Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 22, Issue 4, 2022
PRINT ISSN 2284-7995, E-ISSN 2285-3952

CARBON FOOTPRINT ESTIMATION IN EGYPTIAN AQUACULTURE FARMS

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Abstract

This study discusses the result of a life cycle assessment (LCA) for three Egyptian aquaculture farms categorized as semi-intensive culture. The cradle-to-grave system was used to calculate the overall carbon footprint of fish unit production. The major data came from a study of three feed factories in Egypt, which included a wide range of feed manufacturing and agricultural practises in order to reveal the varied greenhouse gas (GHG) emissions. Pre-farm, farming, and post-farming were the three stages of the life cycle assessment. Feed manufacture, which was primarily tied to the production and processing of raw materials, was the largest source of GHG emissions for all three processes. GHG emissions were also produced during the transport of raw materials to the factory. GHG emissions were also produced during the transportation of raw materials to manufacturers, as well as feed from factories to fish farms, via ship or road. Energy consumption in feed factories varies due to variances in design technology and manufacturing efficiencies. Feed conversion ratios (FCR) have a significant influence on GHG emissions since more feed is required to produce one kilogramme of fish. The kind of packaging material and energy utilised in the factories had an impact on GHG emissions, as each type had a distinct emission factor (EF). Aside from fingerling production, there are direct and indirect N_2O emissions, as well as post-farming operations like packaging, ice serving method, and customer transportation. The conclusions of the investigation revealed that According to the results of the study, the emissions linked with the three farms varied greatly. Hanafy farm had the greatest emissions, with 3.265 kg CO_2e/kg fish and 50.917 tonnes CO_2e/Season, followed by Hashim farm with 2.259 kg CO_2e/kg fish and 45.829 tonnes CO_2e/Season, and finally Aly farm with 2.223 kg CO_2e/kg fish and 38.864 tonnes CO_2e/Season.

Key words: *aquaculture, carbon footprint, life cycle assessment, green-house gas emissions (GHG), climate change*

INTRODUCTION

Egypt, out of all the Arab countries, is the greatest sensitive to global warming. Climate change representations project that rising sea levels would flood significant parts of Egypt's the Delta, risking Egypt's food security and the livelihoods of millions of agricultural workers. Key population areas, such Alexandria and Port Said, are also in jeopardy. Furthermore, rising average temperatures may impede Egypt's ability to grow enough food to feed its growing population, producing further disruptions in the agricultural sector, which now employs over thirty percent of the country's workers. Another danger is the influence of climate change on rainfall patterns in highland Ethiopia, which supplies more than eighty percent of the Nile River's water [23].

In Egypt, the volume of fish production in 2019 reached 2.0 million tons compared to in 2018 was 1.90 million tons, an increase by 5.4% owing to amount of farm production fish increase, where its production come in the first place, and its percentage reached 79.7%, followed by Lakes, then marine waters, then fresh water then rice fields. The value of fish production reached 61.1 billion LE in 2019 compared to 48.3 billion LE in 2018, an increase of 26.6% due to the increase in production and prices [6].

Aquaculture can be definite as the farming organisms from both the sea and the freshwater. A definition of aquaculture as the controlled production of aquatic animals such as fish, oyster, and unicellular plants [26].

Aquaculture has accounted for the majority of net growth in fish output during the last decade [8]. An aquaculture system can be classified using a variety of characteristics. In terms of economics, the most important measure is intensity, or the distinction between intense, semi-intensive, and widespread kinds of culture. Stocking density, production by area, feeding regime, and input costs are all measures of intensity, but the most interesting aspect is the degree of control within the production process or according to the fish farmed species of monoculture and polyculture [2]. Semi-intensive earthen ponds are the most common aquaculture practise in Egypt. Intensive aquaculture farming has increased in popularity in the last 15 years, particularly in the deserts of northern Sinai, based on agricultural drainage waters [12].

The majority of the aquaculture production is obtained from semi-intensive fish farms in earthen ponds, which are dispersed throughout the Nile Delta region and concentrated mostly in the Northern lakes (Manzala, Edko, Burulus, and Maruit) area. The majority production of aquaculture derives from semi-intensive clay pond fish farms [25]. Semi-intensive systems produce between 5 and 25 tonnes per hectare per year. The Nile tilapia is the most widely grown fish in both tanks besides ponds [22]. Intensive pond aquaculture is currently displacing semi-intensive ponds in significant areas. Small earthen ponds of 3,000 to 6,000 m^2 used in intensive pond systems, with an average production of 14 to 25 tonnes/ha [11].

Increasing temperatures diminish dissolved oxygen levels and raise fish metabolic rates, resulting in a rise in fish fatalities, a decrease in productivity or an increase in feed requirements, as well as an increase in disease risk and spread. Furthermore, climate change may have an indirect impact on aquaculture activity. Wide swaths of aquaculture ponds in low-lying places, for example, may be particularly vulnerable to sea level rise inundation [10]. Increasing temperatures diminish dissolved oxygen levels and raise fish metabolic rates, resulting in a rise in fish fatalities, a decrease in productivity, or an increase in feed requirements, as well as an increase in disease risk and spread. Furthermore, climate change may have an indirect impact on aquaculture activity. Wide swaths of aquaculture ponds in low-lying areas, for example, may be particularly vulnerable to sea level rise inundation [10].

The high levels of GHG emissions documented for some aquaculture systems as aquaculture in the top 21 fish-producing countries generates 218 Tg CO_2 carbon dioxide equivalent which mean the amount of CO_2 equivalent to the quantity of GHG gases associated with a process (CO_2e) CH_4 and 11 Tg CO_2e N_2O annually [29].

Due to their significant global warming potential (GWP) (34 and 298 times more than carbon dioxide (CO_2) over a 100-year time horizon, respectively, methane (CH_4) and nitrous oxide (N_2O) emissions are the most relevant [18].

Aquaculture is anticipated to produce more than 5% of total anthropogenic N_2O emissions by 2030 [19].

Earthen shallow fish ponds are GHG emission hotspots, accounting for more than 80% of all aquaculture GHG emissions [29].

Agricultural systems account for 10 to 12 percent of global total GHG emissions; however, if all agriculture-related emission sources are included, this proportion might rise to between 17 and 32 percent (8.5-16.5 Pg CO_2e) [4].

LCA is a process for charting and quantifying a product's environmental consequences throughout its life cycle. The ISO 14000 set of environmental management standards includes LCA. LCA is all-encompassing since it considers the entire life cycle, or production system, as well as a complementary set of environmental implications. Global warming, acidification, eutrophication, ozone layer depletion, and aquatic eco-toxicity are some of the most common LCA impact categories [3]. The assessment of the total quantity of GHG emissions linked with a product along its supply chain is known as carbon foot printing (CF) [9].

As a result, a product's carbon footprint refers to the product's total GHG emissions over its entire life cycle, from raw materials to manufacturing, distribution, consumer use, and disposal [7].

CF estimation results will vary greatly depending on the methods used. The following system boundaries determine the life cycle stages [17]:

-Cradle-to-grave: covers emissions and removals released throughout the product's entire life cycle.

-Cradle-to-gate: includes emissions and removals up to the point where the product leaves the company.

-Emissions and removals in the supply chain are included in the gate-to-gate approach.

-Partial CF: only emissions and removals related to specific phases are included.

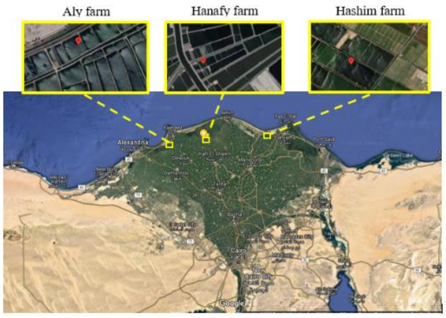
Publically available specification 2050 (PAS 2050), GHG Protocol, and ISO 14067 are the three most widely used Carbon Footprint (CF) standards in the world [5]. All three provide standards and guidance for making decisions during a carbon footprint analysis. All of them are based on existing LCA methodologies such as ISO 14040 and ISO 14044. LCA problems like as aim and scope definition, data gathering methodologies, and reporting are all part of the decision-making process. Furthermore, these criteria include requirements for land-use change, carbon uptake, biogenic carbon emissions, soil carbon change, and green electricity, all of which are important to the CF [24].

The main objectives of this study to estimate Greenhouse gases for LCA of Egyptian semi-intensive earthen ponds aquaculture and calculating fish unit production of equivalent carbon dioxide. Also, the annual emissions associated with aquaculture from raw material production across raw material transport and shipping to factories. Besides, feed manufacturing types and energy. As well as on farm energy and feed consumption and N_2O emissions. Finally, post farming emissions from packaging, ice serving and transporting of final products.

MATERIALS AND METHODS

Materials

The current study established on three aquaculture farms located in north of Egypt these farms were Hanafy farm at Kafrelshikh government, Hashim farm at Dakahlia government and Aly farm at Elbehira government as shown in Map 1 and Table 1. There are three feed factories under study located in Damro, 6th October and Baltim cities. The aquaculture production system common was the semi-intensive.



Map 1. Location of aquaculture farms under study on Egypt satellite map
Source: Google Maps.

In the three Egyptian semi-intensive earthen pond aquacultures, the system boundary is "cradle to grave," and the life cycle assessment (LCA) was chosen as the environmental management technique to analyze the net aquaculture production sectors from a life cycle viewpoint, as illustrated in Figure A.

In this study, the International Standards Organization (ISO) 14040, 14044 outlines and PAS 2050 were applied on each stage of the LCA was detailed in figure 2. Mortality and FCR calculated as follows [21]:

- Mortality = fingerlings death + disease + treatment + categorizing + discharges.
- Yield mass = harvest mass – fingerlings mass.

FCR = Yield mass (kg)/Taken feed(kg).

Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 22, Issue 4, 2022
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Table 1. Feed contaminants and formulation

	Units	Wheat bran	Maize gluten	Soyabean meal	Fish meal	Oil	Maize	Rice bran	Salt	Mineral and vitamin premix
Dry matter%	%	85	94	88	89	82	87	81	0	93
Gross energy	MJ/kgDM	18.9	18.8	19.7	21.9	21.2	18.7	20.5	0.0	9.2
Digestible energy	MJ/kgDM	16.0	17.7	17.3	19.4	17.3	16.3	16.6	0.0	8.5
Nitrogen	gN/kgDM	23.5	10.1	71	106.7	66.7	15.4	19.5	0.0	80.0
Crude protein	gCP/kgDM	147	63	444	667	417	96	122	0.0	500.0
Phosphorus	gP/kgDM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	114.0
Feed formulate (CP 25%)		15	5	32	3	2	20	21.7	0.5	0.8

Source: Feedipedia at www.feedipedia.org.

Stage GHG	Pre-farming	Farming	Post-farming
N_2O	• cultivation manure use • In organic N	• Fertilization of pond • Direct and indirect N_2O from excreted N and uneaten feed • Fingerling's feed	
CO_2	• on-farm buildings and equipment • Operations energy • feed material processing energy • Fertilizer manufacture • Production of non-crop feeds • Land use change (LUC) • feed packaging • nurseries feed production • Transport feed material to processing • Transport shipping of imported feeds • Transport road from port to feed mill • Transport manufactured feed to farm	• pond sediments • Direct on-farm energy use for pumping and lighting	• Main products and by-products processing • Transport from farm to capital markets • Transport from farm to medium markets • Transport from farm to small markets • Ice production • Fish HPDE boxes
CH_4	• Rice cultivation	Enteric fermentation	

Fig. 1. Cradle to Grave system boundary (under study parameters are inside dotted shapes and the outside parameters aren't under study).
Source: Authors' determination.

RESULTS AND DISCUSSIONS

After collecting data from the survey results estimated and discussed as below and emission factors for parameters and other constants collected in Tables 2 and 3.

Firstly, Pre-farming EI

Figure 2 showed that at Pre-farming EI stage the extruded feed for the third factory has the maximum EI with 1.283 $kgCO_2e$/kg feed and the pelleted feed at the first factory has the minimum EI with 1.043 $kgCO_2$/kg feed.

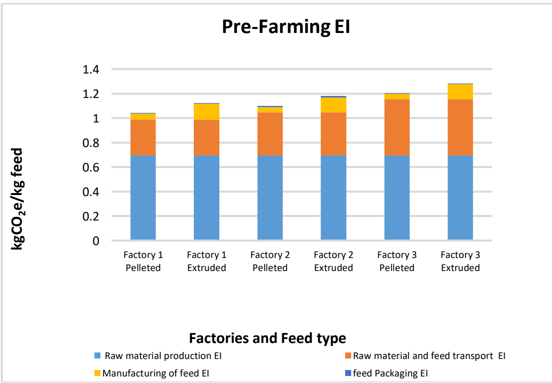

Fig. 2. Pre-farming stage main parameters EI.
Source: Own design and results.

This result was due to the effect of Transport to factory EI and the technology of manufacturing affecting on the energy consumed. Also Feed packaging material EI and transport feed to farm EI has a significant effect on the total EI.

Also, for example for the pelleted feed of factory 1, the raw material production occupied the largest percentage with 66.6% of EI and feed packaging had the lowest percentage with 0.62% EI.

Table 2. Emission factors and other constants values for different parameters and references

No	Item	Unit	Value	Reference
1	EF of ship	$kgCO_2e/t.km$	0.037	[27]
2	EF of lorries	$kgCO_2e/t.km$	0.085	[27]
3	EF of vehicles	$kgCO_2e/t.km$	1.0818	[20]
4	EF of electricity	$kgCO_2e/kW$	0.458	[15]
5	EF of diesel	$kgCO_2e/kg$	3.193	[20]
6	EF of Petrol	$kgCO_2e/kg$	3.01	[7]
7	EF of PP bag	$kgCO_2e/kg$ bag	2.69	[28]
8	EF of PPT bag	$kgCO_2e/kg$ bag	2.70	[28]
9	EF of PP&PE bag	$kgCO_2e/kg$ bag	2.695	[28]
10	EF of HDPE boxes	$kgCO_2e/kg$ bag	3.19	[28]
11	Density of diesel	Kg/L	0.832	[1]
12	Density of petrol	Kg/L	0.74	[1]
13	Nitrogen use efficiency	% of feed N	23.22	[14]
14	N excreted	% of feed N	76.78	[14]
15	N_2 to N_2O	N (44/28)	1.5714	[14]
16	GWP	N	298	[16]
17	N excreted converted to N2O-N	%	1.8	[14]
18	Ice manufacturing electricity	kWh/t ice	58	[13]
19	Ice manufacturing diesel	kg/t ice	0.25	[13]

Source: Set up by authors based on the studied literature.

Table 3. LCA stages emission intensities (EI) and main parameters

Pre-farming EI	Farming EI	Post-farming EI
• Raw material production EI • Raw material and feed transport EI • Feed Manufacturing EI • Feed packaging EI	• Farming Feed and energy EI • Fingerling Feed and energy EI • N_2O EI	• Fish high density polyethyler (HDPE) Boxes EI • Ice manufacturing energy EI • Transport to markets EI

Source: Authors' conception.

Raw material production EI

The results declared that raw material production EI is the sum of cultivation not including land use change (LUC) EI, transport to handling EI, manufacturing EI and LUC EI which were 0.415, 0.083, 0.168 and 0.027 $kgCO_2e/kg$ feed acting 39.82, 7.96, 16.14 and 2.66 % of pre-farming EI, respectively as shown in Figure 4. Every crop production has different EI as indicated in Table 4. Results shown in Figure 3 also indicated that all factories have the same value of EI of cultivation (not including LUC), transport to processing, processing and LUC as the raw material have been purchased from the same source.

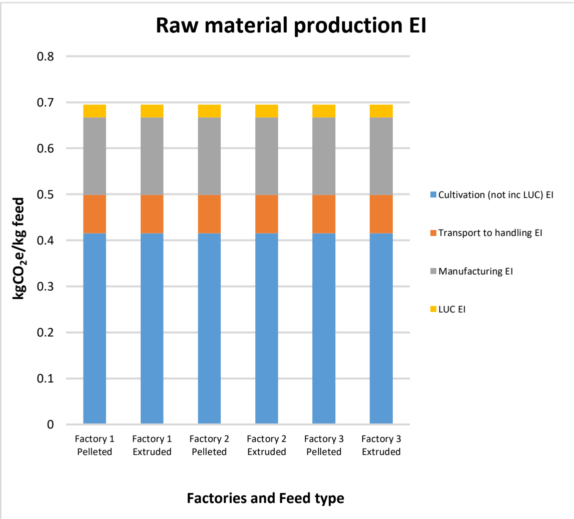

Fig. 3. Raw material production EI
Source: Own results.

The results pointed that maximum EI value for raw material production obtained for non-crop was 5.175 kg.CO_2e/kg dry material of mineral and vitamin premix and for crops was 1.862 kgCO_2e/kg dry material of maize gluten. Also, the minimum EI value for crops was 0.312 kg.CO_2e/kg dry material of rice bran as presented in Table 4. The analysis for this data indicated that processing stage has a significant effect on all raw materials EI.

Table 4. Raw material production EI

	Units	Wheat bran	Maize gluten	Soyabean meal	Fish meal	Oil	Maize	Rice bran	Salt	Mineral and vitamin premix
Cultivation (not inc LUC)	gCO_2e/kg. production	122.0	317.0	347.6	440.5	690.0	727.0	119.8		
Transport to handling	gCO_2e/kg. production	31.0	145.0	141.6	158.5	90.0		23.8		
Manufacturing	gCO_2e/kg. production	190.0	1199.0	90.4	513.1	95.0		29.0		
Main production	gCO_2e/kg. production	343.0	1661.0	579.6	1112.1	875.0	727.0	172.6		
LUC EI	gCO_2e/kg. production	0	0	0	0	0	0	108.16	0	0
Total EI at production	gCO_2e/kg. production	343.0	1661.0	579.6	1112.1	875.0	727.0	280.8	18.0	5175.0
Dry matter ratio	%	0.883	0.892	0.874	0.919	0.928	0.872	0.899	1	1
Total EI end cultivation	gCO_2e/kg dry	388.44	1862.1	663.157	1210.1	942.8	833.71	312.29	18	5175

Source**:** Feedprint Manual.

Raw material and feed transport EI

EI of raw material transporting consists of shipping EI for imported materials and transport from stores locally to factories EI as shown in Tables 3 and 6.

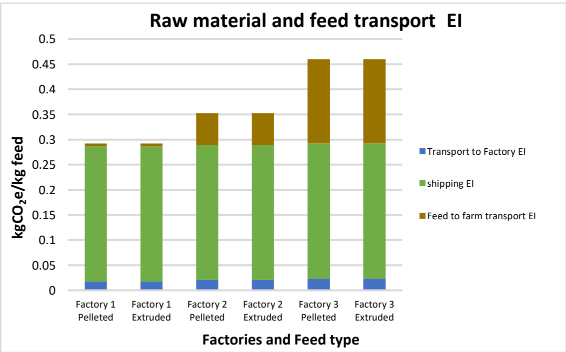

Fig. 4. Raw material and feed transport EI.
Source: Own results.

Also, for the pelleted feed of factory 1, the shipping EI acted the largest percentage with 92.2% of raw material and transport EI and feed to farm transport EI had the lowest percentage with 1.9% raw material and transport EI.

The results indicated that maximum EI for shipping was 546.49 gCO_2e/kg for maize gluten and minimum EI for shipping was 242.794 gCO_2e/kg for fish meal.

This result obviously related to the shipping distance from the importer as declared in Tables 2 and 5. The data also revealed that total transport EI was high for Maize gluten and low for salt, with 557.7 and 4.33 gCO_2e/kg, respectively. Since maize gluten was imported while salt was produced locally.

Feed manufacturing EI

Data collected from survey declared that energy at factories comes from electricity and diesel. Also, the extruded feed consumed energy more than the pelleted. So, the EI for the extruded is more than the pelleted at all factories as shown in Figure 5.

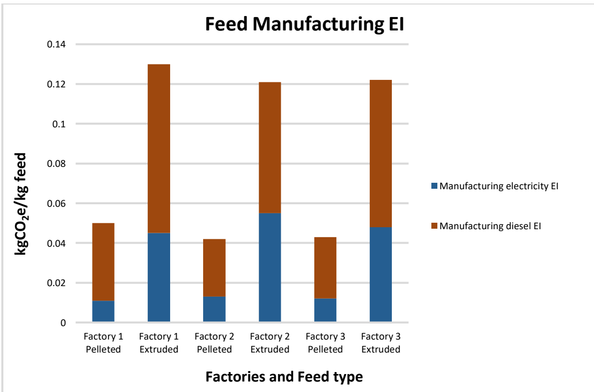

Fig. 5. Feed manufacturing EI for different factories and types feed
Source: Own results.

As well as, the minimum feed EI for pelleted feed obtained from factory 2 was 42.964 gCO_2e/kg.feed, while the maximum feed EI for pelleted feed obtained from factory 1 was 51.301 gCO_2e/kg.feed as shown in Tables 1 and 6. The differences between factories EI related to the energy use efficiency and technology type and design.

Table 5. Raw materials and feed transport EI

	Units	Fine wheat bran	Maize gluten	Soyabean meal	Fish meal	Oil	Maize	Rice bran	Salt	Mineral and vitamin premix
Origin		local	imported	imported	imported	local	imported	local	local	local
exporter		-	China	USA	India	-	Argentina	-	-	-
Shipping	km	-	14,770	11,621	6,562	-	13,107	-	-	-
EI of shipping	gCO2e/kg	0	546.49	429.977	242.794	0	484.959	0	0	0
importer to Factory 1 road	km	177	114	114	114	220	114	25	25	65
importer to Factory 2 road	km	115	211	211	211	5	211	75	3	35
importer to Factory 3 road	km	262	133	133	133	333	133	65	4	56
EI of factory 1 road transport	gCO2e/kg	15.05	9.69	9.69	123.33	238.00	9.69	2.13	27.05	70.32
EI of factory 2 road transport	gCO2e/kg	9.78	17.94	17.94	228.26	5.41	17.94	6.38	3.25	37.86
EI of factory 3 road transport	gCO2e/kg	22.27	11.31	11.31	143.88	360.24	11.31	5.53	4.33	60.58
Total Transport EI of factory 1	gCO2e/kg	15.05	556.18	439.67	366.12	238.00	494.65	2.13	27.05	70.32
Total Transport EI of factory 2	gCO2e/kg	9.78	564.43	447.91	471.06	5.41	502.89	6.38	3.25	37.86
Total Transport EI of factory 3	gCO2e/kg	22.27	557.80	441.28	386.68	360.24	496.26	5.53	4.33	60.58

Source of shipping distance: http://ports.com.

On the other hand, transport from factory to farm EI varied from factory to another related to the distances and emission factors for type of transport as shown in Tables 2 and 6.

The maximum transport from factory to farm EI obtained for factory 3 feed with 167.682 gCO_2e/kg.feed while the minimum transport from factory to farm EI obtained for factory 1 feed with 5.409 gCO_2e/kg.feed.

Table 6. Feed manufacturing EI for different factories and types of feed

Ration (gCO_2e/kg feed)	Electri - city	Diese l	Total energ y EI	Transpo rt EI factory to farm
Feed factory 1 pellet	11	39	51.30 1	5.409
Feed factory 1 extruded	45	85	130.8 2	5.409
Feed factory 2 pellet	13	29	42.96 4	62.745
Feed factory 2 extruded	55	66	122.2 9	62.745
Feed factory 3 pellet	12	31	44.70 5	167.682
Feed factory 3 extruded	48	74	122.4 7	167.682

Source: survey data analysis.

Feed packaging EI

Every factory has a different packaging material which has a significant effect on packaging EI. PP, PPT and PP&PE materials used in factories 1, 2 and 3 respectively as showed in Figure 6 and Table 7.

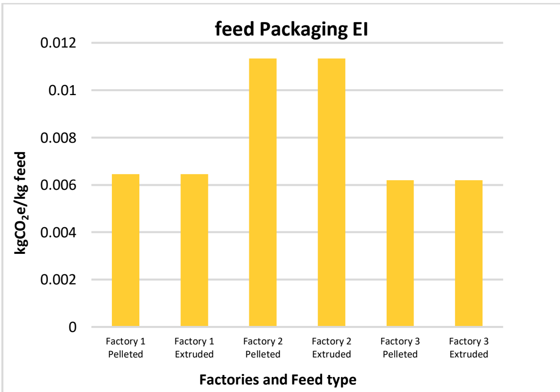

Fig. 6. Feed Packaging EI for different factories and feed types.
Source: Own results.

From Tables 2 and 7, data collected and obtained that maximum packaging EI obtained was 11.64 gCO_2e/kg.feed for the second factory and minimum packaging EI obtained was 6.1985 gCO_2e/kg.feed for the third factory as declared in Figure 7.

Table 7. Feed packaging consumption and EI.

		Factory 1	Factory 2	Factory 3
		Egypt	Egypt	Egypt
	Units	Damro	6th october	Baltim
PPT bag	g/bag	0	105	0
PP bag	g/bag	120	0	0
PP&PE bag	g/bag	0	0	115
PPT bag	kgfeed/bag	0	25	0
PP bag	kgfeed/bag	50	0	0
PP&PE bag	kgfeed/bag	0	0	50
PPT bag	ton/year	0	63	0
PP bag	ton/year	10.8	0	0
PP&PE bag	ton/year	0	0	20.7
feed production	ton/y	4,500	15,000	9,000
EI	gCO_2e/kg feed	6.456	11.34	6.1985

Source: Own results.

Secondly, Farming EI

At this stage results obtained showed that Hanafy farm had the maximum EI value compared to Hashim and Aly farm with 3.131, 2.05 and 2.036 kg CO_2e/kg.fish, respectively. This was due to high amount of feed used with high value of FCR as indicated in Figure 7.

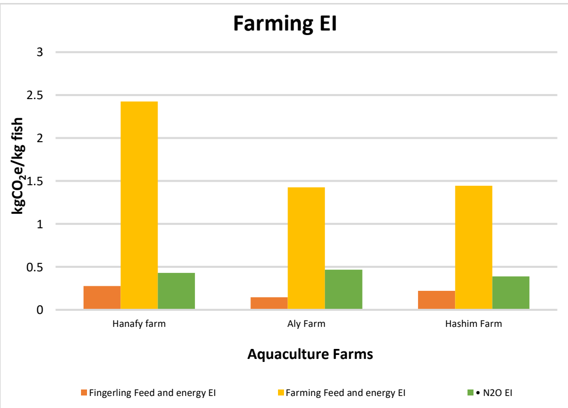

Fig. 7. Farming EI stage parameters
Source: Own results.

As indicated in Figure 8, The highest fingerling feed and energy EI value obtained at Hanafy farm with 0.278 kg CO_2e/kg.fish, while the lowest value was at Aly farm with 0.147 kg CO_2e/kg.fish.

Hanafy farm had the greatest farming feed and energy EI value of 2.42 kg CO_2e/kg.fish, while Aly farm had the lowest value of 1.42 kg CO_2e/kg.fish.

Aly farm had the highest N_2O EI value of 0.465 kg CO_2e/kg.fish, whereas Hashim farm had the lowest EI value of 0.39 kg CO_2e/kg.fish.

Also, bad water quality at the source of Hanafy farm led to more water change and more energy (diesel and petrol) consumption with high EF values as mentioned in Table 2.

While the other farms had sources for electricity and had the abilities for improving water quality by paddle wheel aerators and other sources.

Fingerling Feed and energy EI

Fingerling Feed and energy EI sub main stage consists of three parameters which are: Fingerling feed, Fingerling diesel and Fingerling electricity.

Fingerling feed had the highest effect on EI at all farms under study followed by fingerling diesel and fingerling electricity, respectively as shown in Figure 8.

Tables 2, 8 and Figure 8 showed that Aly farm had the greatest fingerling electricity EI value of 0.009 kg CO_2e/kg.fish, while Hanafy and Hashim farms had the lowest value of 0.0 kg CO_2e/kg.fish.

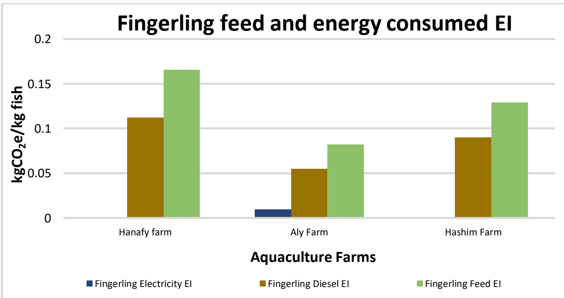

Fig. 8. Fingerling feed and energy consumed EI
Source: Own results.

The highest fingerling diesel EI value was 0.112 kg CO_2e/kg.fish at Hanafy farm, while the lowest value was 0.055 kg CO_2e/kg.fish at Aly farm.

The greatest fingerling feed EI value was 0.166 kg CO_2e/kg.fish at Hanafy farm, while the lowest EI value was 0.08 kg CO_2e/kg.fish in Aly farm.

Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 22, Issue 4, 2022
PRINT ISSN 2284-7995, E-ISSN 2285-3952

Table 8. Fingerling feed and energy consumed EI

		Unit	Hanafy Farm	Aly Farm	Hashim Farm
fingerling number		n	63,000	120,750	78,750
fingerling weight		kg	0.015	0.04	0.03
total fingerling weight		kg	945	4,830	2,362.5
Feed		kg/season	150	350	250
Electricity		MJ/season	0	360	0
Diesel		MJ/season	1,412	3,530	2,824
Feed	pellet	$kgCO_2e$/season	156.675	220.266	241.106
	extruded	$kgCO_2e$/season	0	177.099	64.165
Electricity		$kgCO_2e$/season	0	45.8	0
Diesel		$kgCO_2e$/season	106.268	265.671	212.536
Feed EI		$kgCO_2e$/kg	0.165	0.082	0.129
Electricity EI		$kgCO_2e$/kg	0	0.009	0
Diesel EI		$kgCO_2e$/kg	0.112	0.055	0.089
Total EI		$kgCO_2e$/kg	0.278	0.146	0.219

Source: Own results.

Farming Feed and energy EI

Farming petrol, farming diesel, farming electricity and farming feed are the four parameters that constitute the Feeding and energy for farming EI sub main stage.

As demonstrated in Figure 10, farming feed had the greatest impact on EI across all farms studied. Tables 2, 9, 10, 11 and Figure 9 showed that Hanafy farm had the highest farming petrol EI value of 0.071 kg CO_2e/kg.fish.

While Hashim farm had the lowest value of 0.0256 kg CO_2e/kg.fish. Hanafy farm had the highest farming diesel EI value of 0.68 kg CO_2e/kg.fish, while Hashim farm had the lowest value of 0.053 kg CO_2e/kg.fish. Hashim farm had the highest farming electricity EI value of 0.101 $kgCO_2$e/kg.fish, while Hanafy farm had the lowest value of 0.0 kg CO_2e/kg.fish.

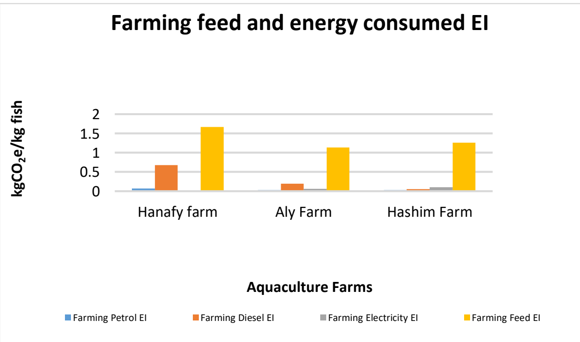

Fig. 9. Farming feed and energy EI
Source: Own results.

At Hanafy farm, the highest EI value for farming feed was 1.67 kg CO_2e/kg.fish, while the lowest EI value was 1.137 for Aly farm.

N_2O EI N_2O EI sub main stage consists of farming feed N_2O and fingerling feed N_2O.

Farming feed N_2O had the biggest impact on EI across all studied farms, as shown in Figure 10. Aly farm had the highest N_2O EI value of 0.465 kg CO_2e/kg.fish, while Hashim farm had the lowest value of 0.39 kg CO_2e/kg.fish, as shown in Tables 2 and 12 and Figure 10. The maximum fingerling feed EI value was 0.04 kg CO_2e/kg.fish at Hanafy farm, while the lowest value was 0.018 kg CO_2e/kg.fish at Hashim farm.

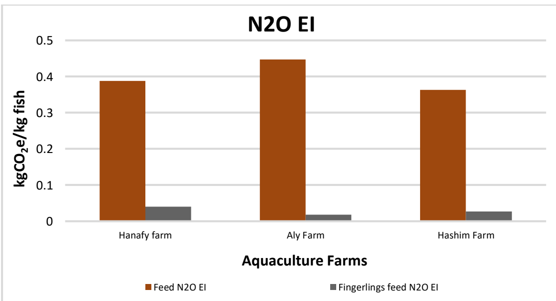

Fig. 10. Farming and fingerling N_2O EI.
Source: Own results.

Aly farm had the highest farming feed N_2O EI value of 0.447 kg CO_2e/kg.fish, while Hashim farm had the lowest value of 0.363 kg CO_2e/kg.fish, as shown in Tables 2 and 12 and Figure 10.

Table 9. Study area, farm and species specification

No	Item	Unit	Hanafy Farm	Aly Farm	Hashim Farm
1	Governorate and town	n	Kafrelshikh, sidy salim	Elbehira, Edko	Eldakahlia, Belqas
2	Ccoordinates	n	31°22'58.9"N 30°47'20.8"E	31°17'00.1"N 30°16'12.7"E	31°26'18.3"N 31°25'11.2"E
3	Area	m^2	42,000	96,600	63,000
4	Water depth	m	1.5	1.25	1.25
5	Water volume	m^3	63,000	120,750	78,750
6	Aquaculture density	Fish/m^3	5	4	5
7	Fish quantity	Fish/Farm	315,000	483,000	393,750
8	Species and ratio	Tilapia	70	80	90
		Mugiliade	25	17	9
		Carp	5	3	-
		Catfish	-	-	1

Source: Own results.

Table 10. Estimation of FCR and consumed feed

		Hanafy Farm	Aly Farm	Hashim Farm
Survival	%	90	70	85
Season	Days	190	175	170
fingerlings weight	kg	0.015	0.03	0.04
Average harvest weight	kg	0.29	0.27	0.3
Total harvest per year	t/y	15.5925	20.286	17.40375
Total feed per year	t/y	23.857	35.703	24.887
FCR	Kg feed/ kg fish	1.53	1.759	1.429
Harvest per area	kg/m^2	0.37	0.21	0.276
Feed Type, ratio	Pellet	0.4	0.55	0.25
	Extruder	0.6	0.45	0.75
Feed Type, t/y	Pellet	9.543	19.637	6.222
	Extruder	14.314	16.067	18.665

Source: Own results.

Table 11. EI for feed and consumed energy

		Hanafy Farm	Aly Farm	Hashim Farm
Diesel	l/year	4,000	1,500	350
Petrol	l/year	500	250	200
Electricity	kW/year	0	2800	3850
Diesel	l/kg	0.257	0.074	0.02
Petrol	l/kg	0.032	0.012	0.015
Electricity	kW/kg	0	0.138	0.221
EI, Pellet	kg Co_2e/year	9.967	21.626	7.500
EI, Extruder	kg Co_2e/year	16.089	18.968	23.953
Total feed EI	**kg Co_2e/kg fish**	**1.671**	**1.137**	**1.264**
Diesel	kg Co_2e/kg fish	0.682	0.196	0.053
Petrol	kg Co_2e/kg fish	0.072	0.027	0.026
Electricity	kg Co_2e/kg fish	0	0.063	0.101
Total Energy EI	**kg Co_2e/kg fish**	**0.753**	**0.287**	**0.181**

Source: Own results.

Table 12. N_2O emissions calculation

		Hanafy Farm	Aly Farm	Hashim Farm
Kg Feed/ton fish		1,530	1,759.982	1,429.979
kg of N in feed /t fish	Kg N feed/t fish	60.05	69.077	56.125
N content of fish	kgN/t fish	13.944	16.039	13.032
kg of N excreted per t of fish	kgN/t fish	46.106	53.037	43.093
kgN_2O-N/t fish	kgN_2O-N/t fish	0.829	0.954	0.776
kgN_2O/t of fish	kgN_2O/t fish	1.304	1.5	1.218
Emission of kg N_2O/kg of fish	$kgCO_2e$/kg fish	0.388	0.447	0.363
Fingerling emissions	$kgCO_2e$/kg fish	0.0403	0.018	0.027
Total N_2O	$kgCO_2e$/kg fish	0.429	0.465	0.39

Source: Own results.

Thirdly, Post-farming EI

At this stage, the data revealed that Aly farm had the highest EI value, with 0.222 kg CO_2e/kg.fish, while Hashim and Hanafy farms EI values were 0.18 and 0.13 kg CO_2e/kg.fish, respectively as shown in Figure 11.

This was owing to the large distance of transport fishes to markets compared to others. As shown in Figure 11, Hashim farm had the greatest ice manufacturing energy EI value of 0.0079 kg CO_2e/kg.fish, while Hanafy farm had the lowest value of 0.0035 kg CO_2e/kg.fish.

The highest transport to markets EI value was 0.218 kg CO_2e/kg.fish for Aly farm while the lowest value was 0.13 kg CO_2e/kg.fish for Hanafy farm.

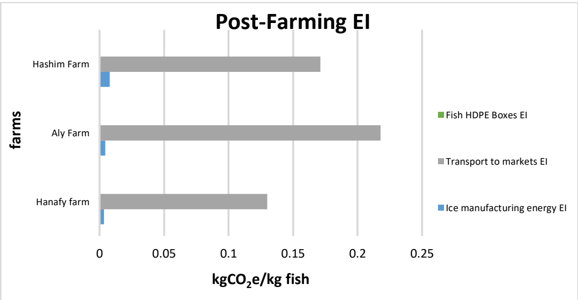

Fig. 11. Post-farming stage parameters
Source: Own results.

Fish HDPE Boxes EI

From table 2 and survey conducted that all the three farms had the same value for fish HDPE Boxes EI with 0.00063 kg.CO_2e/kg.fish which were 1kg HDPE boxes and capacity of 25 kg fish for 200 times use.

Table 13. Ice manufacturing energy EI calculation

	unit	Hanafy Farm	Aly Farm	Hashim Farm
Ice use	ton	2	3.2	5
Electricity use	kw	116	185.6	290
Diesel use	kg	0.5	0.8	1.25
Electricity EI	$kgCO_2e$/ kg fish	0.0034	0.00419	0.0076
Diesel EI	$kgCO_2e$/ kg fish	0.0001	0.00013	0.000235
Total EI	$kgCO_2e$/ kg fish	0.0035	0.0043	0.0079

Source: Own results.

Ice manufacturing energy EI

Ice manufacturing electricity and ice manufacturing diesel are the two parameters that make up the ice manufacturing energy EI sub main stage.

As demonstrated in Tables 2 and 13 and Figure 12, Ice manufacturing electricity had the greatest impact on EI across all farms studied.

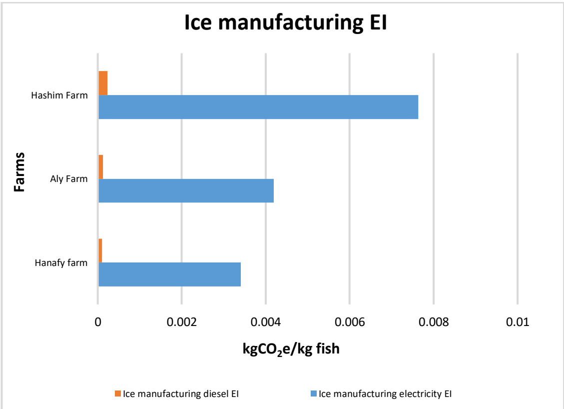

Fig. 12. Ice manufacturing energy EI
Source: Own results.

Hashim farm had the highest ice manufacturing EI value of 0.0079 kg CO_2e/kg.fish, while Hanafy farm had the lowest value of 0.0035 kg CO_2e/kg.fish as shown in Figure 12.

Transport to markets EI

As indicated in Tables 2 and Figure 13, the EI of conveying fishes to markets consists of transporting to small markets EI, transporting to medium markets EI and transporting to large markets EI.

Also, transporting to medium markets had the greatest impact on EI across all farms under study.

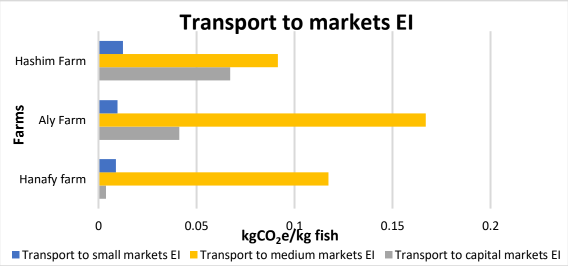

Fig. 13. Transport to markets EI
Source: Own results.

The highest EI for transporting to medium markets was 0.16 kg.CO_2e/kg fish for Aly farm, and the minimum EI for shipping was 0.09 kg.CO_2e/kg for Hashim farm.

While, 0.067 and 0.041 kg.CO_2e/kg fish were the highest and lowest transporting to capital markets EI for Hashim and Aly farms, respectively.

Total EI

Table 14 and Figure 14 indicated that the main parameters (Fingerling, Feed, N_2O, Energy on farm, Transport to markets, Ice consumption and Fish HDPE Boxes) and sub main (Farming Petrol EI, Farming diesel EI, Farming Electricity EI, Farming Feed EI, Fingerling Electricity EI, Fingerling Diesel EI, Fingerling Feed EI, Feed N_2O EI, Ice manufacturing electricity EI, Ice manufacturing diesel EI, Transport to capital markets EI, Transport to medium markets EI, Transport to small markets EI, Fish HDPE Boxes EI and Fingerlings feed N_2O EI) parameters contributing in LCA and carbon foot print.

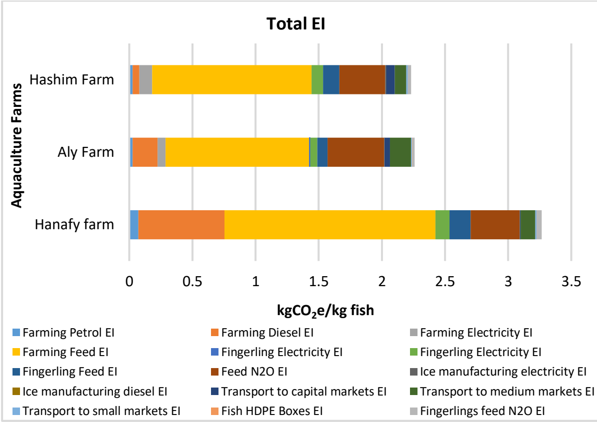

Fig. 14. Total EI parameters.
Source: Own results.

Farming feed parameter had the highest EI percentage at total EI for all farms under study with 51.8, 50.33 and 56.6% for Hanafy, Aly and Hashim farms, respectively.

While, ice manufacturing diesel had the lowest EI percentage at total EI for all farms under study with 0.003, 0.005 and 0.01% for Hanafy, Aly and Hashim farms, respectively.

Hanafy farm had the highest EI value of 3.265 kg.CO_2e/kg fish and 50.917ton CO_2e/season compared with Hashim farm which had the lowest EI value with 2.23 kg.CO_2e/kg fish and 38.86 ton CO_2e/season as shown in Table 14 and Figure 14.

Table 14. Total EI for the three farms

		Hanafy Farm	Aly Farm	Hashim Farm
Fingerling	Kg.CO_2e/kg fish	0.278	0.146	0.219
Feed	Kg.CO_2e/kg fish	1.671	1.137	1.263
N_2O	Kg.CO_2e/kg fish	0.429	0.465	0.39
Energy on farm	Kg.CO_2e/kg fish	0.752	0.287	0.18
Transport to markets	Kg.CO_2e/kg fish	0.13	0.217	0.171
Ice consumption	Kg.CO_2e/kg fish	0.0035	0.0043	0.0079
Fish HDPE Boxes	Kg.CO_2e/kg fish	0.0006	0.0006	0.0006
Total EI per kg fish	Kg.CO_2e/kg fish	**3.265**	**2.259**	**2.233**
Total EI per season	Ton.CO_2e/Season	**50.917**	**45.829**	**38.864**

Source: Own results.

CONCLUSIONS

As Egypt from the most countries vulnerable to global warming, estimating carbon footprints in aquaculture farms is a crucial topic. As a result, this study focuses on the LCA of semi-intensive aquaculture in Egypt. Hanafy farm had the greatest EI value, with 3.265 kg.CO_2e/kg fish and 50.917 tonne CO_2.e/season, while Hashim farm had the lowest, with 2.23 kg.CO_2e/kg fish and 38.86ton CO_2.e/season.

Also, for all farms under research, the farming feed parameter had the greatest EI percentage at total EI, with 51.8, 50.33, and 56.6 percent for Hanafy, Aly, and Hashim farms, respectively. While, ice manufacturing diesel of 0.003, 0.005, and 0.01 percent for Hanafy, Aly, and Hashim farms, respectively had the lowest EI percentage at total EI for all farms under study.

Finally, more research is needed to reduce GHG sources and optimize techniques that reduce emissions across all LCA.

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