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Comparing the energy consumption and environmental impacts of ostrich meat and egg production

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Abstract

The research assesses the energy inputs and outputs, as well as the environmental effects, of raising ostriches and chickens for meat and egg production. The findings demonstrate that ostrich meat and eggs require less energy and have lower environmental impacts compared to chicken meat and eggs. This is attributed to the lower feed requirements and waste production of ostriches, as well as their adaptability to a wider range of environmental conditions. The results of this study can be utilized to guide sustainable agricultural practices and food production decisions. The study also examines the energy usage and environmental impacts of raising ostriches for meat and chickens for eggs. The energy analysis reveals that ostrich meat and egg production offer a more comprehensive comparison of energy consumption and production. Specifically, the total energy consumption for meat and eggs is 1086825.54 and 1197794.25 MJ 1000 pieces^{-1}, respectively. In essence, egg production can be justified in terms of protein supply relative to total energy consumption for comparison with meat. The study also evaluates the impact of egg and meat production on human health. With a difference of 0.23 DALY, it is evident that egg production may have slightly greater negative effects on human health than meat production. These findings suggest that egg production may be a more sustainable option compared to ostrich meat production in terms of energy use and environmental impacts. Further research is required to explore potential strategies for reducing the energy use and environmental impacts of ostrich meat production.

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Introduction

An energy audit involves analyzing the quantity and usage of energy in a system or procedure with the goal of enhancing energy efficiency, minimizing energy wastage, and implementing sustainable technologies and renewable energy sources. Enhancing energy management aids in cost reduction, the advancement of sustainable technologies, and the protection of the environment. The greenhouse gas emissions (GHG) resulting from energy consumption, such as carbon dioxide, methane, and nitrogen oxide, have impact on climate change and global warming (Kaab et al., 2019; Liu et al., 2020). In various countries, the breeding of ostriches as an economic and industrial pursuit has experienced considerable growth in recent years. Ostriches, large birds native to dry and desert regions, are raised primarily for their meat, which is used to create a variety of products such as sausages. Due to their delectable meat and high protein content, meat ostriches have gained popularity among consumers (Manap and Serikkyzy, 2022). Furthermore, ostriches lay large and valuable eggs that are highly sought after for their use as a food source. These eggs are utilized in their fresh state or cooked in various settings such as the food industry, restaurants, and hotels. Apart from their high nutritional value, ostrich eggs also possess antioxidant properties and contain a variety of essential nutrients. The breeding of both meat and egg-laying ostriches necessitates the use of specialized facilities and equipment (Shibak et al., 2023). Ensuring optimal growth and production of ostriches necessitates a spacious, natural environment, along with proper nutrition, grooming, and medical care. The cultivation of meat and eggs from ostriches offers a lucrative business opportunity, contributing to agricultural diversification and increased income for farmers. The surging global demand for ostrich products has led to a rise in ostrich breeding units, with worldwide meat production exceeding 100,000 tons and egg production surpassing 1,000 tons annually in 2019 (Barends-Jones and Pienaar, 2020). The energy consumption in ostrich meat and egg production is influenced by various factors, including diet, living conditions, rearing methods, advanced technologies, and overall production levels (Ramedani et al., 2019). However, significant water consumption during animal growth and feeding can strain water resources, leading to shortages in high meat production areas. The use of fertilizers and contaminated water in breeding may result in water and soil pollution, impacting their quality and biodiversity (Kolawole and Iyiola, 2023).

Employing sustainable breeding methods can mitigate negative impacts on animal health, productivity, and welfare (Llonch et al., 2017). Animals in the growth and feeding stages require large amounts of water, putting a strain on water resources and leading to shortages in areas with high meat production. The use of fertilizers and contaminated water in animal breeding can result in water and soil pollution, damaging their quality and biodiversity. Life cycle assessment (LCA) is being considered as a new method for evaluating environmental emissions (Chau et al., 2015). Collect the key ingredients needed to make meat and egg products, making sure they come from sustainable and reusable sources. Focus on obtaining high-quality materials through efficient procedures that reduce environmental harm. Use low-energy methods to minimize GHG and minimize waste during production (Kumar et al., 2023). Proper care, encompassing food and water provision, healthcare, egg and chick oversight, and disease and pest control, is essential for sustaining the well-being and optimal development of ostriches. The farm setting should offer favorable conditions, including sufficient space, access to equipment, and skilled personnel. Further research on nutritional aspects, feed ingredients, and grazing management strategies is needed to enhance ostrich farming practices (Shibak et al., 2023).

Brand et al. (2003) it is recommended that breeding female ostriches be fed a diet containing at least 8.5 MJ kg^{-1} of energy and 105 g kg^{-1} of protein to ensure optimal egg production. Research on the environmental impacts of poultry production indicates that poultry farms are the main contributors to these impacts, with feed production and on-farm emissions being the leading factors. To address these issues, a multi-objective optimization model was used to minimize environmental impacts and maximize economic benefits, resulting in a 15.14% reduction in environmental indicators per performance unit for the selected alternative (López-Andrés et al., 2018). Optimizing feed and nutrition management can enhance livestock productivity and mitigate environmental effects, contributing to greater sustainability. As climate change continues, prioritizing animal welfare and environmental protection is essential for long-term sustainability in animal production and meat processing (Ponnampalam and Holman, 2023).

According to the LCA, climate change is a major issue, as evidenced by the 5.58 kg CO_2 eq kg^{-1} emissions per egg produced. By implementing an eco-efficient program that prioritizes energy usage, there is potential for a 49.5% reduction in total energy consumption and a 56.3% decrease in environmental impacts (Estrada-González et al., 2020a). According to the environmental impact assessment of livestock products, selecting an environmentally friendly option can lessen the environmental impact. Beef production required the most land and energy and had the highest global warming potential (GWP) per kilogram, followed by pork, chicken, eggs, and milk. The production of meat (pork, chicken and beef) had a more significant impact than producing milk and eggs due to their high water content (de Vries and de Boer, 2010). The aim of this study is to compare the energy use and environmental impacts of raising meat and egg production of ostrich. This will involve analyzing the resources and energy inputs required for ostrich farming, as well as the environmental impacts such as GHG, water usage, and land usage. The goal is to provide a comprehensive understanding of the sustainability of ostrich farming and to identify potential areas for improvement in the industry.

Materials and methods

Study area

The climate in Qazvin province is minimally affected by latitude, with altitude having a more significant impact on temperature variation. As elevation increases, temperatures decrease, leading to colder weather in the mountains and highlands compared to the low plains and valleys. The province's climate is also influenced by external factors such as different air masses entering from various regions and seasons, each with distinct effects. The location of Qazvin province is shown in Figure 1 (Ministry of Jihad-e-Agriculture of Iran, 2021), where data was collected from ostriches using a questionnaire covering various input sources, manufacturer information, and product performance. Random sampling was conducted within the study area to ensure greater accuracy in data collection and findings, with the sample size determined using the Cochran technique outlined in Equation 1 (Cochran, 1977).

$$n=\frac{\frac{z^2pq}{d^2}}{1+\frac{1}{N}\left(\frac{z^2pq}{d^2}-1\right)} \qquad (1)$$

where n is the required sample size, N is the number of ostrich farms per target population, z is the reliability coefficient (equals to 1.96, denoting 95% confidence level), p is the estimated proportion of an attribute that is present in the population (equals to 0.5), q is 1-p (equals to 0.5), and d is the permitted error ratio deviation from the average population (equals to 0.05).

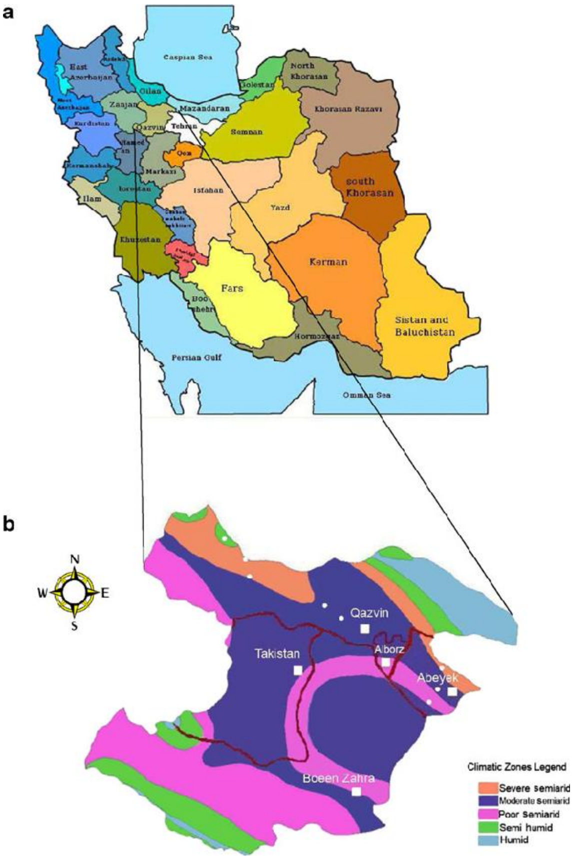


Figure 1. Geographical status of the investigated region in Qazvin Province, Iran

Energy use

An energy analysis can assist manufacturers in improving production processes and optimizing energy usage, leading to a more efficient use of resources. This can ultimately help in reducing the environmental impact of energy consumption. The study involved monitoring and recording the consumption of electricity, gas, fuel, and other energy sources in the ostrich production unit. It also included examining energy consumption for various activities such as lighting, heating, cooling, transportation, processing, and packaging. Additionally, the research involved measuring and recording the energy usage of equipment related to ostrich breeding, processing, packaging, and fodder supply. The collected data was then analyzed in detail to assess energy efficiency and identify potential areas for improvement (Kaab et al., 2023).

By conducting a comprehensive energy analysis, ostrich breeding units can identify ways to reduce energy consumption, improve efficiency, and enhance overall sustainability. This can result in cost savings, reduced environmental impact, and improved long-term viability of the operation. Energy consumption data for ostrich production units was collected through face-to-face interviews (Table 1), allowing for personal communication between the interviewer and the interviewee. This accurate and complete information can lead to better analysis and interpretation. The interviews also created an opportunity for communication and cooperation between the two parties, contributing to problem-solving and effective interaction (May et al., 2015).

Table 1. Energy inputs-outputs and energy coefficients in ostrich breeding units.

Items	Unit	Energy equivalent (MJ unit $^{-1}$)	References
A. Inputs			
1. Human labor	h	1.96	(Ghasemi-Mobtaker et al., 2022)
2. Machinery	h	62.7	(Kaab et al., 2021)
3. Diesel fuel	L	56.31	(Mohammadi Kashka et al., 2023)
4. Natural gas	m^3	49.50	(Nabavi-Pelesaraei et al., 2014)
5. Electricity	kWh	12.00	(Taherzadeh-Shalmaei et al., 2023)
6. Feed	kg		
(a) Corn		7.90	(Kitani, 1999)
(b) Barley		14.70	(Kitani, 1999)
(c) Alfalfa		15.80	(Kitani, 1999)
(d) Rice bran		14.57	(Kitani, 1999)
(e) Wheat		13.70	(Kitani, 1999)
(f) Soybean meal		12.60	(Kitani, 1999)
(g) Sugar beet pulp		16.80	(Kitani, 1999)
(h) Vitamins and minerals		1.59	(Kitani, 1999)
(k) Salt		1.59	(Kitani, 1999)
(l) Fatty acid		37.00	(Kitani, 1999)
7. Ostrich chick	kg	10.33	(Ramedani et al., 2019)
B. Outputs	kg		
1. Ostrich meat		10.33	(Ramedani et al., 2019)
2. Ostrich egg		7.28	(Ramedani et al., 2019)

Energy use efficiency is quantified as the ratio of useful energy output to the total energy input in a system or process, expressed as output energy (MJ) divided by input energy (MJ). This metric serves as a gauge for assessing how effectively energy is harnessed and finds application across diverse contexts, including industrial processes, transportation, and building systems. A higher energy use efficiency signifies that a system can generate more useful output relative to the energy input, leading to reduced waste and enhanced overall performance (Alluvione et al., 2011). The pursuit of improved energy use efficiency is pivotal in endeavors to curtail energy consumption, mitigate environmental impact, and optimize resource employment. Attaining this objective involves leveraging technological advancements, implementing process enhancements, and fostering behavioral changes.

Energy productivity, on the other hand, gauges the economic output generated per unit of energy input, denoted as production (kg) divided by input energy (MJ). A higher energy productivity value indicates that more economic output is derived from a given amount of energy input. Meanwhile, specific energy pertains to the energy content of a given quantity of material and is typically expressed as input energy (MJ) divided by production (kg) (Zhang et al., 2019).

LCA

The Life Cycle encompasses successive and interconnected phases in the production or provision of a product or service, spanning from the extraction of natural resources to its eventual disposal. To comprehensively assess the environmental impact of a product, process, or activity throughout its entire life cycle — from raw material acquisition to manufacturing, transportation and disposal — LCA serves as a valuable tool (van der Werf et al., 2020). Initially employed primarily for product comparisons such as assessing the environmental effects of disposable versus reusable products, LCA has evolved to become integral in government policy, strategic planning, marketing, consumer education, process enhancement, and product development. It also forms the basis for global environmental labeling and consumer education initiatives (Estrada-González et al., 2020b). The first step in the LCA process is to define the goal and scope of application, a crucial aspect that outlines the study's purpose, scope, main hypothesis, system boundaries, data quality, and any limitations. The functional unit in LCA serves as a reference unit for comparing products or processes and is typically used to measure resource consumption and emissions (Fnais et al., 2022). In this study, one ton of ostrich meat and egg production was chosen as the basis for calculating environmental emissions, aiming to assess the environmental impact and identify avenues for performance improvement. The assessment includes measuring water consumption, energy usage, GHG, and environmental degradation.

Inventory analysis involves gathering data to quantify inputs and outputs of the defined system, including energy and raw material consumption, as well as emissions to air, water, soil, and solid waste produced over the entire life cycle of the product or service. The system is divided into subsystems or processes, and the collected data is categorized in the Life Cycle Inventory (LCI) (Zhu et al., 2022). Life Cycle Impact Assessment (LCIA) is employed to identify and describe the potential environmental effects of the system under study, starting with the inventory phase, where information is collected. The final interpretation stage involves presenting results concisely, highlighting key sources of impact, and proposing potential strategies to reduce these impacts. ReCiPe2016 in SimaPro software was chosen to assess environmental emissions. Interpretation also entails a thorough review of the entire LCA process, ensuring consistency of assumptions and data quality in relation to the study's purpose and scope (Asem-Hiablie et al., 2019). The relationship between the different stages is illustrated in Figure 2.

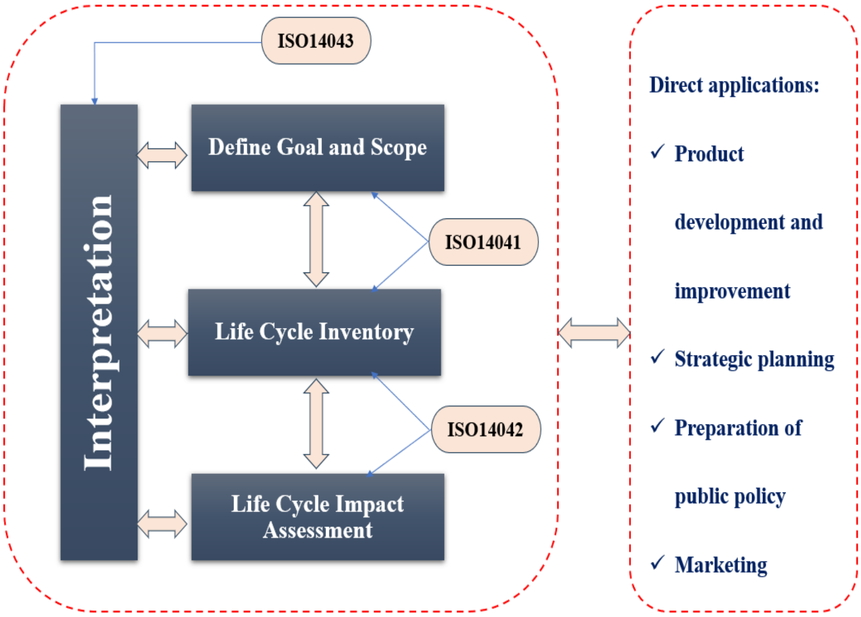


Figure 2. Stages of LCA according to ISO definition.

Results and discussion

Energy use results

The results of the energy analysis for egg and ostrich meat production provide a comprehensive comparison of energy consumption and production. In Table 2, energy inputs per 1000 pieces for the target product production are presented. The total energy consumption for meat and eggs is 1,086,825.54 and 1,197,794.25 MJ per 1000 pieces, respectively. The output energy for meat and eggs is 536,182.33 and 768,610.90 MJ per 1000 pieces, respectively. Despite egg production consuming more energy than meat production, it also generates a higher energy output for consumers. Each input's consumption was individually calculated for every 1000 pieces and then multiplied by its energy coefficient. Consequently, egg production can be justified in terms of protein supply per total energy consumption compared to meat. Ramedani et al. (2019) the energy state and environmental impacts of production systems are crucial factors in achieving sustainability. The total input energy in ostrich and broiler systems was calculated as 150,419.81 MJ (per ton of bird year) and 344,579.58 MJ (per ton of bird year) respectively. Diesel fuel and feed accounted for 41.39% and 36.95% of the energy in broiler production, while electricity accounted for 45.87% in the ostrich production system.

Figure 3 illustrates the input contributions to meat and egg production, with natural gas consumption accounting for over 33.40% and 34.03% of meat and egg production, respectively, making it the largest contributor. Diesel fuel follows as the second-highest energy consumer. The data indicates that energy and fuel supply are more crucial for egg production in ostrich breeding environments. However, feed (22.57%) and electricity (5.23%) consumption for egg production are lower than for meat production. This suggests that feed supply does not significantly impact producers' decisions. Table 2 presents the energy contribution of specific feeds, revealing that rice bran, sugar beet pulp, vitamins and minerals, and fatty acids significantly contribute to total energy consumption for meat production. These ingredients are reported to be in lower amounts for egg production, likely due to the differing nutritional and energy needs of egg-laying ostriches compared to those raised for meat. It is possible that small ostriches require specific fatty acids, vitamins, and minerals for egg production. Furthermore, the nutritional requirements for egg-laying ostriches may differ from those raised for overall growth and development. Consequently, the energy contribution of each specific feed may vary based on the intended purpose of the animal and its unique nutritional needs.

Table 2. Amounts of inputs-outputs energy in ostrich breeding units under different production.

Items	**Ostrich (meet)**		**Ostrich (egg)**	
	Unit per ha	Energy use (MJ 1000 pieces $^{-1}$)	Unit per ha	Energy use (MJ 1000 pieces $^{-1}$)
1. Human labor	213.42	418.31	302.76	593.41
2. Machinery	772.21	48417.83	1096.94	68778.60
3. Diesel fuel	5616.21	316249.02	6352.34	357700.38
4. Natural gas	7332.66	362967.00	8233.55	407560.85
5. Electricity	5034.19	60410.28	5222.18	62666.21
6. Feed				
(a) Corn	3496.00	27618.46	3590.76	28367.02
(b) Barley	2331.98	34280.13	2458.42	36138.78
(c) Alfalfa	1603.17	25330.15	2070.18	32708.91
(d) Rice bran	7644.41	111379.09	6335.26	92304.78
(e) Wheat	1640.92	22480.71	1651.94	22631.67
(f) Soybean meal	1372.00	17287.23	1425.47	17960.96
(g) Sugar beet pulp	1254.64	21077.98	1250.05	21000.88
(h) Vitamins and minerals	1453.60	2311.22	1160.84	1845.73
(k) Salt	356.12	566.24	402.60	640.14
(l) Fatty acid	544.78	20157.07	453.73	16788.26
7. Ostrich chick	1536.76	15874.75	2914.57	30107.60
Total energy use (MJ)	-	**1086825.54**	-	**1197794.25**
B. Output (kg)				
1. Ostrich meat	51905.35	536182.33		
2. Ostrich egg			105578.42	768610.90

Table 3 displays energy indicators for input and output energy balance. Eggs have a higher energy use efficiency (0.64) compared to meat (0.49), but neither eggs nor meat had an energy use efficiency above 1, indicating that energy production was less than energy consumption. Both eggs and meat have energy use efficiencies below 1, meaning that the energy output is lower than the energy input, resulting in the need for more energy to produce the final product. However, eggs have a higher energy use efficiency than meat, making egg production relatively more energy-efficient than meat production. The energy productivity of both products is low in relation to their energy consumption. Energy intensity values show that meat production requires 21.06 MJ kg^{-1}, while egg production requires 11.40 MJ kg^{-1}, indicating that meat production has lower energy productivity compared to egg production. This information can guide decisions on resource allocation and production processes to improve overall energy productivity, as the net energy had a negative value.

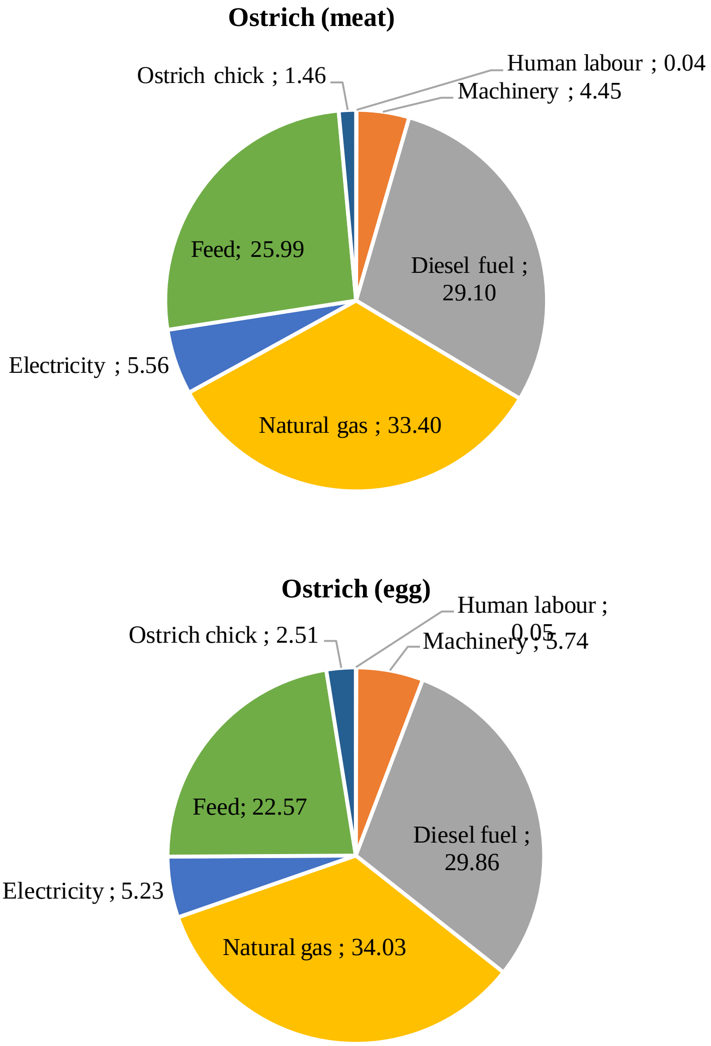


Figure 3. Contributions of energy sources in ostrich breeding units under different productions.

Table 3. Energy indices in ostrich breeding units under different production.

Items	Ostrich (meet)	Ostrich (egg)
Energy use efficiency (ratio)	0.49	0.64
Energy productivity (kg MJ^{-1})	0.04	0.08
Specific energy (MJ kg^{-1})	21.06	11.40
Net energy gain (MJ 1000 pieces $^{-1}$)	-550643.20	-429183.35

LCA results

Table 4 presents on-farm emissions associated with the background research for meat and egg production inputs. Emissions from feed production can vary based on factors such as the type of feed, production methods, and transportation. Similarly, emissions from energy use on ostrich breeding units depend on the sources of energy, including electricity, natural gas, or diesel, as well as the efficiency of energy use and the utilization of renewable energy sources. Moreover, emissions from the transportation of inputs and outputs to and from the ostrich breeding units may fluctuate based on factors like distance, mode of transportation, and the fuel efficiency of vehicles (Bhavani et al., 2023).

In general, the emissions produced by ostrich breeding units are influenced by diverse factors such as feed production, manure management, energy use and transportation, and water use, contingent upon the specifics of the production system. Ostrich breeders are advised to consider these factors and implement practices that mitigate emissions, contributing to environmental sustainability (Barends-Jones and Pienaar, 2020).

Table 4. On-farm emissions in ostrich breeding units under different production based on 1 ton.

Items	Ostrich (meet)	Ostrich (egg)
1. Emissions by diesel fuel to air (kg)		
(a). Carbon dioxide (CO_2)	23560.55	26648.67
(b). Sulfur dioxide (SO_2)	7.62	8.62
(c). Methane (CH_4)	0.97	1.10
(d). Benzene	0.05	0.06
(e). Cadmium (Cd)	7.55E-05	8.54E-05
(f). Chromium (Cr)	0.0003	0.0004
(g). Copper (Cu)	0.01	0.01
(h). Dinitrogen monoxide (N_2O)	0.90	1.02
(i). Nickel (Ni)	0.0005	0.0005
(j). Zink (Zn)	0.007	0.008
(k). Benzo (a) pyrene	0.0002	0.0002
(l). Ammonia (NH_3)	0.15	0.17
(m). Selenium (Se)	7.55E-05	8.54E-05
(n). PAH (polycyclic hydrocarbons)	0.02	0.02
(o). Hydro carbons (HC, as NMVOC)	21.50	24.32
(p). Nitrogen oxides (NOx)	335.22	379.16
(q). Carbon monoxide (CO)	47.43	53.65
(r). Particulates (b2.5 µm)	33.83	38.27
2. Emission by human labor to air (kg)		
(a). Carbon dioxide (CO_2)	149.39	211.93

Table 5 presents the results of the ReCiPe2016 method for the endpoints, with positive values indicating a negative impact on the environment and negative values indicating a positive impact. The positive values for meat and egg production sensitive points suggest a detrimental effect on the environment. A comparison of the impact on human health shows a slightly higher negative impact for egg production compared to meat production, as indicated by the 0.23 DALY difference. Meat production is described as having a more acceptable impact on the ecosystem (0.003 species.yr) and resources (9215.47 USD2013) in comparison to egg production, according to the ReCiPe2016 method. It is important to consider that these results are based on specific parameters and may not encompass the full range of environmental impacts. Other factors such as animal welfare, land use, and GHG should also be taken into account when evaluating the overall sustainability of meat and egg production (Guinée et al., 2010). Furthermore, it is important to take into account the wider scope of sustainability, encompassing social and economic aspects, when interpreting these findings. To gain a complete understanding of the environmental effects of meat and egg farming, additional research and analysis may be required (Alves et al., 2023).

Table 5. Values of the damage assessment per one ton in ostrich breeding units under different production goals.

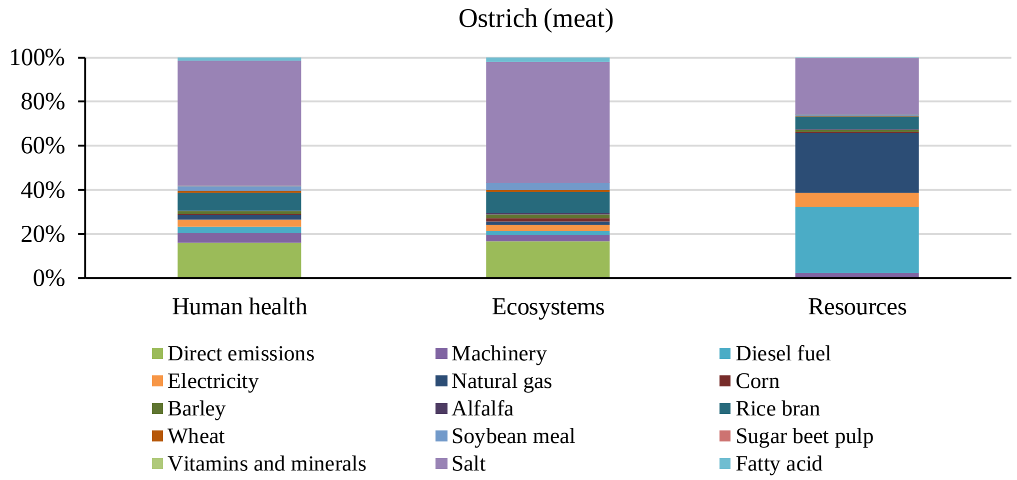
Items	Unit	Ostrich (meet)	Ostrich (egg)
Human health	DALY [a]	2.15	2.38
Ecosystems	species.yr [b]	0.003	0.004
Resources	USD2013	9215.47	10227.76

[a] DALY: disability adjusted life years. A damage of 1 is equal to: loss of 1 life year of 1 individual, or 1 person suffers 4 years from a disability with a weight of 0.25.

[b] species.yr: the unit for ecosystems is the local species loss integrated over time.

The comparison of environmental emissions from different inputs at the three endpoints (as shown in Figure 4) has revealed significant impacts from the use of machinery and diesel fuel in ostrich breeding environments. The analysis shows that machinery has a 60% impact on the ecosystem and human health, indicating a need to control and mitigate its environmental effects in ostrich breeding operations. Additionally, diesel fuel consumption has a 30% impact on the resource category, suggesting significant implications for resource consumption and sustainability. These findings emphasize the importance of evaluating and managing the environmental impacts of inputs like machinery and fuel in ostrich breeding, and point to the need for targeted efforts to reduce these impacts in order to improve the overall environmental performance of ostrich farming operations.

Nunez et al. (2005) the impact of food production and consumption on the environment is becoming increasingly important as consumer awareness grows. This paper conducts a comparative study of the environmental impact of beef, pork, and ostrich meat using LCA methodology. The results of the analysis highlight the need for valid databases, particularly in relation to agricultural processes, and the development of new methodologies to evaluate land use. Additionally, the increasing demand for environmentally friendly food products is driving the need for more research in this area.



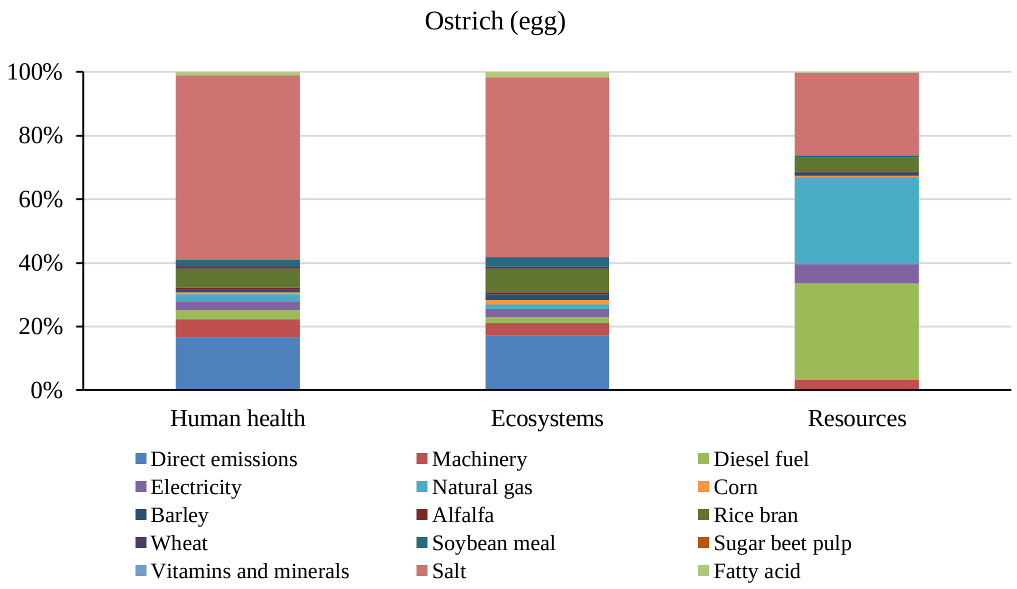


Figure 4. Contribution of different inputs in the damages categories in ostrich breeding units under different productions.

Conclusion

Comparing the energy use and environmental impacts of ostrich meat and egg production reveals that ostrich farming has lower energy use and environmental impacts than traditional livestock farming. Ostriches require less water, feed, and land to produce meat and eggs, and also generate fewer GHG and waste. Therefore, ostrich farming could serve as a more sustainable and environmentally friendly alternative to traditional livestock farming. However, further research and analysis are necessary to fully comprehend the potential benefits and drawbacks of ostrich farming in comparison to other forms of animal agriculture. The study indicates that the highest share of natural gas consumption is over 33.40% for meat and 34.03% for eggs, with diesel fuel consumption ranking second in terms of energy usage. The findings suggest that fuel and energy supply in ostrich breeding environments are particularly crucial for egg production. Decision makers in the ostrich breeding industry can utilize these findings to carefully manage energy and fuel for egg and meat production, ultimately reducing costs. In comparing egg and meat production, the study found a slight difference of 0.23 DALY in the impact on human health, suggesting that egg production may have slightly more negative effects on human health than meat production. Additionally, meat production was found to have a more acceptable impact on ecosystems (0.003 species.yr) and resources (9215.47 USD2013) compared to egg production, according to the ReCiPe2016 method. These results can help guide decision-makers and environmental planners in optimizing food production to support human health and environmental protection.

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