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The Institutionalization of Life Cycle Assessment in Mexico

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Abstract

This article presents a study of Life Cycle Assessment (LCA) at a slaughterhouse located in northwestern Mexico with the purpose of testing the premise of a low degree of institutionalization of Industrial Ecology in Mexico. The article aims at analyzing the current role played by the Mexican academia in increasing the degree of institutionalization of the concept of LCA in northwestern Mexico. There was conducted a life cycle analysis study according to the standards ISO 14040: 2006, NMX-SAA-14040-IMNC-2008NOM in a Federally Inspected Type (TIF by Spanish acronym) Slaughterhouse in the state of Sonora in Northwest Mexico. The slaughter process was characterized by observing the production tasks during several walkthroughs the production lines and by having short interviews with workers, supervisors, and the manager. The CH_4 emissions were calculated using the guidelines suggested by the Intergovernmental Panel on Climate Change (IPCC 2006). The present LCA case study revealed opportunities for improving the environmental performance of the slaughterhouse by taking measures such as the reduction of CH_4 from enteric fermentation since methane was one of the main greenhouse gases responsible for climate change. Although, the LCA generated reliable information in terms of climate change or water eutrophication, the chances of implementing sustainable initiatives were unlikely because the benefits to reduce the impacts to climate change or to reduce the water crisis would be unnoticeable and unaffordable for companies. Findings in this study also confirmed the importance of Mexican universities for promoting and conducting more LCA studies among private and public organizations in order to guide firms towards this tool. The case study here presented gives insights to LCA stakeholders in Mexico to implement or improve the effectiveness of their potential LCA initiatives through the identification of strategies, opportunities, and barriers.

Keywords

1. Introduction

As stated by reference [1] some years ago, Industrial Ecology provides the technological and scientific basis for being considered a path toward sustainability. This has been the case mainly in European countries, particularly in The Netherlands, where the concept is disseminated due to its influence on the positive ecological results from the industrial symbiosis at the Kalundborg industrial park in Denmark [2]. In order to create an industrial symbiosis, Boons and Spekkink [3] found the mobilization capacity, which was the ability of actors within the industrial park to activate relevant firms and other parties to develop symbiotic linkages, to be critical.

Life Cycle Assessment (LCA) is another key concept in Industrial Ecology that is used as analytical tool to address the environmental impacts of products and services [4]. In recent years, LCA has been useful for decision makers in business and policy [5].

From its beginning to present day, LCA has been used for different environmental purposes in several settings such as: cement manufacture [6]; wood production [7]; carbon nanotube products [8]; renewable resources [9]; industrial waste [10]; fisheries [11]; organic waste [12] and many other applications. Most of these, along with other LCA-case studies found in the literature, were unsurprisingly conducted in Europe thus proving the institutionalization of the concept in that continent. The fact that it is not possible to find literature on LCA studies in Mexico in the most prestigious sustainability journals indicates there is a lack of institutionalization of Industrial Ecology, pertaining to LCA, in Mexico.

Thus, one of the goals of this study was to test this premise and explore the degree of institutionalization of LCA in northwestern Mexico by conducting a life cycle analysis case study at the slaughtering stage of the beef production system of Mexico Supreme Quality, official brand, in a Federally Inspected Type (TIF for its Spanish acronym) Slaughterhouse within the state of Sonora, Mexico.

Beyond the technical difficulties, the study also aimed at analyzing the current role played by the Mexican academia in increasing the degree of institutionalization of the LCA in northwestern Mexico.

2. Methodology

2.1. Case Study Profile

The life cycle analysis study was conducted according to the standards ISO14040: 2006, NMX-SAA-14040-IMNC-2008NOM in a Federally Inspected Type (TIF by Spanish acronym) Slaughterhouse in the state of Sonora in Northwest Mexico. The Slaughterhouse was built in 2007 covering an area of 21,000 square meters in a suburb of the capital city of Hermosillo. The average daily cattle slaughter is 200 bovines, including cows, bull, calves, heifers, and bullocks, from several farms. Eighty-seven workers are employed in the slaughterhouse covering two shifts.

The slaughter process was characterized by observing the production tasks during several walkthroughs the production lines and by having short interviews with workers, supervisors, and the manager.

2.2. Functional Unit (FU)

A mass balance for the slaughterhouse process was required to get the functional unit of the system under examination. The average weight of livestock, the average weight of bovine meat, and the average weight of the organic waste generated in three days were calculated.

2.3. Inputs and Outputs Inventory

The rate of livestock slaughtered per day, the water and natural gas consumption per day, and the electricity consumption per month were all considered. The hazardous substances used for housekeeping were also included in the inputs inventory. The emission inventory included the production of methane (CH_4) calculated from the enteric fermentation, manure, and the natural gas emissions from the boiler. Additionally, emissions of carbon dioxide (CO_2), carbon monoxide (CO), nitrous oxide (N_2O), nitrogen oxide (NO_X), sulfur dioxide (SO_2), and the volatile organic compounds (VOC's) from the use of natural gas were calculated as well. Furthermore, the CO_2 emissions from electricity generation were also taken into account.

2.4. Data Calculations

a) CH_4 emissions from enteric fermentation

The CH4 emissions were calculated using the guidelines suggested by the Intergovernmental Panel on Climate Change [13], whose formula for enteric fermentation is shown in Equation (1):

$$\text{CH}_4 \text{ emissions} = \text{number of animals} \times \text{CH}_4 \text{emission factor} \tag{1}$$

where the CH_4 emissions factor is equivalent to 56 kg/animal/year.

b) CH_4 emissions from manure

It was considered for the tier 1, emissions factors with high uncertainty, from the 2006 IPCC guidelines.

c) CO_2, N_2O, NO_X, CO, SO_2 emissions and VOC's from natural gas

Emission factors for criteria pollutants and greenhouse gases from natural gas combustion were taken from the U.S Environmental Protection Agency guidelines [14].

d) CO_2 emissions from electricity generation

The CO_2 emissions from electricity generation were obtained by using a Mexican Calculator of CO_2 [15] created by the National Institute of Ecology, a Mexican governmental agency, Pronatura Mexico, and a private organization called "Reforestemos Mexico".

e) Wastewater

Wastewater was analyzed, taking into account the Mexican Official Norm (NOM for its Spanish acronym) NOM-001-SEMARNAT-1996, at a certified laboratory of the National Water Commission in Mexico (CONAGUA). The water quality parameters analyzed were phosphate (PO4-P), total suspended solids (TSS), the biochemical oxygen demand (BOD), the chemical oxygen demand (COD), and the total Kjeldahl nitrogen (TKN).

f) Environmental impacts

Environmental impacts such as water depletion, water eutrophication, global warming potential, human toxicity, air acidification, and the photochemical ozone creation potential were evaluated with the GaBi Education Software, version 4.

3. Results

a) Boundary system

Figure 1 shows the boundaries of the slaughterhouse production system, indicating inputs and outputs per work station.

b) Mass balance

Table 1 indicates the mass balance with a functional unit of 299.5 kg, which was calculated as described in the methodology section.

Table 1. The slaughter process—mass balance.

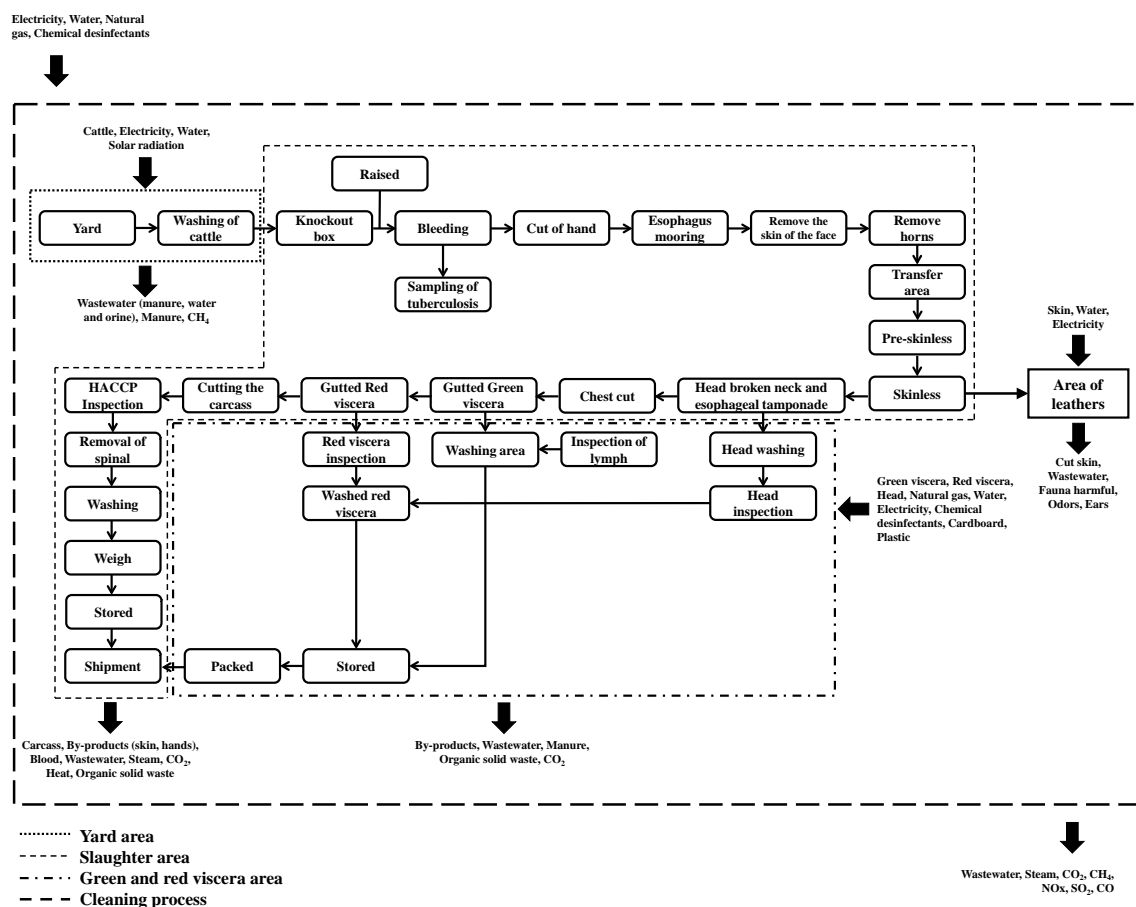| Raw Material		Kilograms	
Livestock		473.5	
Waste	Kilograms	Meat	Kilograms
Farms	8	2 Carcasses	299.5
Slaughter	30	Byproducts	Kilograms
Green Viscera	58	Legs (4)	6.28
Red Viscera	7	Leather	33.16
Total	103.00	Head	15
		Giblets	5.23
		Belly Washed	3.96
		Liver	4.78
		Heart	1.54
		Milk Gut	1.05
		Total	71.00

Figure 1. Characterization of the slaughter process.

c) Inputs inventory

The consumption of resources in relation to the functional unit is shown in **Table 2**. The time period is presented on a monthly base.

d) Hazardous inputs

Chemicals are also used in the slaughter process, **Table 3** presents these inputs. In addition, products for cleaning and disinfection of facilities are also considered in **Table 4**.

e) Emissions to environment

Table 5 shows the sources of the emissions per functional unit (FU) associated to the production process as well as the potential impact on the environment.

f) Organic waste

Table 6 depicts the organic waste generated per functional unit.

g) Potential environmental impacts

The assessment of the potential environmental impact was done using the method CML 2001 of the Center of Environmental Science of Leiden University and taking into consideration the slaughter average rate per month of 4333. **Table 7** shows the numbers.

4. Discussion

The present LCA case study revealed opportunities for improving the environmental performance of the slaughterhouse by taking measures such as the reduction of CH_4 from enteric fermentation since methane is one of the main greenhouse gases responsible for climate change. The LCA showed that CH_4 contributes to about 99%, 215,566 CO_2-equivalent kilograms, of the total emission in the slaughterhouse.

According to the Greenhouse Gas (GHG) emission inventories and forecasts report (I & Fs) of the state of So-

Table 2. Inventory of inputs used in the slaughterhouse.

Month	Slaughters	Monthly consumption of natural gas (m³)	Monthly water consumption (m³)	Monthly electricity consumption (kWh)
July	4048	470	7116	323
August	4132	408	6852	327
September	4819	387	6407	
Total	12,999	1265	20,375	650
Average	4333	421.67	6791.67	325
Functional unit*	299.5 kg*	0.10	1.58	0.08

Table 3. Chemical inputs.

Chemical	Chemical formula	CAS number	Monthly consumption	Daily consumption	Consumption per FU	Function
Caustic soda	NaOH	1310-73-2	396 kg	18 kg	0.09 kg	Bleach
Triple wash		Patent	198 l	9 l	0.045 l	Bleach
Hydrogen peroxide		7722-84-1	198 l	9 l	0.045 l	Bleach

Table 4. Products for cleaning and disinfection of facilities.

Chemical	Chemical Formula	CAS Number	Monthly Consumption	Daily Consumption	Consumption per carcass
Alkaline detergent	H_2O_2		84 l	3.50 kg	0.0175 kg
Sodium hypochlorite, 5%	NaClO	7681-52-9	5.082 kg	0.23 kg	0.00145 kg
Potassium hydroxide, 14%	KOH	1310-58-3	76.96 kg	3.20 kg	0.02 kg
Neutral detergent			48.00 L	2.00 l	0.01 l
Quaternary base detergent	$C_6H_5CH_2N\,(CH_3)2RCl$, R = C_8H_{17} - $C_{18}H_{37}$	63449-41-2	36.00 L	1.50 l	7.5E−2 l
Sodium hypochlorite	NaClO	7681-52-9	53.24 kg	2.42 kg	0.02 kg
Det-Excel			44.00 kg	2.00 kg	0.01 kg
Multipurpose detergent			44.00 kg	2.00 kg	0.01 kg
Sodium hypochlorite, 13%		7681-52-9	44.00 kg	2.00 l	0.01 l

Table 5. Emissions to the environment and potential impact per functional unit.

Emissions	Source	Reference	kg/FU	Impact
Methane (CH_4)	EF, M, NGC, EP	IPCC 2006, EF (EPA)	1.99	GWP, POCP
Carbon dioxide (CO_2)	EP, NGC	EF (EPA)	3.12 E−01	GWP
Nitrous Oxide (N_2O)	NGC	EF (EPA)	3.52E−06	GWP
Sulphur dioxide (SO_2)	NGC	EF (EPA)	9.60E−07	AP, HTP, POCP
Volatile organic compounds (VOCs)	NGC	EF (EPA)	8.8E−06	GWP, HTP, POCP
Nitrogen oxides (NOx)	NGC	EF (EPA)	1.6E−04	AP, HTP, POCP
Carbon monoxide (CO)	NGC	EF (EPA)	13.44E−05	POCP
Phosphorus	Blood, chemicals	WS	0.03	EP
Solid suspended total	Fat	WS	2.03	EP
Nitrogen	Blood, chemicals	WS	0.87	EP
DBO	Blood	WS	5.72	EP
DQO	Blood	WS	1.13	EP

GWP = Global Warning Potential, EP = Eutrophication Potential, AP = Acidification Potential, POCP = Photochemical Ozone Creation Potential, HTP = Human Toxicity Potential, EF = Enteric Fermentation, M = Manure. NGC = Natural Gas Combustion, EP = Electric Power, EF (EPA) = Emission Factors (Environmental Protection Agency), WS = Wastewater Samples.

Table 6. Organic waste per functional unit.

Co-products	Average weight (kg)	Type disposal	Area
Fat	33.00	Re-processing	Green guts
Booklet	4.18	Re-processing	Green guts
Lung and trachea	2.81	Re-processing	Red guts
Ears	2.00	Re-processing	Slaughter
By-Products			
Gall	0.53	Landfill (container)	Red guts
Ilio	0.25	Landfill (container)	Green guts
Baso	0.82	Landfill (container)	Green guts
Esophagus	0.47	Landfill (container)	Green guts
Manure	19.00	Landfill (container)	Green guts
Horns	0.39	Landfill (container)	Slaughter
Fat	33.00	Re-processing	Green guts
Booklet	4.18	Re-processing	Green guts
Tail	0.11	Landfill (container)	Slaughter
Tail cut	0.16	Landfill (container)	Slaughter
Cut-nosed	0.58	Landfill (container)	Slaughter
Inspection head	0.23	Landfill (container)	Slaughter
Cut liver	0.18	Landfill (container)	Slaughter
Trim	0.75	Landfill (container)	Slaughter
Spinal	0.27	Landfill (container)	Slaughter
Penis	0.30	Landfill (container)	Slaughter
Confiscation of guts	1.20	Landfill (container)	Green guts

nora [16], 52.6% of total greenhouse gas emissions in 1990 was generated from enteric fermentation in the state's farms, and it has been forecasted that by 2020 enteric fermentation will account for 53.3% of the total greenhouse gas emission in the state. These data rank the agriculture sector and the energy supply conjointly as the main sources of GHG emission in the state.

Another environmental concern is wastewater due to its high contents of blood, air, fats, and chemicals that increase the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD) that consequently cause, the eutrophication of water. There is strong evidence that water crisis worsens as climate change increases [17]. In spite of the water scarcity in homes, the agricultural sector concentrates almost 80% of world water consumption [18]; additionally, important amounts of water are also consumed in the production of meat and dairy products [19]. For those reasons, wastewater treatment is vital nowadays in order to avoid water shortages that have prevented economic growth in many countries around the world [20].

From the academic perspective, the case study was a success because it was possible to collect data for conducting the LCA, despite of the lack of interest of administrators in this methodology. Since a basic tenet of business is generation profits, when thinking about sustainability, administrators are expected to be not only green but also cutting costs. Although, the LCA generated reliable information in terms of climate change or water eutrophication, it is true that decision makers at the slaughterhouse were more interested in production process data that could cut costs and protect the environment at a local level. For this reason, the chances of implementing sustainable initiatives are unlikely because the benefits to reduce the impacts to climate change or to

Table 7. Environmental impacts-CML2001.

Potential Impact	Emission	Quantity	% of Total Emissions	Total Emissions
Global Warming CO_2	CH_4	215,566.75	99	
	CO_2	1351.83	1	216,923.80
	VOC	0.61	NS*	
	N_2O	4.54	NS*	
Depletion of Water "m^3"	Wastewater	5546.24	100	5546.24
Eutrophication "kg Phosphate-Equiv."	BOD	545.265	52	
	Phosphorus (P)	397.77	38	1050.84
	COD	107.71	10	
	NO_x and N_2O	0.091	NS*	
Acidification "kg SO_2 Equiv."	NO_x	0.485	92	0.52
	SO_2	40E−03	8	
Photochemical Ozone Creation "kg Ethanol-Equiv"	CH_4	51.736	100	
	COVs	0.004	NS*	51.775
	NO_x	0.019	NS*	
	CO	0.016	NS*	
Human Toxicity	NO_x	0.83	100	0.833

reduce the water crisis would be unnoticeable and unaffordable for companies.

Now, the challenge is to transfer LCA from academia to public or private organizations. In Europe, this tool has been more deeply-rooted in scientific settings with less degree of institutionalization among business and lesser among consumers [21] perhaps due to the complicated math behind the methodological steps of this tool; mainly, in the allocation methods for the life cycle inventory analysis, which have been debated in numerous articles about LCA [22].

Institutionalization has been studied from many perspectives, but many coincided in defining this concept around values, norms, traditions, routines, interactions, and relationships within organizations [23].

According to Cohen and Howard [24] the degree of institutionalization of a concept is determined by the following conditions: professional legitimacy, viable clientele, entrepreneurial acumen, and prospective occupational opportunities.

The first condition deals directly with the academic field; one of the most important proactive efforts in northwestern Mexico to promote Life Cycle Assessment came from the Sustainable Development Certificate (SDC) at Engineering College of the University of Sonora. The SDC is considered by the Mexican Council of Science and Technology (CONACYT) as a Graduate Program of excellence with international recognition. This is the highest rank granted to a graduate program in Mexico by CONACYT; only 1% of all Mexican graduate programs reach this level. As an international competence graduate program, faculty have been influenced by peers in foreign institutions, mainly in Holland, Sweden, and Germany. Consequently, Industrial Ecology is part of the SDC curricula and students are taught to conduct LCA studies.

Viable clientele refers to the existence of a need that establishes the demand for LCA studies. This was not the case in this study, external drives for adopting and implementing Industrial Ecology tools such as LCA do not exist in Mexico. The main driver to conduct the LCA study was academic; therefore, it was done for free.

The third condition is entrepreneurship, which is inherently risky because it implies changes to organization's structures [25]. Perhaps for this reason, it was easier to get access to a small business than to larger companies. Although, permission was granted, the absence of philosophies, techniques, procedures, and rules in the slaughterhouse made the development of the LCA study more difficult. Gibb [26] also noted that entrepreneurial beha-

viors are less evident in larger companies than in small businesses, confirming another obstacle for the institutionalization of LCA in Mexico; the lack of adequate managerial and engineering skills in small businesses.

The last indicator to prove the institutionalization of a concept is the labor market. Labor market refers to information about what jobs and skills employers looking for. In other words, the number of jobs available, demand, and number of people with the competence for these jobs, supply.

A survey conducted in the state of Sonora at six manufacturing plants that import and assemble duty-free electronic components for export found that none of the participants in the survey claimed to perform material and energy balance or other tool of Industrial Ecology [27]. This survey suggests that there is no demand for industrial ecologists; despite that there are people having a set of skills needed to be competent in LCA.

5. Conclusions

By mimicking European LCA experiences in a slaughter house in northwestern Mexico, it was possible to confirm the premise that there was a low degree of institutionalization of LCA in this country.

In the case study here presented, LCA was not known by the administrators of the slaughterhouse; however, they accepted to grant access to slaughterhouse's facilities as long as data could cut costs and protect the environment at a local level. Although this was not the case, it was important to conduct the LCA in order to institutionalize the concept among private enterprises.

This LCA study identified two major opportunities to improve the environmental performance in the slaughterhouse: the CH_4 emissions from enteric fermentation and its wastewater. Beyond technical limitations to conduct the study; the LCA has proven to the administrators of the slaughterhouse that preventive measures can be taken particularly on these two pollution sources in order to reduce its environmental load. However, the consequences of these pollution sources resulted in global impacts making it unattractive to administrators to invest in projects that would have no direct benefits for the slaughterhouse.

Findings in this study also confirmed the importance of Mexican universities for promoting and conducting more LCA studies among private and public organizations in order to guide firms towards this tool.

As a closing insight, it is necessary to remark the potential of LCA as a viable alternative to help organizations to be more sustainable.

Acknowledgements

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