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Decreasing the Environmental Impact in an Egg-Producing Farm through the Application of LCA and Lean Tools

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Abstract: Intensive poultry farming transforms vegetable protein into animal protein through shelf egg and chicken meat production. Mexico is the largest egg consumer and fifth-ranked egg producer worldwide. However, the environmental impact of egg production in this country is scarcely reported. This research aimed to design an eco-efficient approach for egg production in a semi-technified farm based on door-to-door life cycle assessment (LCA) and value stream mapping (VSM) methodologies. The LCA points out that the climate change category is a hotspot in egg production, with emissions of 5.58 kg CO_2 eq/kg per egg produced. The implementation of an eco-efficient scheme focused on energy usage could result in a 49.5% reduction of total energy consumption and 56.3% saving in environmental impacts. Likewise, by using an environmental economic evaluation system, it is identified that the eco-efficient scheme allows more sustainable production through the internalization of externalities. From an environmental–economic point of view, externalities—that is, those environmental damages that are not initially considered part of the production cost—were included, meaning they were internalized. The integral framework for LCA and VSM provides a possible path for sustainable productivity.

Keywords: life cycle assessment; value stream mapping; egg production; eco-efficiency

1. Introduction

Facing environmental degradation and a decrease in resources, eco-efficiency has been proposed as one of the main tools to promote sustainable development. Eco-efficiency means that a system provides an affordable service while satisfying human needs and reducing the intensity of consumption of inputs and environmental impacts [1]. Consumers are looking for better quality products through environmentally friendly production. Thus, producers are obliged to increase or maintain a level of production while reducing their environmental impact, without compromising either the quality of performance of their processes [2,3].

Animal husbandry is one of the production processes necessary for world food security [4]; dairy farming, meat poultry, and aquaculture are the most representative. These processes are the world's primary industries that transforms vegetable protein into animal protein. This production process maintains an intensive specialized egg production sector, which consists of separating chicken meat and shelf egg production. The hatching egg sector is not taken into account in this work. Shelf egg production demands food and water inputs due to the biological need for birds and environmental conditions [5,6]. The energy consumption is a consequence of the farm operations and their level of automation. It has been reported that the most energy-demanding processes in the poultry industry are climate control and lighting, with variable energy consumption of 3 to 4.4 kWh/bird/m^2/year [7]. The analysis of egg production is gaining importance, which is why studies have been carried out in countries such as Germany, Australia, Canada, the United Kingdom, and Switzerland to create a history of the consumption of energy inputs and materials to estimate the carbon footprint for each kilogram of egg produced according to its housing system (Table 1).

Table 1. Carbon footprint in egg production according to the poultry housing system.

Place	Accommodation System	GHG (kg CO_2-eq/kg Egg)	References
Australia	Controlled cage	1.3 +/− 0.2	[8]
Switzerland	Cage Cage (includes packaging)	1.4 1.6–1.8	[9,10]
Canada	Cage	2.5	[11]
England	Cage Barnyard	3.9 4.6	[12]
United Kingdom	Cage Barnyard	5.25 6.18	[13]
Australia Germany	Barnyard Barnyard	1.6 +/− 0.3 4	[8] [14]

Mexico is the world's leading egg consumer, with an estimated annual per capita consumption of 23.3 kg [15]. There is a high demand in the national diet, so the poultry sector has considerable participation in the production of shelf eggs and gross domestic product (GDP). In 2018, the poultry sector represented 63.3% of the country's agricultural activities, of which 28.2% corresponded to the generation of egg products. According to the Mexican National Union of Poultry Producers [15], shelf egg production in 2019 reached 2.88×10^6 t. Expectations for growth in this field are 1.45% per annum [16,17]. Despite the importance of shelf egg production in Mexico, as it represents 17% of the protein contribution by the livestock sector, there is no national data reporting on environmental assessments. As part of the contribution to food sovereignty, the aim is for agricultural production to be carried out under eco-efficient production schemes. Therefore, it is essential to identify significant environmental issues and opportunities for improvement in this sector.

There are tools such as life cycle assessment (LCA) that allow us to estimate potential environmental impacts within a supply chain, and that can integrate improvement strategies into the process [18]. Globally, LCA has been applied to the study of egg production, considering inputs such as diets, electricity, water expenditure, and land-use change [14]. Value stream mapping (VSM) is one of the techniques that can be integrated into LCA. This tool allows visualization of the flow of information in terms of the unitary productivity, efficiency, and reduction of process wastage [19,20]. The solution obtained through the integration of these instruments reduces waste by 20%–50%, understood as being due to reducing problems in the supply chains of a process [21]. For example, [20] reported a 25% decrease in material consumption, 19% decrease in energy consumption, and 7% decrease in the carbon footprint of an automotive production line in India. To the best of the author's knowledge, there are no reports on the integration of LCA and VSM for shelf egg production. There is a lack of studies on eco-efficient scenarios that integrate the environmental impacts derived from inefficiency into the use of inputs. This study aimed to design an eco-efficient scheme for a semi-technified poultry farm.

2. Methodology

LCA and VSM methodologies were integrated into this work to design a tailor-made eco-efficient scheme for egg production. LCA was applied to determine the potential for environmental contribution through 18 impact categories for each production stage. The VSM, on the other hand, made it possible to identify opportunities in the system. The work plan for this research is shown in Figure 1.

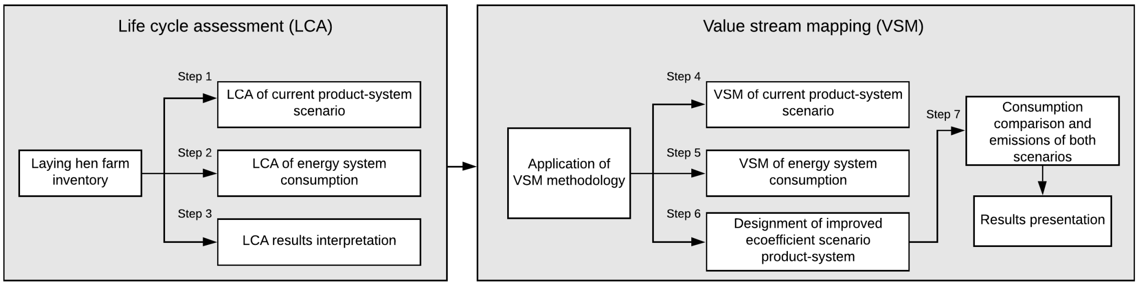

Figure 1. Work plan for the design of an eco-efficient scheme in the production of eggs in Mexico. Note: LCA, life cycle assessment; VSM, value stream mapping.

2.1. Life Cycle Assessment

This methodology is oriented to the evaluation of the environmental impacts of products and services. It has four phases according to ISO 14040:2006 (Figure 2), in which objectives and scopes that define inputs and outputs of a system product are limited.

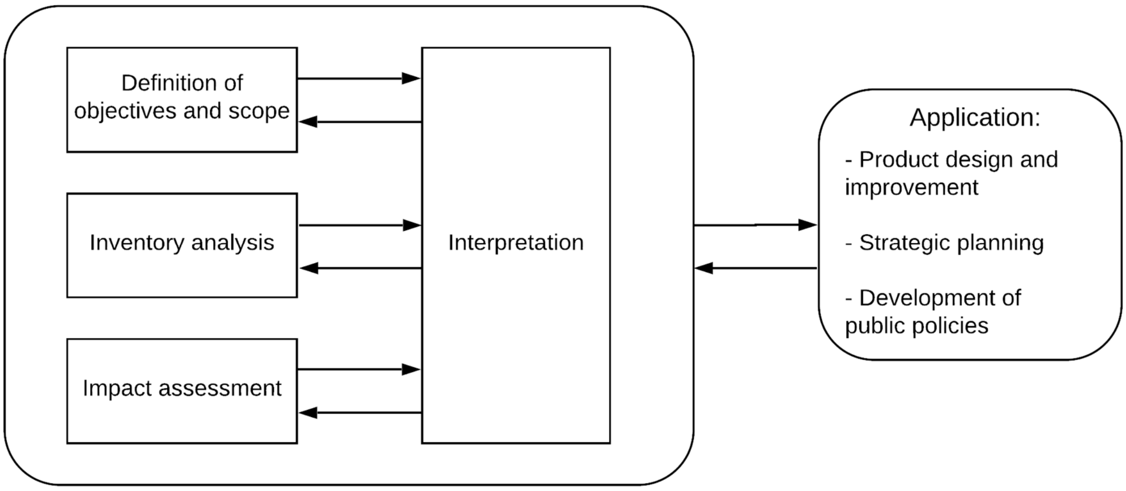

Figure 2. Life cycle analysis framework of reference [22].

2.1.1. Description of the System and Area of Study

The study of shelf egg production for the present work was conducted on a semi-technified farm, located in Tepatitlán de Morelos, Jalisco, Mexico, known as "*Laguna Colorada*"; (20°45′48.811″ N; 102°49′47.504″ O). The location has an average elevation of 1880 m above sea level and an annual average temperature of 19.1 °C. In Mexico, there are three different production systems, characterized by their technological level: (i) technified, (ii) semi-technical, and (iii) backyard systems. The differences between these systems are due to the technology that is handled. A technified farm is firstly characterized by high technology and automated processes that allow handling of large numbers of animals and a reduction of costs, depending on the volume of production; and secondly by the forms of disposition of credit or risk capital and integration of social capital. The technified and semi-technical schemes make use of the maximum possible efficiency of the food conversion index, so that they produce more efficient food and conditions for production, with rigid sanitary controls [23]. In the studied farm, only two parts of the process were automated (breeding and posture phases). The laying phase was handled manually by farmworkers. The chicken breed was Hy-Line W-36 and a battery cage system (450 cm^2, or three birds/cage) was used to house 96,000 1-day old chicks per poultry house. Adult laying hens were accommodated in three poultry houses.

The poultry houses at the studied farm have dimensions measuring 10 m × 3 m × 100 m and a controlled environment (31.46 °C for breeding, 20.81 °C for laying, and 21.92 °C for posture; humidity = 50% with forced ventilation). A total of 917 incandescent bulbs were used per poultry house to provide 15 lux (laying hens require illumination for 16–17 h/day). The eggs are manually collected and packed in cardboard boxes containing 360 eggs. Waste, such as manure and bird carcasses, were manually removed from the poultry houses and composted. The obtained data of the life cycle inventory correspond to the summer of 2016. The system at this farm is intensive for shelf egg production.

2.1.2. Functional Unit and Reference Flow

The functional unit was a kilogram of egg production on a semi-technified farm. A reference flow of 1,800,000 kg for egg production was presented for a total production period of 76 weeks (June 2016–February 2017).

2.1.3. System Limits

The system product was limited to the stages of chick breeding (6 weeks), bird development (10 weeks), egg laying (60 weeks), and egg product packaging. Figure 3 represents the limits of the system.

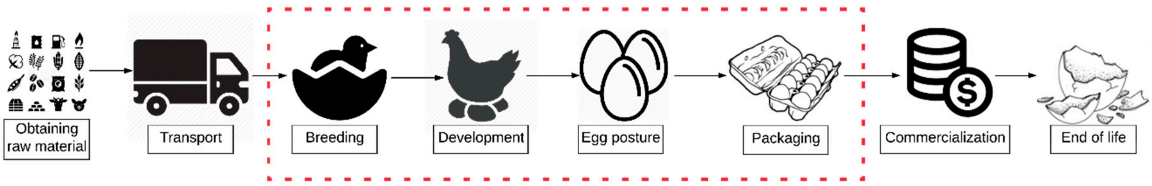

Figure 3. Limits of the system product in the valuation of environmental impacts by LCA.

2.1.4. Data Sources and Life Cycle Impact Assessment to Obtain Environmental Dimension Metrics

According to the limits of the system, both material and energy input data were obtained directly from the egg production poultry farm. For the environmental impact analysis, Ecoinvent 3.4 and Agri-footprint databases in SimaPro software, version 8.5, were used. The evaluation was carried out using the method "ReCiPe Midpoint V 1.13/World ReCiPe H", which considers 18 midpoint impact categories (Table 2). The most significant categories of impact on egg production were selected (Section 3.1). Subsequently, a second impact assessment was carried out considering only the energy demand of the system (Figure 1). The results obtained in both cases were the metrics for the environmental impact assessment.

Table 2. Middle-point impact categories.

Category Impacts	Indicator	Unit
1. Climate change	Radioactive forcing as global warming potential	kg carbon dioxide-eq (CO_2-eq)
2. Ozone depletion	Ozone depletion potential	kg trichlorofluoromethane-eq (CFC-11-eq)
3. Terrestrial acidification	Accumulated exceedance	kg sulphur dioxide-eq (SO_2-eq)

Table 2. *Cont.*

	Category Impacts	Indicator	Unit
4.	Freshwater eutrophication	Fraction of nutrients reaching freshwater end compartment	kg phosphor-eq (P-eq)
5.	Marine eutrophication	Fraction of nutrients reaching marine end compartment	kg nitrogen-eq (N-eq)
6.	Human toxicity	Comparative toxic unit for humans	kg 1,4 dichlorobenzene-eq (1,4-DB-eq)
7.	Photochemical oxidant formation	Tropospheric ozone concentration increase	kg non-methane volatile organic compounds (NMVOC)
8.	Particulate matter formation	Impact on human health	kg particulate matter 10-eq (PM_{10}-eq)
9.	Terrestrial ecotoxicity	Comparative toxic unit for ecosystems	kg 1,4 dichlorobenzene-eq (1,4-DB-eq)
10.	Freshwater ecotoxicity	Comparative toxic unit for ecosystems	kg 1,4 dichlorobenzene-eq (1,4-DB-eq)
11.	Marine ecotoxicity	Comparative toxic unit for ecosystems	kg 1,4 dichlorobenzene-eq (1,4-DB-eq)
12.	Ionising radiation	Human exposure efficiency relative to U^{235}	kg 1,4 dichlorobenzene-eq (1,4-DB-eq)
13.	Agricultural land occupation	Soil quality index, biotic production Erosion resistance, mechanical filtration Ground water replenishment	m^2a, area
14.	Urban land transformation		m^2a, area
15.	Natural land transformation		m^2
16.	Water depletion	User deprivation potential (deprivation-weighted water consumption)	m^3, volume
17.	Metal depletion	Abiotic resource depletion	kg iron-eq (Fe-eq)
18.	Fossil depletion	Abiotic resource depletion—fossil fuels	kg oil-eq

2.1.5. Input Data of the LCA Limits

The data inventory was obtained directly from the poultry farm through surveys. Table 3 contains the database of material inventory for egg production phases. Two products were obtained as residues, bird carcasses, and manure; both were composted. Table 4 contains the fuel inventory database for the studied poultry farm.

Table 3. Material inventory database from poultry farm per production phase.

Breeding Phase			
Inputs from technosphere	**Amount**	**Unit**	**Description**
Compound feed broilers/NL Mass MX Lq	30,240	kg	Grain
Tap water {RoW} tap water production, conventional treatment | Alloc Def, U	60,322	kg	Water
One-day-chickens. At hatchery/NL Mass Lq	94,752	piece	Chicks
Outputs to technopshere	**Amount**	**Unit**	**Description**
Biowaste {MX} treatment of, composting | Alloc Def, U	561.6	kg	Bird carcasses
Poultry manure, fresh {ROW}| market for | Alloc Def, U	102.9	kg	Manure

Table 3. *Cont.*

Development Phase			
Inputs from technosphere	**Amount**	**Unit**	**Description**
Compound feed broilers/NL Mass MX Lq	282,240	kg	Grain
Tap water {RoW} tap water production, conventional treatment | Alloc Def, U	564,480	kg	Water
Laying hens < 17 weeks, breeding, at farm/NL Mass MX Lq	94,657	Piece	Bird
Outputs to technopshere	**Amount**	**Unit**	**Description**
Biowaste {MX} treatment of, composting | Alloc Def, U	128.2	kg	Bird carcasses
Poultry manure, fresh {ROW}| market for | Alloc Def, U	514.3	kg	Manure
Egg posture Phase			
Inputs from technosphere	**Amount**	**Unit**	**Description**
Compound feed broilers/NL Mass MX Lq	3362.3	kg	Grain
Tap water {RoW} tap water production, conventional treatment | Alloc Def, U	7,301,700	kg	Water
Laying hens > 17 weeks, breeding, at farm/NL Mass MX Lq	94,184	Piece	Birds
Outputs to technopshere	**Amount**	**Unit**	**Description**
Biowaste {MX} treatment of, composting | Alloc Def, U	756.8	kg	Bird carcasses
Poultry manure, fresh {ROW}| market for | Alloc Def, U	4549.1	kg	Manure
Package Phase			
Inputs from technosphere	**Amount**	**Unit**	**Description**
Linerboard board box production, with gravure printing {ROW} carton board production servidem with gravure printing | Alloc Def, U	39,375	kg	360 cardboard egg boxes
Linerboard {ROW} | production, kraftliner | Alloc Def, U	63,455	kg	Dozen linerboard egg box

Table 4. Fuel inventory database from poultry farm per production phase.

Breeding Phase			
Inputs from Technosphere	**Amount**	**Unit**	**Operation**
Electricity, medium voltage {MX} electricity voltage transformation from high to medium voltage | Alloc Def, U	582.7 2960.9 107.4 62.6	kWh kWh kWh kWh	Illumination Air extraction Water pump Food supplying
Liquefied petroleum gas {RoW} petroleum refinery operation | Alloc Def, U	2.80	kg	Heating
Development Phase			
Electricity, medium voltage {MX} electricity voltage transformation from high to medium voltage | Alloc Def, U	272.1 537.1	kWh kWh	Illumination Water pump
Egg Posture Phase			
Electricity, medium voltage {MX} electricity voltage transformation from high to medium voltage | Alloc Def, U	5443.2 3222.7 1418.9	kWh kWh kWh	Illumination Water pump Food Supplying

Alloc Def, U = Allocation, default unit; NL Mass MX Lq = Netherland mass, Mexico adaptation (Agri-footprint).

2.2. Value Stream Mapping

The primary function of this tool is to map activities with or without added value necessary to elaborate a family of products (or just one), following the process of a product from the raw material to its completion or delivery to the client [19,24] (Figure 4).

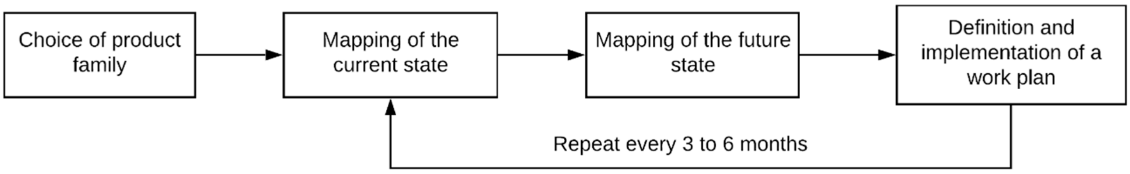

Figure 4. Product system VSM frame of reference [24]).

The shelf egg is the product of interest and is obtained within 76 weeks of the system product process. At the end of the production cycle, a quantity of 1,800,000 kg of eggs were produced. The VSM was limited to the demand for inputs from the chick breeding stages (6 weeks), bird development (10 weeks), and egg posture of laying hens (60 weeks) within the study farm.

Data from the LCA inventory of energy inputs and materials were used. Data were classified according to the equipment used, and the inputs of LCA tools together with VSM were developed through a four part follow up (Figure 5).

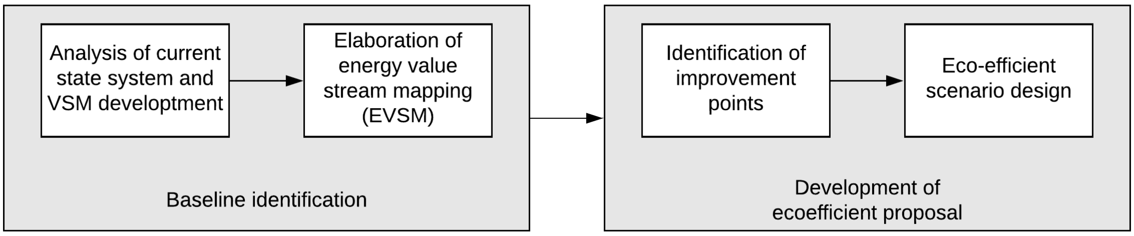

Figure 5. Monitoring of the VSM development stages of the current study.

The equipment used in shelf egg production was classified according to the unit operation and corresponding stage. The standard energy consumption was calculated using shelf egg data. After, with the energy data, an energy flow map (EFM) was developed, presenting the total and partial energy expenditure of each stage of the process. Using Equations (1) and (2), the specific energy and energy productivity per kilogram of the produced egg was calculated.

$$Specific\ energy = \frac{Energy\ use\ (kWh)}{Egg\ production\ (kg)} \tag{1}$$

$$Energy\ productivity = \frac{Egg\ production\ (kg)}{Energy\ use\ (kWh)} \tag{2}$$

An on-site analysis was carried out, where the equipment plate data were reviewed and the information from the equipment manufacturers was consulted. The pieces of equipment with the highest energy consumption at the farm were identified to propose more efficient alternatives. Energy billing concepts (energy consumption, power factor, demand factor) were also considered as relevant data in decision making for the eco-efficient scheme.

Once the improvement opportunities for the process had been identified, a flow map was drawn up to measure future value with an eco-efficient approach, using as a metric the substitution of a certain technology for one with greater energy efficiency. Finally, this was compared with the current scenario of the process only in the category of climate change.

3. Results

The estimated environmental impact profile corresponds to a semi-technified poultry farm with an intensive production system. Laying hen management, productivity (egg/day), and mortality rates were standard according to the management guide for Hy-Line W-36 hens [15]. This breed is advertised as the most efficient laying breed worldwide.

3.1. Life Cycle Analysis

Within the limits of the system (Section 2.1.3), the environmental impact assessment of shelf egg production shows that the egg laying stage accounted for 79% of the environmental impact of the product (Figure 6). Of 18 middle-point impact categories (Table 2), 10 were identified as significant and represent at least 75% of the contribution in each category (Table 5). Of 10 identified categories in the egg-laying phase, seven are related to broiler compound feed. Therefore, this last one is the input with the largest number of impact categories. Other reports about egg production also identify the compound feed as the input with the most significant contribution of environmental impact in the entire system product [25].

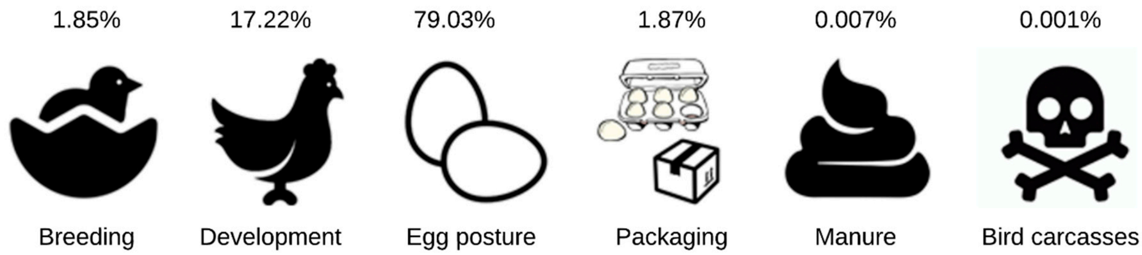

Figure 6. Potential environmental impact in the egg production phases.

Table 5. Significant impact categories for egg posture phase and total shelf egg production process (per kilogram).

LCA Inventory	Impact Category	Symbol	Input	Egg Posture Phase	Total, Process
Compound feed broilers/NL Mass MX Lq	Climate change	CC	Food	4.4 kg CO_2-eq	5.6 kg CO_2-eq
	Water depletion	AA		6.3×10^{-2} m^3	7.8×10^{-2} m^3
	Human toxicity	TH		1.4×10^{-1} kg 1,4-DB-eq	1.6×10^{-1} kg 1,4-DB-eq
	Fresh water eutrophication	EAF		5.3×10^{-4} kg P-eq	6.5×10^{-4} kg P-eq
	Terrestrial ecotoxicity	ECT		6.6×10^{-2} kg 1,4-DB-	8.5×10^{-2} kg 1,4-DB-eq
	Fresh water ecotoxicity	ECAF		2.2×10^{-2} kg 1,4-DB-eq	2.7×10^{-2} kg 1,4-DB-eq
	Agriculture land use	USA		4.2 m^2a	5.2 m^2a
Laying hens > 17 weeks, breeding, at farm/NL Mass MX Lq	Particulate material formation	FMP	Birds	7.5×10^{-3} kg PM_{10}-eq	1.1×10^{-2} kg PM_{10}-eq
Electricity, medium voltage {MX} electricity voltage transformation from high to medium voltage | Alloc Def, U	Fossil resources depletion	AF	Electricity	7.4×10^{-1} kg crude oil-eq	9.4×10^{-1} kg crude oil-eq
	Ozone depletion	AO		2.7×10^{-7} kg CFC-11-eq	3.6×10^{-7} kg CFC-11-eq

Electricity is an input that can be modified by reducing its use in the process without compromising the bird's biology, unlike diet. Table 6 shows the environmental contribution derived from the use of electricity and fuel in the stages of the egg production process (kWh/kg egg).

Table 6. Potential impacts of egg production related to the use of process electricity.

Impact Category	Current Process Scenario			
	Breeding	Process Stage Development Contribution	Posture	Total Impact Potential per kWh/kg Egg
Climate change (kg CO_2 eq)	1.31×10^{-3}	2.85×10^{-4}	3.55×10^{-3}	5.14×10^{-3}
Human toxicity (kg 1,4-DB eq)	4.62×10^{-4}	1.01×10^{-4}	1.26×10^{-3}	1.26×10^{-3}
Ecotoxicity of fresh water (kg q,4-DB eq)	1.25×10^{-5}	2.73×10^{-6}	3.40×10^{-5}	3.40×10^{-5}
Ecotoxicity of sea water (kg 1,4-DB eq)	1.14×10^{-5}	2.48×10^{-6}	3.40×10^{-5}	3.08×10^{-5}
Use of agricultural land (m^2a)	4.99×10^{-5}	1.09×10^{-5}	1.35×10^{-4}	1.35×10^{-4}
Natural land use (m^2a)	2.34×10^{-7}	5.05×10^{-8}	6.30×10^{-7}	6.30×10^{-7}
Depletion of fossil resources (kg oil eq)	4.15×10^{-4}	9.01×10^{-5}	1.12×10^{-3}	1.12×10^{-3}

3.2. Integrated Value Stream Mapping with Life Cycle Analysis

The VSM results of the current state production process are shown in Figure 7. It was identified that 5.58 kg CO_2/kg would be emitted, similar to that reported in other countries (Table 1).

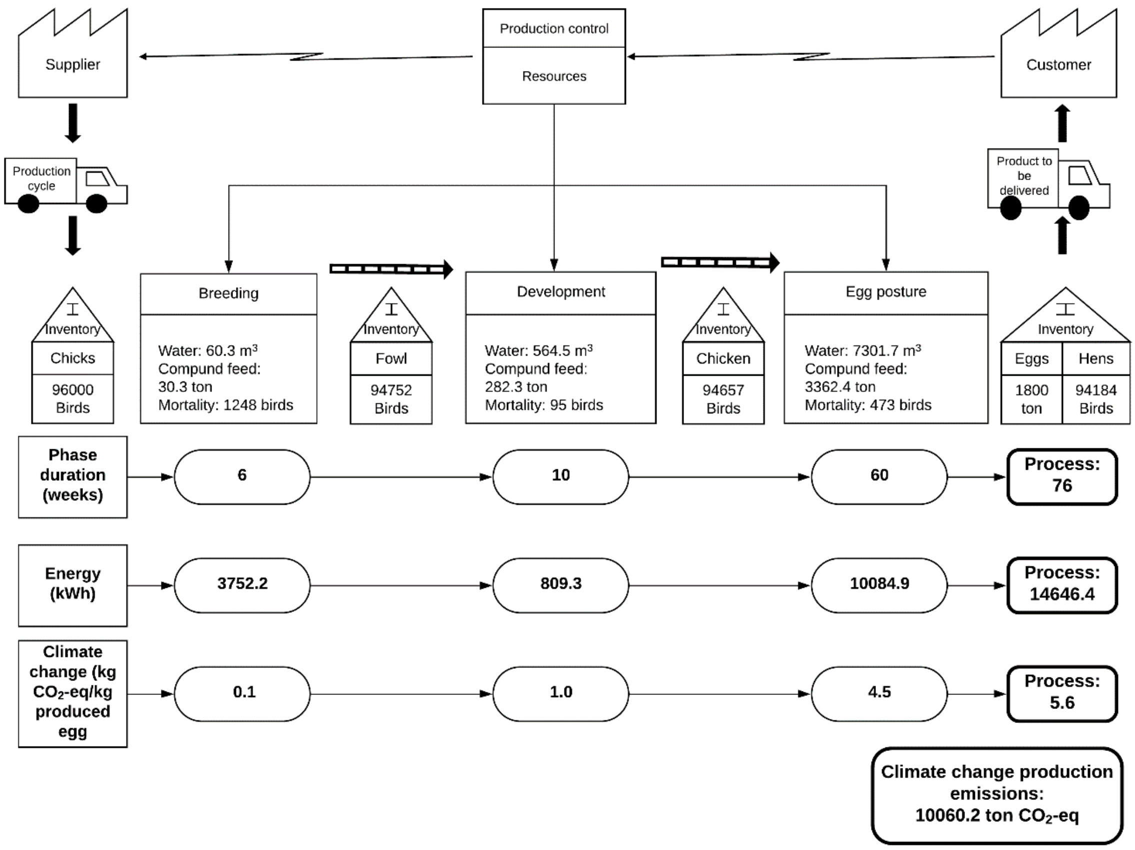

Figure 7. Climate change emissions from the current egg production process.

The results of the VSM, considering equipment with greater energy efficiency in the production stages, are presented in Figure 8. It was identified that the farm has an energy demand of 14,646.3 kWh in the production cycle, and that fluorescent bulbs for lighting are the equipment with the highest units, number of hours in function, and the highest energy consumption. The specific energy used in the production of 1 kg of eggs from the studied farm was 0.0081 kWh/kg, and the energy productivity was 122.6 kg/kWh. This value is higher than that found by [26], who reported specific energy of 0.004 kWh/kg for eggs, due to energy consumption of 365,770 kWh/production cycle, and production of

65,084,680 kilograms of eggs. However, the differences are possibly explained by the differing degrees of each farm's technification.

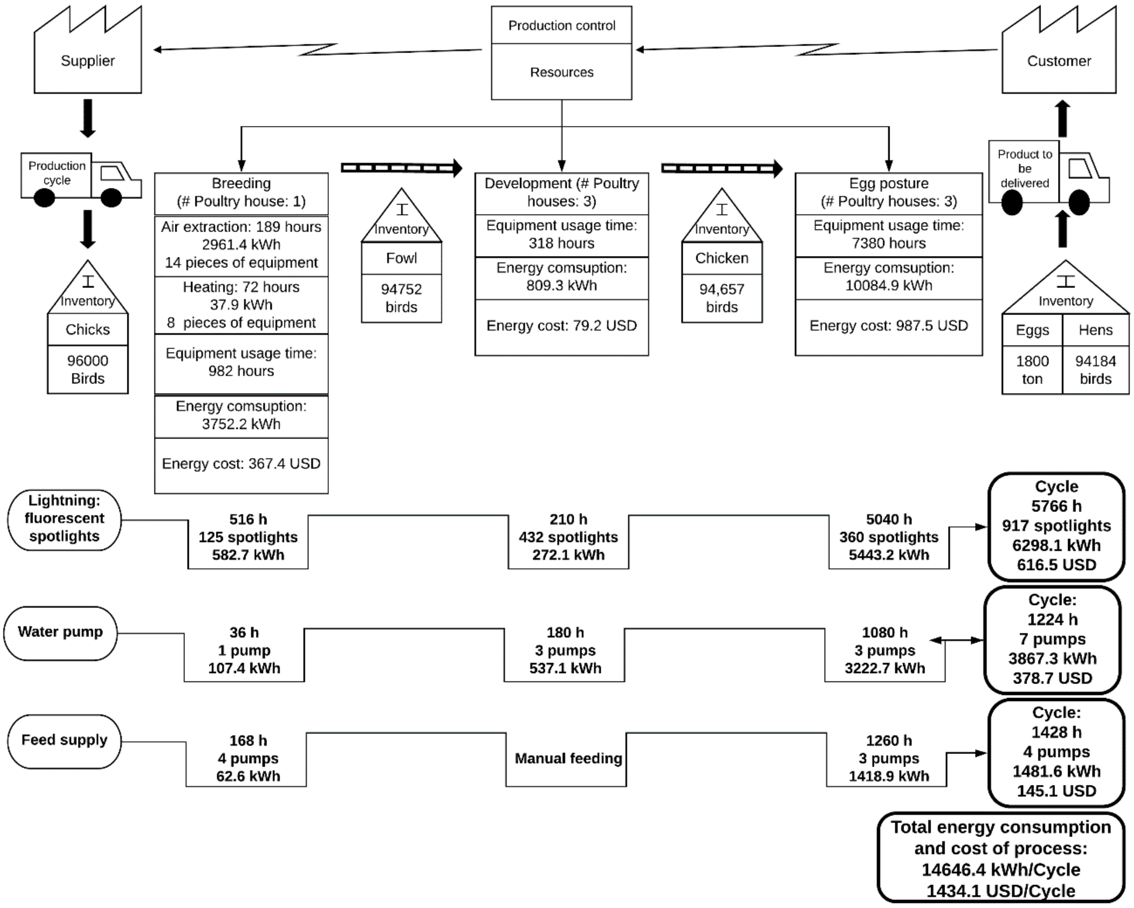

Figure 8. Consumption and cost of energy flows from unitary operations in egg production at current state.

One of the sources that does not provide added value to operations within the energy efficiency of a process is the overvaluation of consumption per power equipment. This is where adjustments are made for efficient operation, reducing consumption without compromising production. When looking for efficiency in lighting by replacing bulbs, it is advisable to look for the equivalent in lumen (lm) rather than watts, because lumen indicate the amount of light emitted rather than the energy consumed. When the motors are working at a high torque they slowly accelerate from low revolutions, thus maintaining better efficiency in transporting material. Figure 9 shows the VSM of the expected future state of the shelf egg production process. Subsequently, Table 7 shows the possible energy saving per operation.

Table 7. Comparison of the energy expenditure of the current state vs. the eco-efficient scenario for the egg production process at *Laguna Colorada* farm.

Unit Operation	Current Scenario Expenditure (kWh)	Eco-Efficient Scenario Expenditure (kWh)	Reduction (%)
Illumination	6298.1	2448.4	61.1
Water pump	3867.7	1933.6	50.0
Food supply	1481.6	987.0	33.4
Extraction	2961.4	1984.5	33.0

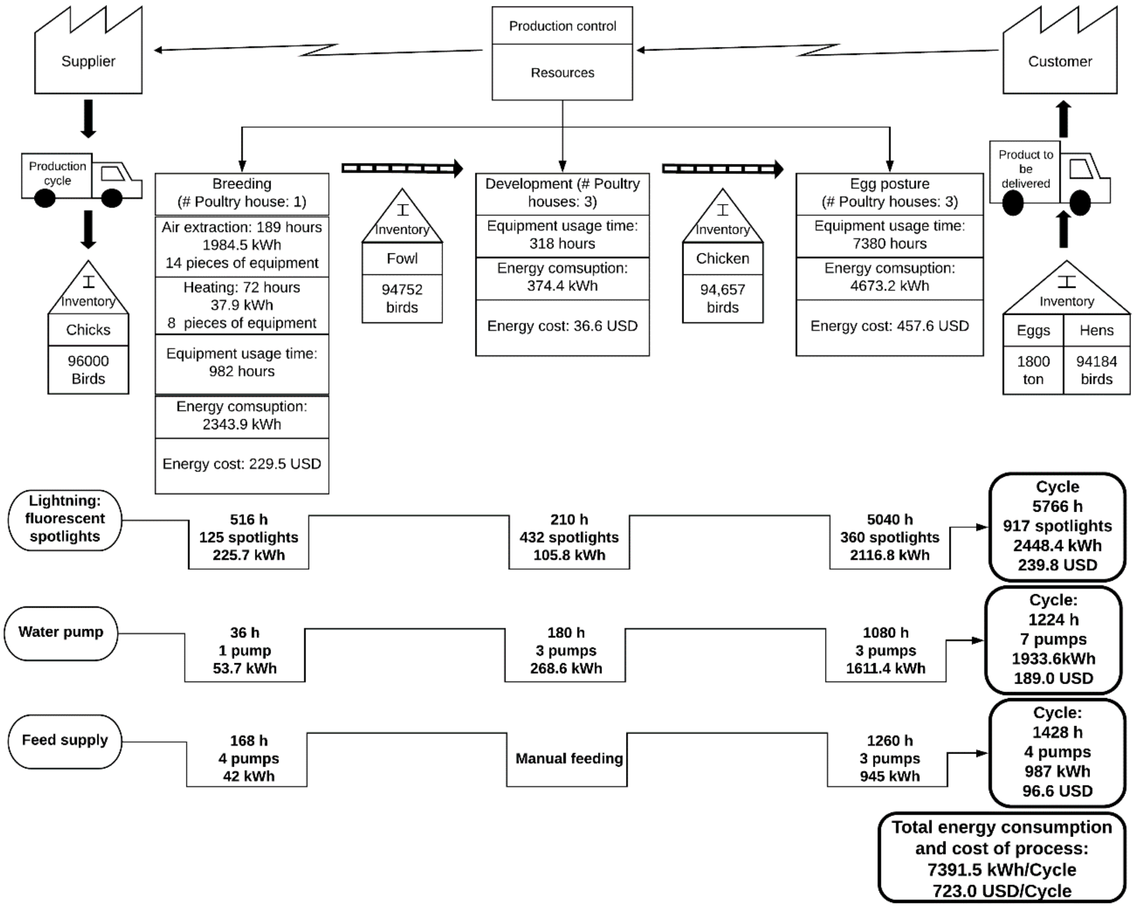

Figure 9. Energy consumption and cost of the expected future scenario of energy flow from unit operations in egg production at a future state.

With the eco-efficient scheme and the adjustment of the consumption/power ratio in the equipment, it would be possible to obtain a 49.5% reduction in the farm's total energy consumption without compromising the current production process. There would also be an average saving of 56.3% in environmental impacts for the electrical cost of egg production. A monetary saving of 686.3 USD (June 2019) would be recorded for each production cycle. Illumination, which is the process with the highest energy demand, would have a 61.10% reduction with the substitution of LED spotlights.

The difference in the reduction of these potentials (Table 5) is known as an externality. These are activities that affect third parties without having the need to pay for them or to be compensated by the final client. There are methodologies for environmental economics that allow conversion of the internalization of such externalities. One is the cost-effectiveness analysis, which focuses on seeking an internal benefit in production, as well as a social benefit. Table 8 shows the social benefit equivalent to various variables for each kilogram of CO_2 (i.e., not emitted into the atmosphere). The integration of this type of improvement is not limited to the type of process. It can be applied to be more productive in industrial processes with less raw materials in mechanical, electrical, chemical, transportation equipment, food, textile, graphics arts, and stationery industries, among others.

Table 8. Social benefits obtained, comparing both scenarios of egg production in activities equivalent to 1 kg CO_2 eq [27,28].

Variable	Equivalence 1 kg CO_2/Variable	Estimated Consumption at Current Scenario	Estimated Consumption at Eco-Efficient Scenario	Estimated Social Benefit
Diesel (L)	2.34	21,649	9434	12,215
Gas LP (L)	1.49	13,813	6019	7794
Crude oil (L)	2.21	20,483	8926	11,557

4. Conclusions

The findings in this study contribute to improving the sustainable performance of the poultry industry and reducing its environmental impact. Lean manufacturing techniques, such as VSM, can improve the process by identifying opportunities for eliminating waste. The application of LCA to a study allows knowledge of the quality of the manufacturing process concerning the environment when identifying environmental impacts. However, when both technics are integrated, a visualization of the process with an eco-efficient approach is provided. This integral framework (LCA and VSM) helps to facilitate sustainable productivity and provides scientific value, intending to ensure best practices. Additionally, this framework offers leveraged benefits that meet lean and environmental needs.

4.1. Limitations Section

- Comparisons of LCA are complicated, even when using the same methodology, as results can differ with particular assumptions in each study.
- The results of an LCA study with national- or regional-level approaches may not be accurate for local applications, or vice versa. This study has an important geographical limitation to consider. The studied farm is located in the main egg-producing zone in Mexico (Jalisco State), which has favourable weather conditions for this activity. Other important egg-producing farms in Mexico are located in hot-dry or hot-humid climates. To provide thermal comfort to laying hens, technified farms are likely to use different technologies than those reported here. Different, additional, newer, or more modern equipment would imply variations of energy consumption as well. Therefore, the results from this semi-technified farm may not be suitable for small farms that employ manual handling.
- The VSM results are also related to the limitations described for LCA.

4.2. Future Research Plan

The technification index for farms has not been reported in Mexico for the poultry sector. Therefore, the official reports of national greenhouse gases (GHG) for this sector do not consider differences among national shelf egg, hatching egg, or poultry production. For this reason, it is important to develop new research in this sector to recognize the real efficiency, impacts, and opportunities for energy management and limitation of environmental footprints.

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