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Evaluation of Environmental Parameters and Energy Consumption in Milk Powder Production

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ABSTRACT

The present study examines energy indicators and environmental impacts related to the production of milk powder in the Moghan Fertile Plain, Iran. This study evaluated energy indicators by determining the consumption and production of energy across various stages of milk powder manufacturing, including fodder supply, milk provision, and milk powder processing. Furthermore, cumulative exergy demand index was used to estimate different forms of energy consumption in the production of one ton of milk powder. In milk powder production, energy consumption across three production stages was found to be 7486.13 MJ/ton, while output energy in those stages amounted to 3063.62 MJ/ton. Consumption of natural gas, diesel, and diesel fuel amounted to 1930.5, 1864.2, and 1805.7 MJ/ton of energy consumption, respectively. These inputs were predominantly attributed to the fodder production process, indicating its significant role in energy consumption during milk powder manufacturing. In conclusion, optimizations in production and efficient energy utilization within the fodder production stage show potential to minimize energy consumption in milk powder production. The study reveals that the energy consumption during milk powder production exceeds the produced energy. With a global warming potential of 0.02 kg CO_2, emissions are minimal.

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INTRODUCTION

With the ever-increasing population growth in different countries on the one hand and the improvement of living standards and the tendency to consume more on the other, the need for food is increasing. The importance of the agricultural sector, as the most important sector in providing food, is clear. Continuous and sustainable supply of the unlimited needs and demands related to the agricultural sector by using limited resources depends on the optimal and efficient use of multiple factors of production, requiring significant multidisciplinary and comprehensive research efforts (Sharifi & Soodmand-Moghaddam, 2024). Attention to the productivity of production inputs in agriculture and efforts to increase productivity represent fundamental steps in promoting the growth and development of the agricultural sector. Growth and development in the agricultural sector relies on optimizing the productivity of production inputs for each product (Kabato et al., 2025).

As the primary source of food, the agricultural sector not only consumes a significant amount of energy but also produces energy, particularly in the form of bioenergy. However, due to the heavy reliance on various fertilizers, chemical poison, and modified seeds, there has been a noticeable shift in the energy consumption pattern. This shift has led to a heightened dependence on fossil fuel energy sources (sharifi et al., 2024). Given the importance of attention to limited natural resources and the harmful effects of improper misuse of various energy sources on human health and the environment, examining energy consumption patterns to use it effectively in the agricultural sector has become essential (Rezvani et al., 2022).

The processing and conversion of agricultural products represent a significant energy-intensive industry worldwide, but in Iran, this industry ranks as one of the major energy-consuming sectors, accounting for 25.7% of final energy consumption in 2011. These industries collectively consume at least 2% of the energy consumed in the country. Moreover, the continuous increase in demand for milk and products containing milk, coupled with projections of substantial growth in the dairy sector, suggests that energy consumption and dairy waste production will escalate. Notably, due to the energy-intensive nature of food production, preservation, and distribution, it contributes significantly to the production and emission of carbon dioxide, ultimately leading to global warming. Consumers in developed countries demonstrate a strong preference for high-quality, healthy food options with minimal negative impacts on the environment, making the dairy industry a particularly critical and economically significant sector (Reinecke et al., 2024).

The sustainable development of the dairy industry is directly influenced by environmental, social, and economic factors (Ahmad et al., 2019). Currently, the industry faces issues such as high water and energy consumption, significant waste production, and degradation of soil, water, and air. To promote the sustainable growth of the dairy industry, strategies should be employed, including the optimal utilization of water and energy resources, employing clean technologies, recycling waste, and safeguarding natural resources. The dairy industry heavily relies on human resources, so for sustainable development, it's crucial to improve workers' working and social conditions, create employment opportunities for youth, protect the rights of workers, and foster public participation in dairy industry-related decisions (Duval et al., 2021). With its significant impact on the global economy, the dairy industry ranks among the world's largest industries. To ensure its sustainable growth, strategies such as efficient resource utilization, maintaining competitiveness, expanding into new markets, and fostering exports should be implemented, while focusing on sustainable development and enhancing product and service quality for customers. Milk, a vital animal product, has long played a pivotal role in human nutrition. As its benefits and constituents have garnered appreciation and acknowledgment, it has assumed even greater prominence as a staple in daily diets (Phipps et al., 2008)

The world is witnessing a rapid surge in the consumption of milk and its products, driven by population growth and shifting consumption patterns, coupled with the heightened importance of milk and its products in human nutrition. This increased consumption is matched by a corresponding jump in milk production, reaching about 5.8 million tons in Iran annually. Iran produces approximately 10–11 million tons of milk annually, of which around 7–8 million tons are used for industrial dairy production and the remaining 3–3.5 million tons are consumed through traditional/rural channels or for personal consumption (Roustaee et al, 2023). As Iran gears up for international demand, regional and global markets, and embraces its position in the World Trade Organization, it's imperative to understand the pivotal role of transformation and complementary industries in the agricultural sector to address changing global requirements. Reflecting on the experiences of Asian countries over the last three decades, particularly China, India, and South Korea, transformation and complementary industries have indisputably played a crucial role in their rural development process. Conversion industry units typically function in semi-competitive settings, necessitating a strong focus on efficiency and productivity enhancements for steady income and profitability. Regular assessment and evaluation of efficiency enable optimum facility utilization, preventing cost imbalances and ensuring high-quality, abundant goods and services. However, the energy and environmental efficiency in Iran's food processing industry remains understudied leading to limited studies on the efficiency of individual food commodities. Current consumer trends, marked by increased environmental awareness, underscore growing attention to environmental indicators across the entire lifecycle of a product, from production to consumption. This underscores the necessity of conducting detailed studies on the energy and environmental efficiency of Iran's food processing industry, which can yield valuable insights into potential for optimization and improvement.

Life Cycle Assessment is a comprehensive methodology that evaluates the entire range of environmental impacts associated with a product, spanning its lifecycle from raw material extraction to production, consumption, recycling, and final disposal (Soodmand-Moghaddam et al., 2024). In Iran, the per capita consumption of dairy products stands at 92 kg, whereas international organizations advise a target of 160 kg per person per year. At present, milk production amounts to 110 liters per person. There exists a remarkable gap between production and consumption in the country. To bridge this gap, the country could focus on exporting powdered milk. However, export statistical trends in recent years have been suboptimal. In 2021, powdered milk exports totaled 12,595 tons, which dropped to 7,110 tons in 2022. Conversely, imports of powdered milk rose from 4996 tons to 6537 tons during the same period. Notably, these imports appear to be largely from unofficial sources. Notably, Iran boasts a surplus milk production of about 1 million tons per year, equivalent to 80,000 to 90,000 tons of milk powder. The escalating demand for powdered milk worldwide is fueled by burgeoning population growth, evolving dietary preferences, heightened globally-driven demand for healthy foods, and growing consumption of powdered milk within diverse industries. Specifically, in numerous nations, feeding programs for children encompass powdered milk consumption, while it serves as a raw material in industrialized countries for manufacturing industrial food and convenience goods. Therefore, addressing the challenges of providing milk powder globally requires concerted efforts in areas such as boosting milk production and bolstering the livestock industry in low-production regions for powdered milk production, optimizing production and transportation expenses, facilitating international trade and removing trade impediments, enhancing quality and safety in production and packaging, refining milk powder production technologies, and utilizing sustainable methods. Ultimately, effective collaboration among governments, producers, industrialists, and other relevant stakeholders is crucial to ensure a stable supply of milk powder, thereby guaranteeing access to healthy food options for global communities.

Extensive research has been conducted to explore energy consumption, economic metrics, and greenhouse gas emissions associated with various goods and systems. However, scant research has focused on the energy expenditure and environmental consequences of milk powder production. This research aims to: A. Assess the environmental indicators throughout the entire lifecycle of milk powder production using a life cycle assessment approach. B. Analyze energy aspects, including the energy ratio, energy efficiency, energy intensity, and net energy addition to factor in input and output energies during milk powder production stages. C. Developing management strategies and recommendations to enhance energy efficiency and minimize environmental impacts throughout the milk powder production process.

The following review encompasses various analyses concerning energy and environmental aspects in diverse production systems. A prime example is the examination of milk production in Spain, which involves comprehensive, high-quality data collection across numerous feed mills, farms, and dairies over a span of more than two years. Conducting LCA on this data set has enabled assessment of potential environmental impacts associated with milk production, as well as identification of potential reductions resulting from the implementation of various improvement measures, such as optimized animal feed formulation and water treatment systems. Notably, the findings suggest that, by implementing these measures, air emissions can be reduced by up to approximately 22%. This review highlights the effectiveness of targeted measures for reducing environmental impacts in the production sector, emphasizing the tangible benefits achievable through conscious intervention and optimization within this domain (Hospido et al., 2003). Aghbashlo conducted a comprehensive review highlighting the integration of exergy analysis into sustainability assessments of food production systems. Their study emphasizes the potential of exergy-based approaches to identify inefficiencies and improve resource utilization in food processing (Aghbashlo, 2023)

An analysis of energy consumption on cattle farms for the period 2009-2010, specifically at a case dairy farm, revealed that the energy balance included direct and indirect energy inputs, encompassing fuel, lubricants, electricity, fodder, grain, concentrate for young livestock, milk, and meat production. Output energy included milk, meat, and fertilizer. The energy values were obtained by multiplying the input and output values by their respective energy conversion factors. The energy output to input ratio for this case farm was calculated at 1.88 in 2009 and 1.85 in 2010, indicating the effectiveness of energy utilization. Notably, the energy input for milk production was determined at 5.4 and 5.3 MJ/kg, respectively. However, the study found that case farm energy consumption is typically higher than average European dairy farms, highlighting the need for more energy-efficient practices in this case farm (Frorip et al., 2012). Da Silva et al. explored opportunities to incorporate ecosystem services into LCA, using milk production in Brazil as a case study (Da Silva et al., 2024).

Their findings suggest that integrating ecosystem services can provide a more holistic evaluation of environmental impacts in dairy production. Despite the existence of several LCA studies on raw milk production in Iran, particularly in regions, there remains a significant gap in understanding the energy consumption patterns and environmental impacts associated with milk powder production, especially in the context of the Moghan region. This study aims to address this gap by analyzing both the energy flows and the environmental burdens linked to milk powder production in agricultural and industrial sectors. It provides insights into the contributions of different processes to environmental degradation and proposes strategies to mitigate impacts on human health, climate change, and resource depletion. To the best of our knowledge, this is the first study to comprehensively evaluate the energy and environmental profile of milk powder production in Iran using a life cycle approach.

MATERIALS AND METHODS

This study assesses the energy indicators and environmental impacts associated with the production of milk powder in the fertile plain of

Moghan, which is situated in the northernmost part of Iran and spans approximately 350,000 hectares. The investigation comprises the introduction of the study area, followed by a description of the methods employed for data collection, data analysis, and the application of life cycle assessment methodologies.

The study area

The Mughan desert in Iran has a latitude ranging from 39.20°N to 39.42°N and a longitude ranging from 47.30°E to 48.00°E. The region experiences warm, humid summers and relatively mild winters, with occasional periods of colder temperatures. The average temperature in the Mughan desert is 20.7°C and 2.75°C, while the maximum and minimum temperatures rarely exceed 40°C and -8°C, respectively. The desert has variable rainfall, with an average of 291 mm over the past 30 years. The minimum rainfall has reached 76.9 mm, while the maximum has reached 523 mm in specific years. The soils in the Mughan desert are generally classified into three types based on their physiography: river terraces, plains, and plateaus. The soil texture varies from light in the river terraces, heavy in the middle plain, to semi-heavy and heavy in the highlands. Brown soils are predominant on the plateaus, while sedimentary soils can be young or old in the riverbanks and middle plain. The soils of Mughan Plain are largely suitable for planting all crops, except those highly sensitive to soil salinity, with a pH of about 7.4 and moderate salinity. Water supply in this plain comes from the Aras River, which can be effectively used for most crops due to its water properties.

Data collection

To gather the information required to complete this study, various methods were employed, including filling out questionnaires, recording information, engaging in discussions and interviews with experts, utilizing statistics available in libraries, and accessing relevant databases.

Energy flow in milk powder production

The energy of production inputs in different systems can be divided into two main groups: direct energy and indirect energy. Direct energy is a type of energy that directly and indirectly leads to work or activity within the system. In other words, indirect energy is a type of energy that has been consumed before the system to produce inputs. Consumable inputs for the production of powdered milk are considered from the fodder production cycle to provide animal nutrition to the preparation of powdered milk. These three stages are associated with different outputs, whose output energy is reported in Table 1. The animal fodder prepared in the second stage for milk production is a part of fodder production in the first stage. 6500 cows in Agriculture and industry produce 200 tons of milk, from which 9 tons of milk powder is produced daily. This difference in the production of milk and milk powder is due to the evaporation of milk water in the milk powder production process, depending on the milk moisture and processing conditions. In general, it can be said that in standard conditions, about 1.5 to 2.5 kg of fodder is needed to produce each kg of milk. To determine the energy equivalent of inputs and outputs, energy coefficients corresponding to each were used, which are presented in Table 1. Consequently, the equivalent energy of inputs is obtained by multiplying the quantity of consumption of each input by the specific energy coefficient associated with that input, as expressed in Equation 1:

$$E_{input} = I_{consumption} \times ec_{input} \qquad (1)$$

where E_input is energy equivalent to consumed inputs in terms of megajoules, I_consumption is the number of consumed inputs (manpower, fuel, etc.) in terms of its unit and ec_(input) is the input energy content in terms of megajoules per unit.

Table 1. Standard energy coefficients of inputs and outputs for milk powder production

Title	Unit	Energy content (MJ/unit)	Reference
Fodder production process			
Manpower	H	1.96	(Nabavi-pelesaraei et al., 2014)
Tractors and self-propelled tools	*kg	9.5	(Gezer et al., 2003)
Diesel fuel	L	47.8	(Kitani et al, 1999)
Gasoline	L	46.3	(Kitani et al, 1999)
natural gas	m3	49.5	(Kitani et al, 1999)
Electricity	kWh	11.93	(Kitani et al, 1999)
Water	m3	1.02	(Pishgar-Komleh et al., 2011)
Milk production process			
wheat straw	kg	10	(Ozkan et al., 2004)
Soy	kg	25	(Beheshti Tabar et al., 2010)
fodder corn	kg	8	(Houshyar et al., 2015)
Alfalfa	kg	15.8	(Tsatsarelis and Koundouras., 1994)
Milk powder production process			
Milk	kg	7.14	(Coley et al., 1998)
Pasteurization	**kg	0.3	(Ramirez et al., 2006)
Standardization	**kg	0.1	(Ramirez et al., 2006)
preheating	**kg	2.7	(Djaeni et al., 2007)
evaporation	**kg	2.6	(Fellows, 20۲۲)
Membrane distillation	**kg	11	(Guillén-Burrieza et al., 2012)
Spray drying	**kg	4.5	(Djaeni et al., 2007)
Outputs			
Milk	kg	7.14	(Coley et al., 1998)
fodder	kg	7.43	(Ozkan et al., 2004)
milk powder	kg	16.74	(Yildirim & Genc, 2017)

kg*: economic life of the machine (years), kg**: kg of milk powder produced

Energy indicators

In this part, the energy indicators in the desired production systems were investigated, which is considered one of the most important measures in the energy analysis process. In this regard, various indicators are used. Some of these indicators that provide a comprehensive understanding of the energy situation, including energy ratio, energy efficiency and specific energy and net energy addition were calculated according to Equations 2 to 3 (Pishgar-Komleh et al., 2011).

Energy ratio = energy output (MJ/ha)/ energy input (MJ /ha) (2)

Energy productivity = performance (kg/ha) / energy input (MJ /ha) (3)

Specific Energy = energy input (MJ/ha)/ performance (kg/ha) (4)

Net Energy Gain = energy output (MJ/ha) - energy input (MJ/ha) (5)

The energy ratio shows how much energy was used to produce a product compared to the energy that was produced by that product. This ratio can be used as a measure to evaluate the energy efficiency of a production process or system. In simpler terms, the energy ratio shows how much energy was used to produce a product compared to the energy that was produced by that product. This ratio can be used as a measure to evaluate the energy efficiency of a production process or system. By reducing the energy ratio, it means less energy consumption versus more production. This reduction can be done in order to reduce energy costs, reduce environmental pollution and increase productivity in the production process. Specific Energy varies depending on the type of agricultural product, location and time, and it can be used as an index to evaluate the efficiency of energy consumption in different production systems. Specific energy refers to the energy consumption required to produce a single unit of the product or service. The unit of Specific Energy is MJ/kg. Energy Productivity means the optimal use of energy in a process, system or industry. In other words, Energy

Productivity refers to the amount of useful energy that is ultimately used to perform the desired task compared to the total energy consumption. Energy Productivity can be measured by various indicators such as energy ratio, energy intensity, total efficiency, efficiency, etc. to be.

Life cycle assessment

Life cycle assessment is used to measure all the environmental impacts of a production process or product, away from limited and deterministic perspectives, and is used to improve efficiency and reduce environmental impacts. This method consists of several steps, which include the following steps:

A. Extraction of raw materials: In this step, the natural resources required for the production of the product are carefully examined.

B. Production: In this stage, the stages of product production including production processes, transportation, packaging and other factors are examined.

C. Use: At this stage, the amount of energy and resources consumed for using the product are evaluated.

D. Recycling and disposal: In this step, the methods of recycling and disposal of waste produced in relation to the desired product are examined.

E. End of useful life: In this step, different methods are considered to end the useful life of the product.

As a result, life cycle assessment in order to improve efficiency and reduce environmental impacts is one of the effective methods used at the industry, city and national level. Using this method, it is possible to carefully examine the environmental effects of processes and products and find solutions to improve efficiency and reduce their effects. In other words, in a life cycle assessment project, all the production processes of a product, from the extraction of raw materials to the disposal of residual waste from the consumption of that product (Tagore's cradle), are examined and the results are used to reduce the harmful effects on the environment. Any life cycle assessment project to assess the environmental impacts of a product, process or service consists of four required steps. These four steps are as follows:

1. Defining the goal and scope: In this step, the goal and scope of the life cycle assessment for the desired product, process or service are defined. In other words, at this stage it should be determined what aspects of the product life should be considered. The purpose of this study is to investigate the environmental emissions of milk powder production from the point of fodder preparation and the use of inputs for milk production and converting it into milk powder in the industry. In the study of the life cycle, three types of functional units have been proposed: 1) based on surface unit; 2) based on currency; 3) Based on the weight of the product.

In this study, the functional unit is considered as one ton of milk powder. This means that all the released pollutants are calculated and reported based on the inputs used to produce one ton of product. One of the important and mandatory measures in the stage of determining the goal and scope is choosing the system boundary. The importance of the issue is determined when we know in which stages the environmental problems of the system can continue. Life cycle assessment is a Tagore cradle approach, but it is possible to consider the system boundary as a part of the whole process in order to focus more on the processes, and the results are selected based on the boundary and expressed for a smaller scale. The focus of this study starts from the production stage and the processes carried out inside the farm to prepare animal fodder and continues until the production of powdered milk inside the industry.

2. Life cycle inventory: In this stage, all stages of the product's life, from the extraction of raw materials to the disposal of waste, are examined. At this stage, various types of environmental impacts including energy consumption, greenhouse gas emissions, consumption of natural resources, air and water pollution, etc. are investigated. The Ecoinvent database is used and the corresponding life cycle inventory table is prepared.

3. Life cycle impact assessment: In this step, the environmental impacts related to the different stages of the product's life are examined. At this stage, the assessment of the

product's effects on the environment and humans, as well as determining the priorities for reducing the environmental effects are examined. The method to be studied is determined at this stage. The Recipe2016 method was chosen in this study.

4. Interpretation of the results: At this stage, solutions are proposed to improve the efficiency and reduce the environmental impact of the product. These solutions can include changes in consumables, production processes, recycling and waste disposal methods, etc. At this stage, optimization suggestions are provided to improve the efficiency and reduce the environmental impact of the product. By using these four stages, it is possible to provide a comprehensive assessment of the environmental impact of the product during its life cycle and find solutions to improve efficiency and reduce environmental impact (Figure 1). SimaPro software has been used to perform life cycle evaluation calculations.

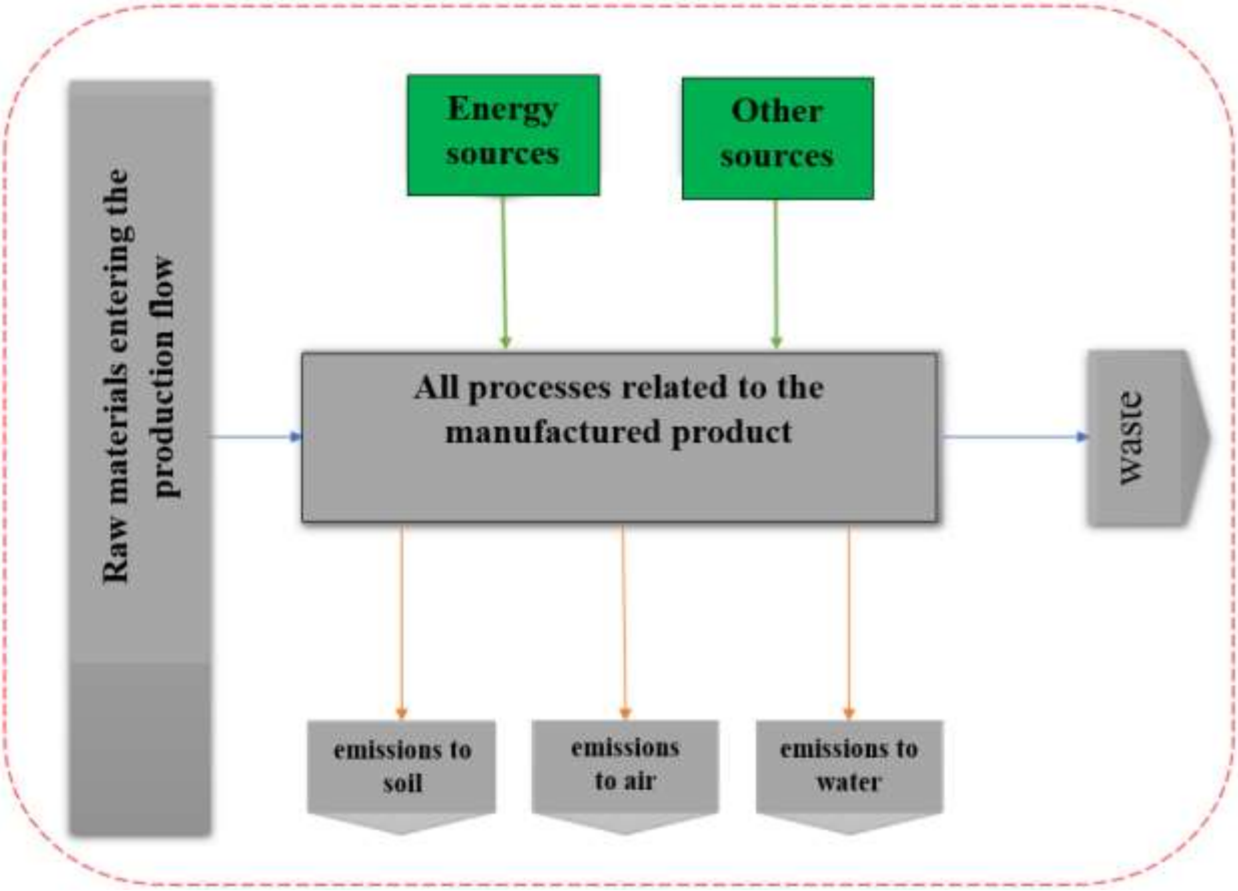

Figure 1. The life cycle of a process in a production system

Cumulative exergy demand

Exergy of the system is the amount of useful work done during a process and the ability of the system to make changes and produce energy. Exergy can be used to do useful work in the system, but after reaching equilibrium with the environment, exergy is spent. To calculate the cumulative exergy demand index, all the resources needed to produce a product or perform a process must first be identified. Then, for each of the required resources, the amount of exergy needed to analyze that resource during the process is calculated. Then, the sum of these values is calculated for all resources required during the process and is expressed as a cumulative exergy demand index. The resource that requires more exergy for its production has the greatest influence on the cumulative exergy demand index. By using this index, it is possible to improve the efficiency and productivity of processes and products and reduce their environmental effects. Cumulative exergy demand index is divided into eight sub-groups, which is defined as the removal of total exergy from nature in order to produce products or services within the desired systems. In this study, milk powder in terms of exergy demand index in the effect categories of non-renewable-fossil resources, non-renewable-nuclear resources, renewable-solar resources, renewable-potential resources, non-renewable-primary resources, renewable-water resources, non-renewable-metals and non-renewable resources. - Minerals were investigated.

RESULTS AND DISCUSSION

In this section, the energy share of each of the forage, milk and milk powder inputs is first calculated and examined. Energy indices are calculated as well as comparing these indices with the energy indices obtained for other products. The LCA in these products is then analyzed and compared with the boundary of the system and the use of Simapro software and the environmental indicators for the product under study have been analyzed and compared.

Energy flow

Many institutions and factors are involved in the human consumption control of various materials and sources, directly or indirectly . The industry can help reduce the consumption of natural resources by producing products that have been used less natural resources. Consumers can also have positive effects on the environment and natural resources by deciding on the use of different substances. Therefore, all of these factors and institutions can play an important role in controlling the use of various materials and environmental protection and natural resources. After calculating the amount of consumption of each input and production at different stages and with the same consideration of each energy, their input and output energy is obtained as shown in Table 2. All inputs are based on the production of one ton of milk production. During the production process, three stages have been taken to separate their energy consumption. The total energy input energy of the milk production in all three stages is 7486 MJ/ton and the sum of the energy of the outputs is calculated in three stages of 3063.63 MJ/ton. Natural gas, diesel fuel and diesel fuel have 1930.5, 1864.2 and 1805.7 MJ/ton, respectively. These three inputs are related to the forage production process, which indicates that this phase has the most impact on energy consumption for preparation.
In fact, operations such as cultivation, harvesting and transportation are operations that consume a lot of energy, and fuel consumption in these operations can have a significant impact on the environment. In addition, fuel consumption in these processes can also increase production costs. Therefore, optimizing energy consumption in the process of forage production can help reduce energy consumption and reduce its negative impact on the environment as well as reduce production costs. Figure 2 shows the breakdown of energy consumption in different stages. Natural gas, diesel fuel, and Gasoil have the highest share of energy consumption in the animal fodder production stage with 31%, 30%, and 29%, respectively. Substituting other sources for livestock fodder can be useful in reducing energy consumption and its negative effects on the environment. For example, other food sources can be used to meet the nutritional needs of livestock. Also, the use of other food sources can improve the nutritional efficiency of livestock. In addition, other methods can be used to reduce energy consumption in the forage production process. For example, the use of sustainable production methods such as intercropping, cultivation without irrigation, the use of organic fertilizers, and optimal management of water resources, can help reduce energy consumption in the forage production process. Also, the use of new technologies such as intelligent agricultural systems and fodder production using modern technologies such as drip irrigation and hydroponics, can help improve production efficiency and reduce energy consumption in the fodder production process.

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Table 2. Consumption of inputs, output production during milk production period

Title	Amount (MJ/ton)	Percent
Livestock Feed Production Process		
Manpower	76.44	0.98
Tractors & Vehicles	37.05	4.73
Diesel Fuel	1864.2	23.81
Diesel	1805.5	23.06
Natural Gas	1930.5	24.66
Electricity	155.09	1.98
Water	13.26	0.17
Milk Production Process		
Wheat straw	180	2.30
Soy	450	5.75
Forage corn	72	0.92
Alfalfa	142.2	1.82
Milk powder production process		
Milk	578.34	7.39
Pasteurization	2.7	0.03
Standardization	0.9	0.01
Preheating	24.3	0.31
Evaporation	23.4	0.30
Membrane Distillation	99	1.26
Spray Drying	40.5	0.52
Total energy inputs	7829.03	-
Outputs		
Milk	1428	-
Forage	2940	-
Powdered milk	150.62	-
The total energy of the outputs	4518.62	-

Soybean with 53% has a huge share in the energy consumption of feed supply for livestock. Soybean is used as one of the most important sources of protein in providing fodder for livestock and is very useful for meeting the protein needs of livestock. To provide proper nutrition for livestock, soybeans can be used as protein processes in livestock nutrition. Due to its high protein content as well as essential amino acids, soy is one of the best sources of protein for livestock. In addition, soybeans can be used as an alternative to protein sources, including plant forages, due to their high digestibility as well as the ability to absorb nitrogen from the air. Therefore, soybean, as one of the most important sources of fodder for livestock, also has a huge share in energy consumption. Milk with 75% and membrane distillation with 13% have the highest share of energy consumption in the stage of converting milk to powdered milk. The valve evaporates and moves to the next stage in the way in which high pressure and temperature are used. Then, in the membrane distillation stage with 13%, the water in the milk is evaporated with the help of polymer membranes and the milk is converted into powdered milk. In addition, other steps such as powder production also require high energy consumption. Using a multi-step distillation process instead of a membrane distillation process can help reduce energy consumption in the formula production process. Optimizing the equipment used in the formula production process can help reduce energy consumption in this process. For example, the use of more modern and higher-efficiency equipment can help reduce energy consumption in the milk powder production process.

Evaluation of energy indicators

The indicators allow us to compare the position and efficiency of product production using different energy sources, to optimize production and energy management. Therefore, to improve production efficiency, preserve the environment and reduce production costs, it is necessary to study energy indicators in the production process of a product. Table 3 reports the calculations made for energy indicators. The energy ratio is calculated to be smaller than one (0.57), which indicates that the output energy is less than the total input energy. The productivity of milk powder production was 27.85 kg/MJ and the net increase of energy for each ton of milk powder was negative. The results show that in the process of milk powder production, energy consumption is more than the energy produced. It seems that the milk powder production process in this unit has not been done using sustainable production technologies and optimization of the production process, with less energy consumption. This issue can be considered as a competitive disadvantage for this production unit in the market and does not attract customers to use the products of this production unit.

Table 3. Energy indicators in the stages of milk powder production**.**

Energy indicators	Unit	Amount
Energy Ratio	-	0.58
Energy Productivity	Kg/MJ	27.85
Specific Energy	MJ /kg	0.0346
Net Energy Gain	MJ /ton	-331.41

Life cycle assessment

The selection of the system boundary to evaluate the emission of environmental pollutants in the production of milk powder is to determine the boundaries in which the production operations and the emission of pollutants are evaluated. The selection of the system boundary can help us to examine more precisely which processes and activities in the milk powder production chain have the greatest environmental effects and what measures should be taken to improve and optimize them.
Considering that the stage of entering the inputs until the preparation of the product in the production of milk powder is important in the production chain of this product and can have significant environmental effects, choosing this stage as the boundary of the system seems reasonable and acceptable. On the other hand, to evaluate the environmental effects of milk powder production, all stages of the production chain of this product must be considered, and these stages include the input stage of fodder production for milk production by livestock and milk powder production processes. In order to obtain the required information, Ecoinvent database was used and data analysis was done with SimaPro software. The calculations have been selected based on one ton of produced milk powder, the results of which are shown in Table 4. Global warming potential with 0.02 kg CO_2 has low environmental emissions. The potential for the formation of suspended particles (2865.13 kg PM2.5) showed that the volume of suspended particles increases with the production of milk powder.

Water consumption during the process should be minimized while maintaining the quality of the products to reduce the resulting emissions (39333/47 m^3). The ozone depletion potential among midpoint categories with 0.003 kg CFC-11 has a negligible effect. Figure 3 shows the share of consumption inputs in the middle point categories of milk powder production. Diesel fuel has a significant effect in most of the impact categories. The greatest effect of diesel fuel on the potential of surplus ore is more than 95%. After that, electricity impacts the potential of suspended particles and the potential of ionizing radiation by 45% and 40%, respectively. Therefore, measures to reduce the ratio of milk to cheese during the life cycle are necessary. Also, reducing emissions of methane fermentation, managing fertilizers and pesticides used in farms and livestock can be significantly effective. In fact, the emissions within the system that are created in the livestock network in the production of raw milk play an important role in most of the impact categories

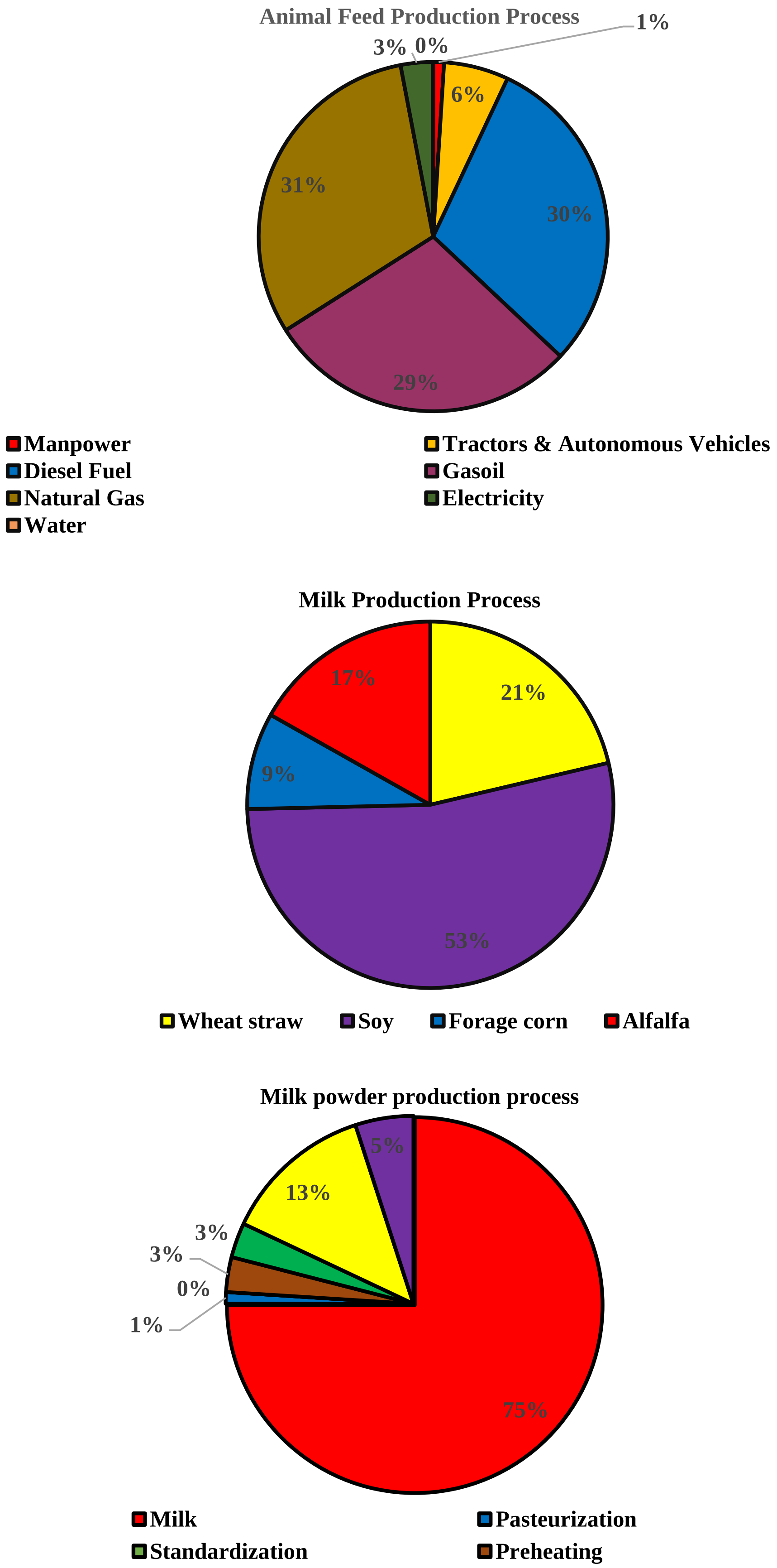

Figure 2. The contribution of each energy input in milk powder production

Table 4. Amount of midpoint impact categories for one ton of milk powder

midpoint	Unit	Amount
Ozone depletion potential (ODP)	kg CFC-11	0.003
Particulate matter formation potential (PMFP)	kg PM2.5	2865.13
Ionizing radiation potential (IRP)	kBq Co-60	195.29
Global warming potential (GWP)	kg CO_2	0.02
Ozone formation potential (OFP)	kg NOx	49.21
Toxicity potential (TP)	kg 1,4-DCB	14.31
Water consumption (WCP)	m^3	39333.47
Land occupation potential (LOP)	m^2 annual crop	24.55
Eutrophication potential (EP)	kg N-kg P	0.036
Fossil fuel potential (FFP)	kg oil	0.99
Surplus ore potential (SOP)	kg Cu	0.82

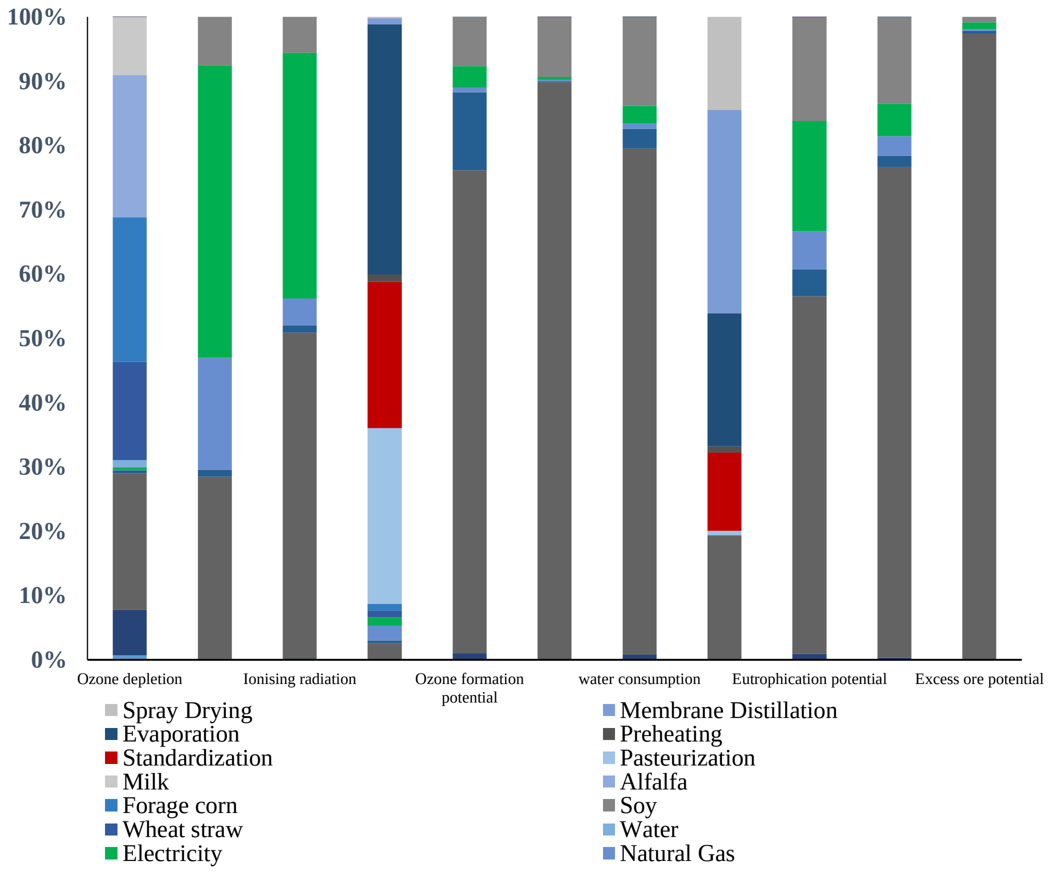

Figure 3. The share of consumption inputs in the section of midpoint impact categories

In the Recipe2016 method, impacts indicators or midpoints are defined based on endpoints and based on the same units. The results of three categories of damage to human health, ecosystem quality and resources according to the method mentioned in Table 5 are presented. As a result, the impact categories of Ozone depletion potential, Particulate matter formation potential, Ionizing radiation potential, Global warming potential, Ozone formation potential, Toxicity potential, Water consumption, have less pollutants in the end point of human health. The damage category of ecosystem quality and resources are reported as PDF*m2*yr 3.09×4-10 and MJ primary 20.18. As a result, fossil fuel potential and excess ore potential have greatly affected resource emissions. Fossil fuels, such as oil and natural gas, have been used as energy sources for many years and have the largest share in meeting the world's energy needs. However, the use of these energy sources causes greenhouse gas emissions and climate change, increasing air and water pollution, and reducing biodiversity. Also, the extraction of minerals in most cases causes air and water pollution, loss of natural resources and reduction of biodiversity. In addition, the use of minerals in the production process can also lead to the production of industrial waste and air and water pollutants. Considering these issues, the use of renewable energy sources and the development of new technologies can help reduce the use of fossil fuels and minerals and reduce their impacts on the environment. Figure 4 shows the share of consumption inputs in the endpoint impact categories section.

Gasoil and diesel fuel have the most pollution on ecosystem quality with more than 75% and 20% respectively. Electricity and diesel had a significant contribution to the resource releases. The environmental effects of fossil fuels on human health are also obvious. Fossil fuels, including diesel and natural gas, release gases into the air that cause air pollution and increase respiratory diseases in humans. Using advanced technologies in the milk powder production process can help reduce the emission of environmental pollutants. For example, the use of technologies such as separation, refining and purification methods can help reduce the emission of various pollutants such as greenhouse gases, suspended particles and ammonia. The use of renewable energy sources, such as the sun and wind, can help reduce greenhouse gas emissions associated with energy production. Also, the use of renewable energy sources can help reduce energy costs and improve the company's financial stability. The positive residual method helps to reduce the emission of environmental pollutants. In this method, environmental pollutants are recycled to produce usable energy and fuel such as biogas and organic fertilizer.

Table 5. The results of the endpoints of the environmental impacts of one ton of milk powder

Category of damage	unit	Amount
Human health	DALY	0.01
Ecosystem quality	PDF*m2*yr	3.09E-4
Resources	MJ primary	20.18

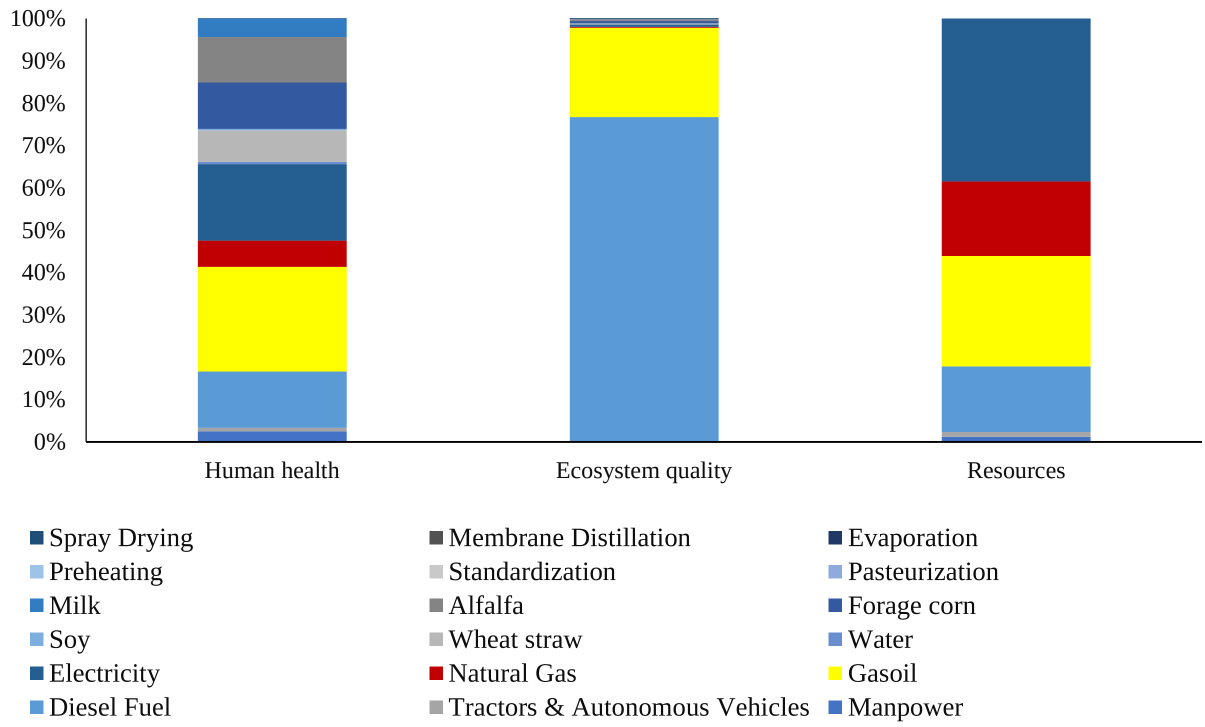

Figure 4. The share of consumption inputs in the section of endpoint impact categories

Cumulative exergy demand

To calculate the cumulative exergy demand, the total energy consumption in all the milk powder production processes should be calculated. Considering that the energy consumption in each of these processes is different; to calculate the cumulative exergy demand, it is better to calculate each process separately and then obtain their sum. Cumulative exergy demand for the production of one ton of milk powder was calculated in SimaPro software, and the values related to each effect category are shown in Table 6. For the production of each ton of powdered milk, the renewable-fossil form consumes 6331.22 megajoules. This amount of energy consumption includes all stages of milk powder production, including animal breeding, milk collection, pasteurization, drying and packaging. The non-renewable form of minerals has an energy consumption of 60.06 MJ/ton. Figure 5 shows the contribution of each of the consumption inputs in the cumulative exergy demand of milk powder. Diesel fuel has the greatest impact on renewable-water and renewable-solar respectively. In fact, diesel fuel contains fine particles and exhaust gases with nitrogen oxides and carbon dioxide, both of which contribute to global warming and climate change. The evaporation process also has a cumulative exergy demand of more than 40% in renewable-potential and non-renewable-minerals.

Table 6. Examination of different forms of energy based on cumulative exergy demand method

Types of energy	Amount (MJ/ton)
Non-renewable - fossil	6331.22
Non-renewable-nuclear	304.71
Renewable-solar	130.73
Renewable potential	120.41
Non-renewable - primary	142.99
Renewable - water	1569.27
Non-renewable - metals	180.59
Non-renewable - minerals	60.06

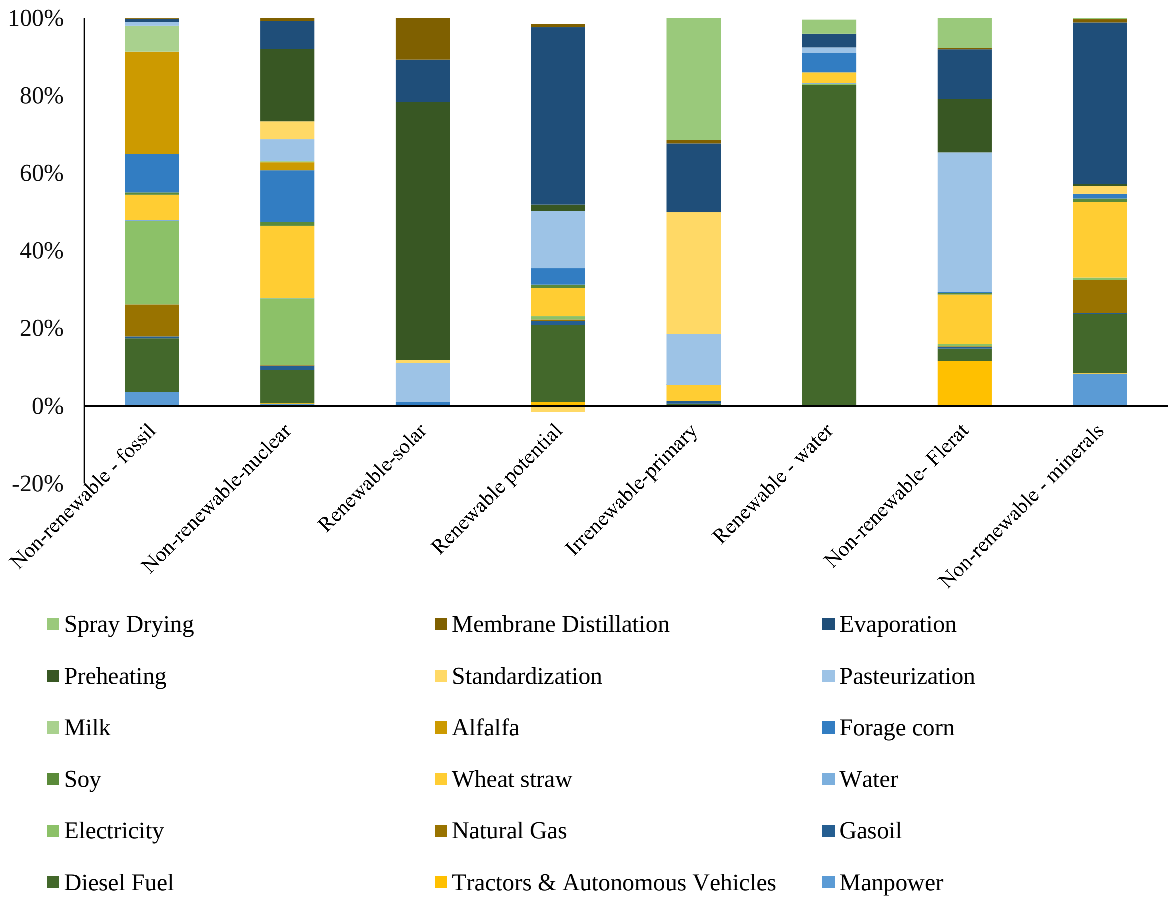

Figure 5. The contribution of consumption inputs in cumulative exergy demand

CONCLUSION

Milk powder production, as one of the most important food industries worldwide, has a significant impact on the environment. For this reason, the evaluation of environmental parameters and energy consumption in milk powder production is very important. These evaluations are discussed below:

The total input energy of milk powder production in all three stages is 7829.03 MJ per ton and the total output energy in three stages is calculated as 4518.62 MJ per ton. The production of powdered milk requires a lot of energy due to the use of complex processes. Therefore, energy consumption in this industry is very high. The energy ratio with a value of 0.57 indicates that the amount of output energy is lower than the total energy of input inputs. The productivity of milk powder production was 27.85 kg/MJ and the net added energy for each ton of milk powder was 3310.41 MJ/t. The results show that in the process of milk powder production, energy consumption is more than the energy produced. Water consumption and the potential for the formation of suspended particles with 39333/47 m^3 and 2865/13 $PM_{2.5}$ kg respectively have the highest environmental emissions and the ozone layer destruction potential with 0.003 kg CFC-11 have the lowest environmental emissions. Gasoil and diesel fuel have the most pollution on ecosystem quality with more than 75% and 20% respectively. Electricity and diesel had a significant contribution to the resource releases. The environmental effects of fossil fuels on human health are also obvious. For the production of each ton of milk powder, the renewable-fossil form has the highest energy consumption with 6331.22 MJ, and the non-renewable form-minerals consumes 60.06 MJ of energy.

With the help of process engineering and optimization of various components of the production process, energy consumption can be reduced. This includes optimizing energy consumption in the process of milk production, pasteurization and turning milk into milk powder. The use of high-quality raw materials can help reduce energy consumption in the milk powder production process. In fact, high quality raw materials can reduce production processes as well as time and energy consumption at each stage. Using new technologies such as milk powder production using solar energy or water purification using solar energy can help reduce energy consumption in the milk powder production process. Efforts to recycle raw materials as well as final products can help reduce energy consumption in the milk powder production process. For example, recycling the water used in the milk powder production process can reduce energy consumption. It is suggested that different methods of optimization be used in the stages of fodder production and especially animal husbandry.

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