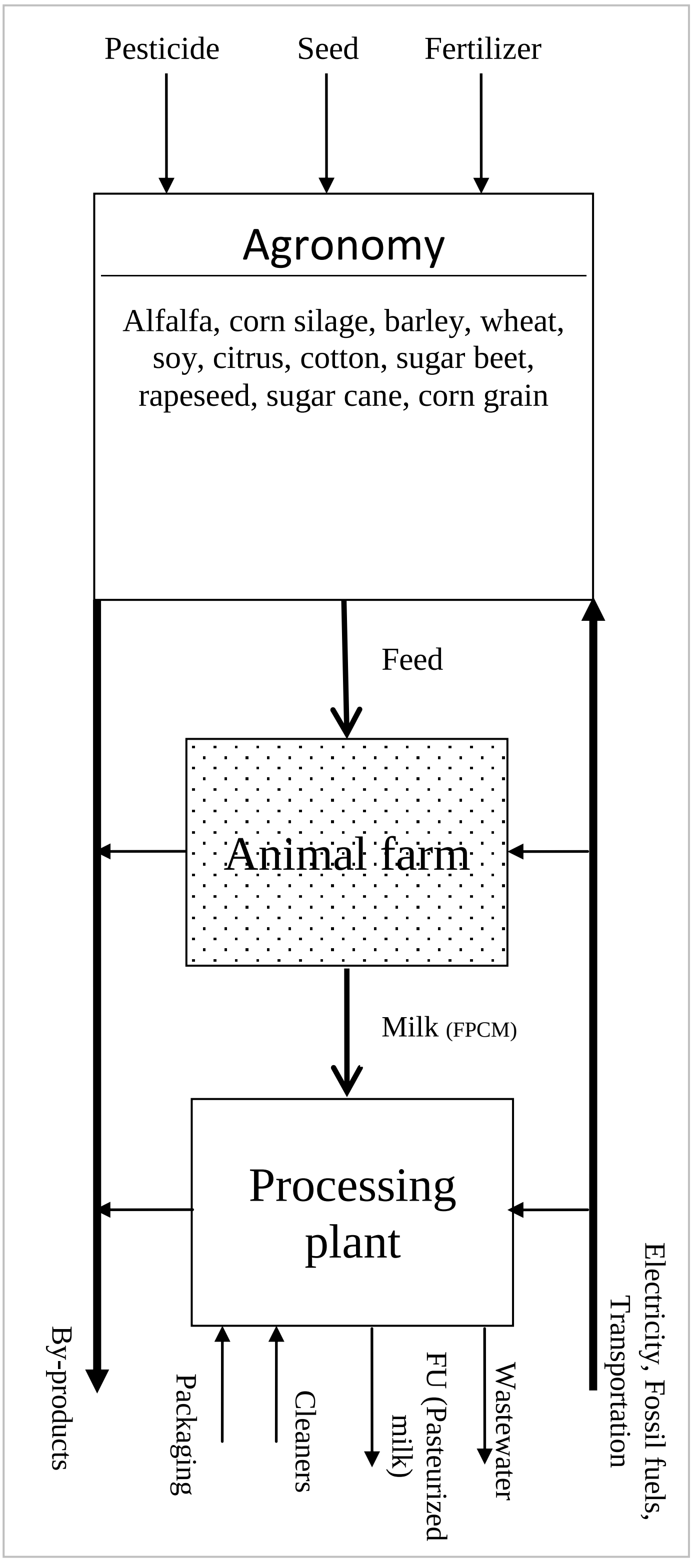

Figure 1 Dairy system in the present study

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2.4.1 Agronomy stage

The direct (e.g. diesel and electricity) and indirect energy (e.g. fertilizers, seed) use data in the agronomy stage, for the production of six main feed items of the ration, were obtained from the recently published regional studies. Those included corn silage, alfalfa, barley, wheat, sugar beet pulp and citrus pulp. For other constituents of the ration, due to the reliance of the country to import of soy meal and corn grain from the countries like Brazil, the USA, Russia and India, Ecoinvent processes were used, accordingly. For other feed items, because of lack of national data, modified Ecoinvent processes (e.g. electricity mix and transportation) were created and used (Ecoinvent, 2010). The import and export data of feeds and their country of origin, plus information about other needed agricultural commodities (e.g. fertilizers) were taken from the statistical report of Ministry of Agriculture (Anonymous, 2010) and Tehran Chamber of Commerce (TCCIM, 2012). Average Iranian diesel had 42.2 MJ kg^{-1} with a density of 0.84 kg per liter (NIOPDC, 2013). The energy value of natural gas and fuel oil were 35.53 MJ/m^3 and 44.48 MJ kg^{-1}, respectively (Zabihian and Fung 2009).

2.4.2 Animal farm stage

From over 50 animal farms that were providing raw milk to the processing plant, seven farms were selected for collecting of energy related data. All animal farms were of industrial feedlot units without grazing in pasture and they obtained feed constituents from other farmers or regions.

Data were collected using face-to-face questionnaires in 2012. The questionnaire included questions about ration and origin of feed items, daily milk weight and fat-protein content (%), meat (live weight) sold (kg), manure sold (m^3), milk transportation distance (km), electricity consumption (kWh) and diesel (L). Average feed constituents in the ration (as fed) of milking cows considering the long-term average ration, and references for the feed inventory data are presented in Table1. Major outputs of the animal farms were milk, animal live weight (meat) and manure. Meat output included surplus calves and culled milking cows. The main uses of energy on farms were groundwater withdrawal and pumping, cooling of animals in warm seasons by water spraying and ventilation, milking machine, and grains grinding to prepare the total mixed rations.

Table 1 Average share of main feed items and sources for input-output energy data

Feed item	**Average feed (as fed)/ FPCM (kg)**	**Energy demand (MJ)**	**Source of inventory**
Corn silage	0.619	0.53	(Pishgar Komleh *et al.*, 2011)
Alfalfa	0.163	11.1	(Mobtaker *et al.*, 2012)
Barley	0.156	6.28	(Azarpour, 2012)
Wheat (straw)	0.057	6.76	(Shahan *et al.*, 2008)
Sugar beet pulp	0.036	2	(Bazrgar *et al.*, 2011)
Citrus pulp	0.008	4.14	(Namdari *et al.*, 2011)
Soy meal	0.051	7.9	(ecoinvent, 2010)
Corn grain	0.051	7.22	(ecoinvent, 2010)
Rape meal	0.111	2.4	Modified ecoinvent
Cotton seed meal	0.046	3	Modified ecoinvent
Sugar cane pulp	0.008	2	Modified ecoinvent

2.4.3 Dairy processing stage

In the processing plant stage, Pegah Tehran dairy Co. with 600 ton/day capacity of milk processing, was selected as the pilot plant. The refrigerated raw milk was delivered to the dairy factory directly from farms or through milk collection centers by insulated tankers. After receiving the raw milk, it cooled immediately and stored in milk silos. Then, the milk pasteurized by high-temperature short time (HTST) method and then after cooling to 4 ^{o}C, it was sent to packaging. The direct energy use in processing plant included natural gas and electricity for heating system, cooling and wastewater treatment. The indirect energy uses in this stage were in the form of packaging material, alkaline and acid cleaners. After pasteurization treatment, milk was packaged in one-liter LDPE pouch and moved to the cold storage for distribution to retailers. Finally, aerobic activated sludge method was used for wastewater treatment.

2.5 Allocations and exclusions

In the feed production stage, allocation between each feed item and the associated co-products were based on economical method. For the animal farms, we used biophysical allocation proposed by IDF (2010) to allocate the energy use between meat (live weight) and milk. The method is based on energy requirements formula, to produce milk and animal live weight, biologically. In the processing plant, allocation of energy consumption among various dairy products was performed on the milk solid basis (Feitz *et al.,* 2007). Milk processors normally use milk solid as an important factor in quality control and pricing. For manure exported from the system, the system expansion method employed using the equivalency factors to convert manure to synthetic fertilizers. The conversion factors were 5 kg N, 2.3 kg P_2O_5 and 5 kg K_2O per ton of manure managed in solid state (Pennington *et al.*, 2009; Pouryousef *et al.,* 2010).

Exclusions from the model were human labor, infrastructure, machinery production and maintenance. Generally, cutoff criteria were set at 5 %. In agronomy, important exclusions were microelement fertilizers like Fe, Zn and Mg. On animal farms, cleaning agents, animal's vitamin supplement and medications were not considered in the inventory collection due to their insignificant contributions and lack of data.

2.6 Impact assessment

For assessing the overall impact, all the energy forms were summed to the common unit of energy, the Mega Joule (MJ).

3 RESULTS

Analyzing energy consumption in the product chain may be a basis for sustainability assessment of pasteurized milk and cost reduction, and could help policy-makers to decide reasonably about producing certain products at some regions, or trying to improve the existing product chain. The seven studied animal farms were almost similar in the sense of using machinery and energy on farms, although there was a large difference in the number of milking heads (25-1206 heads/farm) but there was a weak correlation seen between the energy use per one kilogram of FPCM and the number of milking cows (r = 0.06). As Figure 2 shows, the majority of energy use in the life cycle of pasteurized milk comes from the agronomy stage, where feeds are produced, by about 8.5 MJ per FU. The contribution of several processes at each stage is presented in Table 2.

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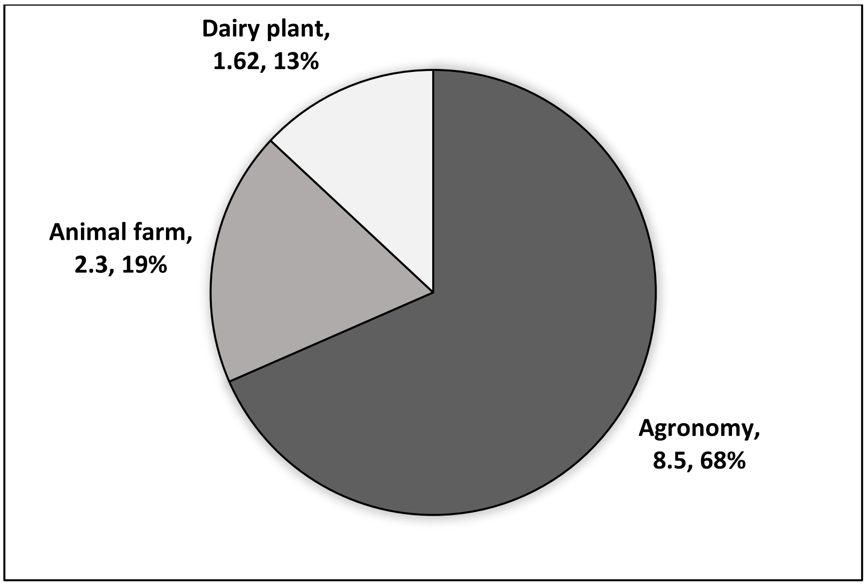

Figure 2 Energy demand of each stage (MJ per FU)

3.1 Agronomy

This stage accounts for about 68 % of the overall energy consumption and electricity, transportation, diesel and synthetic fertilizers were the main contributors to energy use per FU. Based on the data of eight dairy farms, (Cederberg and Flysjö 2004) reported 2.7 MJ kg^{-1} of energy corrected milk, of which 50 to 60 % was required for cultivation and transportation of the purchased feed. Results showed that from all the energy needed to produce one kilogram of FPCM, agronomy stage accounted for 79%. The major contributors to energy need in feed production are shown in Figure 3.

Among the feed items alfalfa, barley and corn grain were responsible for an important part of the energy use by ration per FU. Not only the mass contents of them in the rations were higher than the other minor feed items, but also they might be considered as energy intensive feeds, especially alfalfa that needs high amount of electricity for irrigation.

3.2 Animal farm

Contributions of diesel use and electricity production to the FU in the animal farm stage were 1.38 and 1.23 MJ, respectively. However, the energy saving because of the avoided product from exporting manure was 0.3 MJ/FU. In this study, the energy use per kg of FU from the animal farms was 2.3 MJ. Considering the life cycle, production of each kilogram FPCM needed 10.5 MJ up to the animal farm-gate. The result is higher than the majority of the studies where conventional dairy farms were assessed. Hartman and Sims (2006) surveyed 62 dairy farms and found the average total energy input was 3.9 MJ kg^{-1} liquid raw milk (range 3–5.4 MJ kg^{-1} liquid milk). They found that energy inputs were higher in the South Island of New Zealand where higher amount of energy were used for irrigation.

The calculated allocation factors between milk/meat, two outputs of animal farms, for different animal farms ranged from 82 to 90 %. Variation of allocation factors is perhaps because of different replacement rates, milk yields, animal mortality and herd management.

Table 2 Contribution of processes to the overall required energy of FU

Product stage	Process and Material	Energy (MJ)
Background processes to all stages	Electricity	4.1
	Diesel	2.51
	N-Fertilizer	0.97
	P-Fertilizer	0.27
	Pesticide	0.09
	Transportation	2.44
Agronomy	Barley	1.57
	Corn silage	0.38
	Alfalfa hay	3.42
	Corn grain	1.13
	Wheat Straw	0.56
	Bran	0.15
	Cottonseed meal	0.33
	Rapeseed meal	0.21
	Soy meal	0.6
	Citrus pulp	0.05
	Sugar beet pulp	0.087
	other feeds	0.088
	Sum	**8.5 (68.4%)**
Animal farm	Electricity	1.23
	Diesel	1.38
	Exported manure	-0.31
	Sum	**2.3 (19.2%)**
Processing plant	Natural gas - Boiler	0.39
	Packaging (6 gram)	0.52
	Acid cleaner	0.015
	Alkaline cleaner	0.037
	Electricity	0.36
	Transportation	0.3
	Sum	**1.62 (12.6%)**
Total	1 FPCM at farm gate	≈10.8
	1 FU	≈12.5

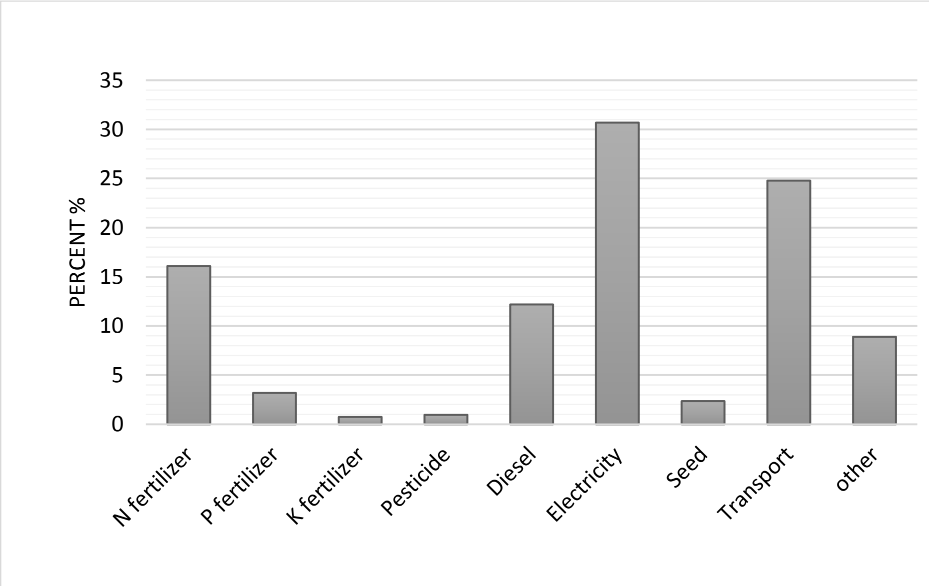

Figure 3 Relative importance of contributing processes to FU in agronomy stage

3.3 Dairy processing plant

The stage's contribution to the overall energy use were 1.62 MJ/FU or about 13 %. Milk collection from the animal farms and packaging production contributed 0.3 and 0.52 MJ/FU as indirect energy. Although electricity use and natural gas burnt in the boilers were top direct energy process in the stage by 0.35 and 0.39 MJ/FU, respectively. Packaging production is usually an energy intensive process and may cause 30 % of the energy need in the processing plant.

4 DISCUSSION

In producing the packaged pasteurized milk, about 87% (10.8 MJ kg^{-1}) of the life cycle energy demand happened in agronomy and animal farm stages for the production of raw milk before even milk entered the dairy processing plant. In an Irish study, total energy use averaged 2.36 MJ kg^{-1} of the raw milk and about 57% of the energy use was due to the application of chemical fertilizers (Upton *et al.*, 2013). In contrast, many researchers in Iran stated that the energy need of irrigation was the most important factor in determining the energy use of crops (Mobtaker *et al.*, 2012; Mohammadi *et al.*, 2013). The potential of lands and climate in the Ireland or New Zealand enables them to grow grass in pastures for the most of the yearlong with no, or minimum needs for irrigation (Upton *et al.*, 2013).

The results also showed that the energy need for packaged pasteurized milk produced in Tehran (12.5 MJ l^{-1}), was two to fivefold higher than previous reports. This may be because of higher energy intensity in each contributing process, or even lower efficiency of machineries along the pasteurized milk's life cycle. Moreover, one aspect to note is the inherent difference between the product system of milk in Iran, and previous reports from the Europe. In the present study, because of the local climate, agronomy and animal farm stages are completely separate but in the most of previous reports from temperate countries with higher precipitation, animal farms also included

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the agronomy stage, and a major share of the feed is produced within their own farms. Therefore, the need for more transportations and the high uncertainty of agronomic data in this case, are two outcomes of the differences in product system. Another process common to all the stages, due to scarcity of perennial surface water, is the need to withdraw and sometimes treat water for multiple purposes (e.g. irrigation, animal drinking and milk processing operations), which again requires extra energy use (e.g. diesel, electricity).

Efficiency of electricity production in power plants affects nearly all processes in the product chain. Of all the electricity produced in the country in 2011, only 4% was from the renewable resources. The conversion efficiency of fossil fuel to the electrical energy considering 15% loss in the grid was calculated about 26% at consumers. This means that nearly three-fourths of the energy in the fossil fuels is lost or vented as heat at power plants or through the distribution grid. The world average efficiencies of fossil-fired power generation (excluding grid loss) are 35% for coal, 45 % for natural gas and 38% for oil-fired power generation (Graus *et al.*, 2007). However, using combined heat and power plants (CHP) to capture a significant portion of the wasted heat, conversion efficiency can be improved up to the total system efficiency of 60 to 80 percent for producing electricity and thermal energy in CHP systems (Tynan 2005).

The methods to allocate energy consumption between main products and co-products can be determining on overall results. In one study, the authors reported about 8% change in energy need of raw milk when switching the allocation method between milk and meat from the biological to economic (Cederberg and Stadig 2003). Each allocation method may have its weaknesses from different points of view. Thus, to allow for comparison, the International dairy federation published an LCA guide for consistent research methodology in dairy sector (IDF 2010a). Some similar reports about milk production and processing and their allocation methods are presented in Table 3.

4.1 Agronomy

It appears that for the most of the country that lies in arid regions, growing feeds is not easy and some natural characteristics are not favorable for most of the crops. To overcome these natural conditions, farmers have to do their job using energy intensive technologies. In fact, one can grow every crop, but obviously with unacceptable costs both economically and environmentally.

The non-renewable energy demand for the production of alfalfa in Spain was 4.36 MJ kg^{-1} (dry weight) (Gallego *et al.*, 2011). This value is considerably lower than 13.6 MJ kg^{-1} alfalfa in Iran, as reported by Mobtaker et al. (2012), which means production of alfalfa in Iran needs threefold more energy than Spain. The highest contributor to the energy need of alfalfa growing in Iran was irrigation electricity (75.8%), followed by chemical fertilizers (13%). Having deep wells in the region, and not using modern and efficient irrigation methods are among the reasons of high consumption of electrical energy in the studied region in Iran.

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Table 3 Comparing the energy analysis results of similar reports from other countries

No.	**Allocation method**		**Energy demand at each life cycle stage**			**Country-Reference**
	Feed	Milk/Meat	Agronomy + Animal farm (MJ/ kg raw milk)	Processing plant	Per Functional Unit	
1	Mass	Economic	1.4	4.8	6.2 MJ l^{-1} milk, Tetra-Brik package	Spain (Hospido *et al.,* 2003)
2	Economic	Economic	2.36	×		Ireland (Upton *et al.,* 2013)
3	Economic	Economic	5	×		The Netherlands (Thomassen *et al.,* 2008)
4	Economic	Biophysical	10.8	1.62	12.5 MJ l^{-1} milk, LDPE pouch	Iran (This study)
5	Economic	Biophysical	3.9	×		France (Nguyen *et al.,* 2013)
6	Mass	System expansion	4.3	2.1	6.4 MJ l^{-1} milk, at store	Finland (Grönroos *et al.,* 2006)

Agriculture is responsible for 92 % of the annual water withdrawal in Iran, and the average irrigation efficiency in agriculture is estimated to be approximately 35% (Emadodin *et al.,* 2012). In the agronomy stage, the major part of the electricity use was because of water pumping. The electrical energy need of agronomy per FU was about 3.8 MJ. There are a number of ways to reduce the irrigation energy need for instance, to estimate the optimal need of each crop for irrigation in different regions and, to increase irrigation efficiency using new technologies like drip or sprinkle irrigation where possible. Although energy use may be higher in these newer methods, by a joint implementation of the expert's suggestions, considerable energy saving of about 34 % was possible (Abadia *et al.*, 2012). And finally to increase the water pump's energy efficiency by applying the optimum size and speed, wiring and leak avoidance (Mora *et al.,* 2013).

Soy meal and corn grain are the two main imported feed items in cow's ration in this study. To deliver 1 kg of corn grain to animal farms needed 7.9 MJ including 3.9 MJ kg^{-1} for only transportation by transoceanic freighter and truck. The Energy need for production of 1 kg of corn is found to be 2–9 MJ in the USA (Heller and Keoleian 2011). Cederberg and Flysjö (2004) reported 2.9 MJ kg^{-1} for shipping of soybean cake from the Brazil to Swedish

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dairy farms of that, 70 percent was from the ocean transport.

Urea application as N-fertilizer contributed about 8 % to the overall energy need of FU. In barley and corn silage production, about 33 % and 37 % of energy need were from N-fertilizer production, respectively. Although the energy efficiency of nitrogen fertilizer production has improved over time, this process remains as one of the most energy-demanding aspect of modern intensive agriculture. For example, of the 60 to 70 % of energy inputs to Chinese agriculture assignable to indirect sources, more than 75 % are accounted for by chemical fertilizer and pesticide production (Pelletier *et al.*, 2011). The world average energy need for production of each kilogram of urea fertilizer is 26.5 MJ. Although, a fertilizer plant built today uses some 28 % less energy per ton of urea produced in comparison to the one built 40 years ago (IFA, 2009).

4.2 Animal farms

Energy represents only 6-8 % of the operating budget of a typical dairy farm in New Zealand (IDF 2010b), but it has negative impacts on nearly all environmental impact categories. In this study, about 47 % of the energy used in animal farms was in form of electricity, mainly for milking and feed preparation, and 53 % was from the diesel use mostly for manure management. Climate dictates the type and the intensity of certain practices in the dairy farms of Iran. For instance, as Holstein cows are adapted to the cool climate of Northern Europe, they may underperform during the warm seasons. As a result, farmers use fans and water sprayers to cool cows, which obviously increase the electricity usage.

By using state-of-the-art technologies and energy efficient methods, it is possible to lower the energy expenditures of animal farms considerably. As reported by the IDF, on an average animal farm, 163 kWh/cow/year was needed, in the energy efficient farm however, this value was lowered to only 92 kWh/cow/year, which means a 43 % reduction in energy consumption for milking machineries, water pumping, milk chilling and water heating. Installation of Variable Vacuum Control of milking machine, where the level of vacuum is matched to the number of cows being milked, has reduced the electricity used by the milking machinery by 58–68% (IDF, 2010b).

There are technologies for generating electricity (or energy) that might be applicable to animal farms, for instance methane from manure, wind power and solar energy. Utilizing solar energy for electricity production and water heating can be a promising practice in the animal farms. The Tehran region has plenty of sunny days with over 500 w/m^2 solar energy potential, which makes the solar photovoltaic processes applicable (Alamdari *et al.*, 2013). Direct heating of water by the sun can be a useful way of reducing hot water heating costs. Solar water heater has an established technology in the country, and they have been used to warm water for households in some regions of the country like Yazd in previous years. It was estimated that a suitably sized solar energy collection system could save 50 % of the energy required to heat water used in a typical dairy farm (IDF 2010b). With the government's plan to remove subsidies of the energy carrier, it is expected that every sector of the economy for instance agriculture consider renewable energy sources for their operations.

4.3 Processing plant

In the pasteurized milk life cycle, about 13% (1.63 MJ/FU) of the total energy need happened in the processing plant, however, due to more control over, and similarities among industrial processes, optimization according to the best available techniques (BAT) guidelines may be possible. Our result is much higher than the average energy use for the processing of dairy

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products, as reported by the IDF (i.e. excluding packaging), which are 0.56 for milk; yoghurt 2.2 and milk powder 10 MJ kg^{-1} product. In a survey of 15 milk processing plant, the average energy need for milk processing in the Netherlands was about 1.06 MJ kg^{-1} fluid-milk. In general, studies showed that milk heat treatments accounted for 38 to 48% of the total energy use in fluid-milk processing, followed by the main supporting processes of CIP 9 % to 25 %, and refrigeration and cooling ranged from 2 % to 19 % (Xu and Flapper 2009).

The energy intensity of milk packaging can vary between 0.46 MJ for LDPE flexible pouches and 3.73 MJ per liter of milk in glass bottles (Foster *et al.*, 2007). In one study in Spain, González-García *et al.* (2013) reported the energy demand of around 12 MJ per liter of UHT milk at the factory gate. In their study, the share of dairy processing stage was about 58 %. Although it must be noted that the UHT process is an energy intensive process, and they had used Tetra-Brik packaging that had contributed about 35 % (about 2 MJ) to the energy demand by the processing plant.

Production management during the milk processing can be determining on hygiene and overall energy use of milk processing stage. For instance, managing the milk reception process to avoid delays in order to decrease the need for washing pipes and primary storage tanks, along with exact production planning to shorten the waiting time before packaging, may reduce the energy demand for cooling and stirring.

In addition, proper temperature, time and flow rate of cleaning-in-place processes and choosing pasteurization systems with a higher heat recovery rate (e.g. over 80%) may all improve the overall energy performance of a processing plant. As a general point, the shortest time from milk reception to the final distribution to market is desirable.

At the processing stage, pasteurization process is responsible for the majority of energy use in the forms of steam and ice water (Brush *et al.*, 2011). However, there are novel methods as possible replacements of pasteurization. Ultraviolet light technology is suggested as an environmentally friendly alternative to pasteurization of milk in the future with less energy need and higher milk safety. Other considered methods to remove pathogens from milk, and to increase shelf life are High Impedance Electroporation, Microwave and Pulsed Electric Field pasteurization but these are not confirmed to have less energy demand than the conventional pasteurization method yet.

In Europe, estimates show 1.2 % of milk solid waste at processing stage (Flysjö 2012). In this study however, a preliminary study showed that 3.5-5 % of all the processed milk in the processing plant is lost to the sewer system, which means that all the energy used in the production chain of the wasted milk was also in vain. Additionally, the wasted milk needs extra energy for treatment. Wastewater from processing plant contains milk and other product wastes as well as cleaning chemicals. Electricity needed for pumping and aeration in wastewater treatment by the activated sludge method may make an important part of the electricity use in a processing plant. However, there are other treatment methods with a considerably less energy need such as Up-flow Anaerobic Sludge Blanket (UASB). The UASB method not only needs less energy but also it can produce biogas, which may be used instead of natural gas in the other processes. In an industrial brewery case, wastewater treatment by UASB method decreased the energy expenditure by 60 % (Cakir and Stenstrom 2005; Scampini 2010).

5 CONCLUSION

Energy is one of the main components in livelihood of dairy sector however; the subsidies of energy carriers in Iran are

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gradually fading. Thus, obtaining energy-efficient feed inputs and modifications in production and processing of milk offer considerable opportunities to decrease energy use and to increase profit in the dairy sector. As the main determinant, agronomy consumed about 68 % (8.5 MJ) of the overall energy use to deliver feeds needed for production of raw milk, and the main contributors in this stage were irrigation and transportation. The average energy need per FU in Iran was considerably higher than the reports from the studies in developed countries.

Our results clearly showed that each stage needed more energy when compared to the values from the countries with an advanced dairy sector, however, the proportion of stages were similar. It seems local climate as well as inefficient practices are causing higher energy need in the product chain compared to previous studies. Generally, however, industrial processes at the processing plant showed fewer variations than, for instance, agricultural processes, where climatic factors play an important role.

In order to lower the energy demand in this sector, it is essential to improve irrigation efficiency, as the main hotspot, throughout the country. Another option for policy makers is to import energy intensive feeds, for instance alfalfa, from other countries with a better condition to grow them. This way, it is feasible to save the fossil energy reserves and the water resources together. Food security and the impacts from transportation of feed items into the country, however, are issues to consider.

Finally to support efficiency in this sector as a whole or in each stage and decide reasonably, we need more detail data about every individual process and sub-processes for example, electricity use for milking, water pumping, ventilation, pasteurization process and transportation alternatives and their impact on final results. Still, more detail studies are required in each stage and in other regions of the country to understand their potentials for growing feeds and producing dairy products. It is also important to consider the relationship among various factors and actors who are influencing or influenced by the Iranian dairy sector considering environmental, social and economic aspects.

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ارزیابی انرژی در زنجیره تولید شیر پاستوریزه: زراعت، دامداری و کارخانه فرآوری

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چکیده اهداف اصلی این تحقیق ابتدا فهم و برآورد مصرف انرژی در مراحل تولید و فرآوری شیر با استفاده از داده‌های منطقه‌ای و سپس ارائه پیشنهادهای لازم برای بهبود فرآیند تولید این محصول می‌باشد. فرآیند ارزیابی با جداسازی سیستم تولید محصول به سه مرحله زراعت، دامداری و فرآوری شیر انجام شد. داده‌ها از منابع مختلف مانند پرسشنامه، مقالات چاپ شده، پایگاه داده‌های ملی و بین‌المللی و پایگاه داده کارخانه فرآوری شیر جمع‌آوری شدند. در طول مطالعه، روش پیشنهادی ISO و دستورالعمل فدراسیون بین‌المللی شیر در ارزیابی چرخه حیات مورد استفاده قرار گرفتند. در این مطالعه واحد کارکردی (FU) برای بیان نتایج، یک لیتر شیر پاستوریزه (۲/۵٪ چربی) بسته‌بندی شده در کیسه‌های پلاستیکی بوده است. متوسط انرژی مورد نیاز برای تولید یک کیلوگرم شیر خام با چربی استاندارد ۱۰/۸ مگاژول به‌دست آمد. اگرچه، برای تولید شیر بسته‌بندی شده در کل ۱۲/۵مگاژول لازم بود. مصارف انرژی مراحل اصلی به‌ترتیب زراعت ۶۸ درصد، دامداری ۱۹ درصد و کارخانه فرآوری ۱۳ درصد برآورد شد. متوسط مصرف انرژی در تولید شیر خام ۲ تا ۵ برابر گزارش‌های منتشر شده اروپایی به‌دست آمد و جهت بهبود کارایی در این صنعت، لازم است تا توان دیگر مناطق برای تولید شیر و علوفه نیز سنجیده شود و سپس بر بهینه‌سازی عملیات آبیاری در بخش زراعت، برای کاهش مصرف انرژی، تمرکز شود و یا نسبت به واردات اقلام پرمصرف جیره هم‌چون یونجه و جو از کشورهای دیگر تصمیم‌گیری شود.

کلمات کلیدی: ارزیابی چرخه حیات، ایران، شیر بسته‌بندی، صنعت لبنیات، کارایی انرژی

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