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Life Cycle Assessment of Cockles (*Anadara granosa*) Farming: A Case Study in Malaysia

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Abstract

Life cycle assessment (LCA) was applied to evaluate the environmental performance of the cockle farming activity in Malaysia. The study was conducted by a mid-point approach following the ISO 14040 series of standard and CML-IA Baseline V3.01 method using SimaPro 8 software. A total of ten impact categories were selected namely abiotic depletion (ABD), global warming potential (GWP), ozone layer depletion (OLD), human toxicity (HT), freshwater ecotoxicity (FET), marine aquatic ecotoxicity (MET), terrestrial ecotoxicity (TET), photochemical oxidation (PO), acidification (ACD), and eutrophication (EUT).Capital goods dominate the impact of HT (82.20%), ABD (81.72%), EUT (81.36%), FET (79.3%), PO (79.02%), MET (75.06%), TET (59.8%), and GWP (53.15%). Operational goods dominate OLD at 80.24% and ACD at 53%. Fiberglass material dominated almost the entire environmental impact except for the eutrophication which was dominated by polypropylene. Harvesting process was identified as the main process contributed to the potential environmental impact in cockle farming. LCA is potentially expanded not only to the entire chain of cockle production, but also to put into practice other aquaculture systems in Malaysia.

Keywords: *Anadara granosa*; LCA;cockle farming;potential environmental impact

1. Introduction

Life cycle assessment (LCA) application in global aquaculture industry has crossed the diversity of farming systems and species of marine fish, fresh water fish, and shellfish (Aubin *et al*., 2009; Bosma *et al*., 2011; Iribarren *et al*., 2011; Jerbi *et al*., 2012). The development of LCA for the aquaculture sector is an important step to encourage the industry to apply the best management production methods and ensure a broader market for aquaculture products worldwide (Cao,2012;Phong *et al*., 2011; Vázquez-Rowe *et al*., 2012). Numerous European Union countries have implemented LCA in the aquaculture industry (Aubin *et al*., 2009; Grönroos *et al*., 2006; Papatryphon *et al*., 2004; Samuel-Fitwi *et al*., 2013). Asian countries, such as China, Thailand, Vietnam, and Indonesia, have also started to explore LCA to improve the environmental performance of aquaculture products (Bosma *et al*., 2011; Cao, 2012; Phong *et al*., 2011).

Malaysia is known for major cockle production in the Asian region with its main market in Thailand and Singapore (Pawiro, 2010). Cockles dominate 94% of shellfish production compared with oysters and mussels (DOFM, 2014). *Anadara granosa* is the main cockle species and economic contributor in Malaysia (Tookwinas, 1985; Pathansali and Soong, 1958; Koh *et al*., 2011). This species is well-known as an affordable source of protein (Koh *et al*., 2011). Natural cockle seeds are abundantly located in the west coast of Peninsular Malaysia. Local cockle farming activities depend on the cockle seeds supply from the natural habitat. The production of local cockle seeds is universal and highly depends on the natural environment (Shamsuddin, 1992). Given the abundance of local cockle seeds, Malaysia remains among the leading producer of cockles in Asia. To date, cockle culture areas in Peninsular Malaysia have reached almost 9,000 ha,with approximately 800 cockle farmers (DOFM, 2014).

This study aims to improve the environmental performance of cockle farming in Malaysia.LCA is a suitable environmental measurement tool that examines quantitative environmental impacts in production processes (Heijungs *et al*., 2013). Findings from this study could be used as an effort to improve the performance of local cockle resources management.

2. Materials and Methods

The study was designed based on the ISO 14040 series of standard for LCA implementation. The four main phases are goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation as shown in Fig. 1.

2.1 System description

The cockle farming sites along the west coast of Peninsular Malaysia include Pulau Pinang, Perak, and Selangor states. The case study was conducted in Lot 63, cockle farm in the Jeram, Selangor State. The farm was selected based on two factors. First, the farm has produced the highest number of adult cockles in the recent five years indicates the effective cockle farming areas. Second, Selangor is the only state that has gazetted the cockle culture areas along its western coast. These gazetted area ensure that Selangor will remain as an active cockle farming site during the LCA study period. Fig. 2 shows a map of the study area and the water quality monitoring station. Water quality data represents the wastewater from the use of fiberglass boat.

2.2 Goal and scope definition

LCA was performed to evaluate the environmental performance of cockle farming activity. The defined functional unit was 70 kg of live weight cockles. The standard weight is equal to the weight of one sack of adult cockles packed for suppliers at the production jetty.

2.3 Boundary system

This LCA study establishes the boundary system from cradle to farm gate and involves five main processes, as shown in Fig. 3. This system covers the five (5) consecutive stages of cockle farming, from seed sowing, scattering, harvesting, cleaning and grading, and the last stages of packaging process. It normally requires about 12 to 18 months for each cycle of adult cockle to complete the cycles and reach the harvesting phase.

The boundary system can be determined by various factors such as the existing system, geographical limits, time limits, or boundaries in the technical system (Tillman *et al*., 1994). Cockle farming does not involve food inputs in contrast to fish farming. Cockles depend entirely on natural food resources and are usually cultured extensively in an open ecosystem. Therefore, this study focused on the infrastructure components in which capital and operational goods were selected as main inputs.

2.3.1 Seed sowing

Seed sowing is the seed distribution phase involves cockle seed sowing at the cockle farming site. Farmers collected the seeds from their natural spat fall sites and sowed the spat into the cockle farming sites. The size of cockle sites is usually 50 ha, and farmers mark the boundaries of the sites with wooden stakes. The farmers usually divide this site into small plots, and each plot is not simultaneously filled with cockle seeds. The existing plots are divided into several subplots and used on a rotational basis. This practice ensures that each subplot has sufficient time to recover before a new breeding cycle begins. The scope of this study does not cover the process of seed collection from their natural sites.

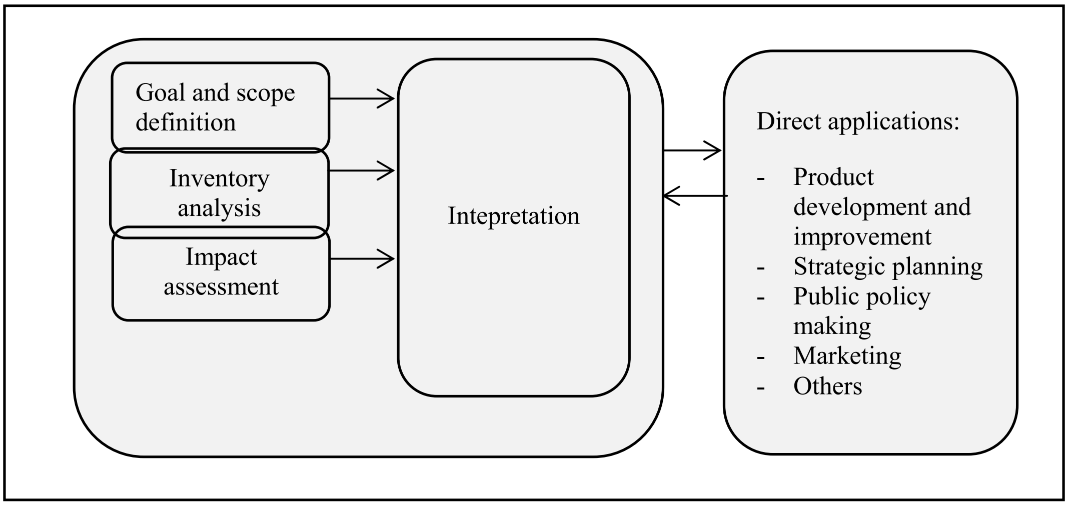

Figure 1. Life cycle assessment model based on ISO 14040: 1997

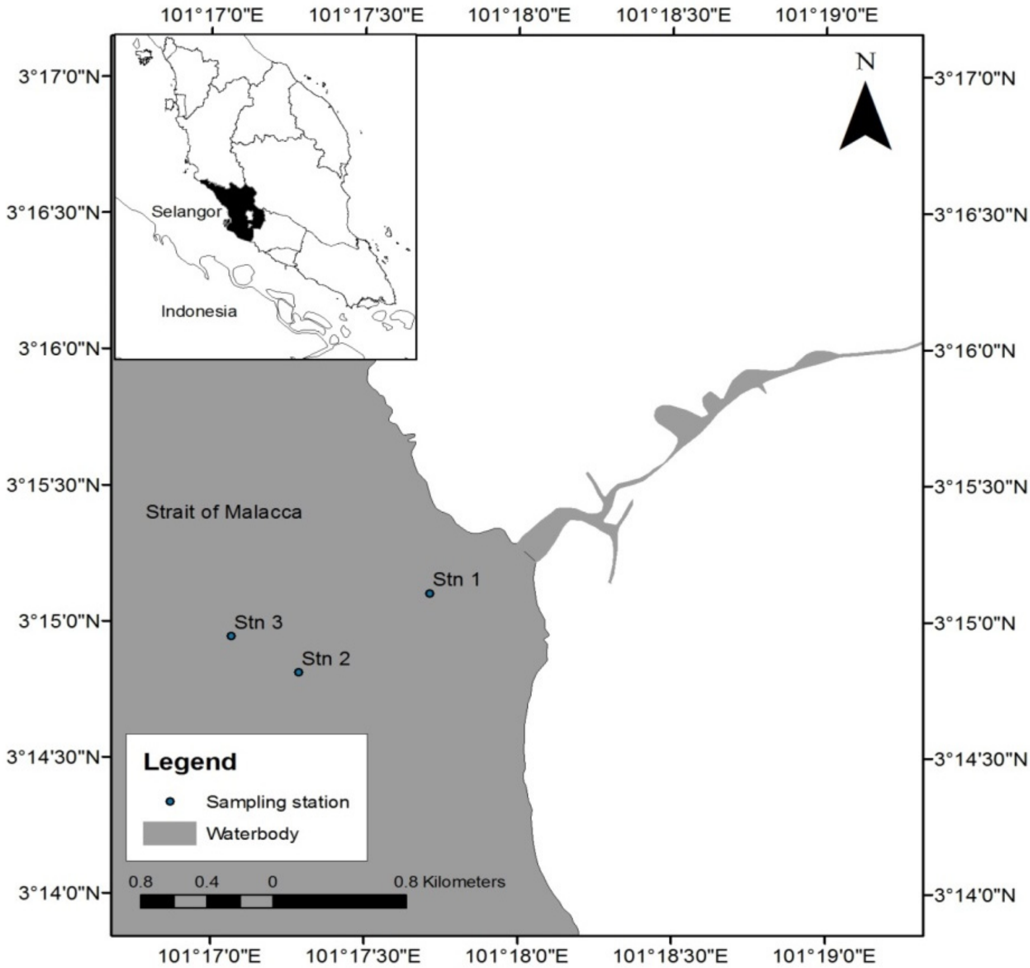

Figure 2. Map of the study area and water quality sampling stations

2.3.2 Scattering

Scattering process occurs monthly through out the 12-18 month cockle breeding period. Cockle farmers practice this process once every two weeks. The process is carried out to distribute cockle position to ensure sufficient space and resources for cockle growth. Otherwise, the density of cockles in particular area increases. This condition could pose a potential risk of cockle death because of the insufficient space for cockle growth and food competition.

2.3.3 Harvesting

Harvesting begins when cockles have reached their maturity size of at least 25 mm. Cockle farmers use a longhand dredge (approximately 76 cm × 25 cm) and start to tow the dredge in the collection area. Harvesting of adult cockles is typically performed in February and March each year. Adult cockles are harvested daily during these months and marketed to wholesalers.

2.3.4 Cleaning and grading

Cleaning and grading are carried out simultaneously by using a cockle grading machine. The water source is pumped from the river for cockle cleaning to minimize bacteria and germs on cockles. Grading is performed to separate small-sized cockles so that they can be returned to the culture area.

2.3.5 Packaging

Cleaned adult cockles are placed in packing sacks with a standard cockle live weight of 70 kg/sack. Wholesalers inform the farmers their desired amount and capacity of cockles depending on the daily demand. A cockle farmer can typically supply more than 20 sacks per day during harvest season. Marketing and cockle waste management were excluded in this study due to the limited information for these processes.

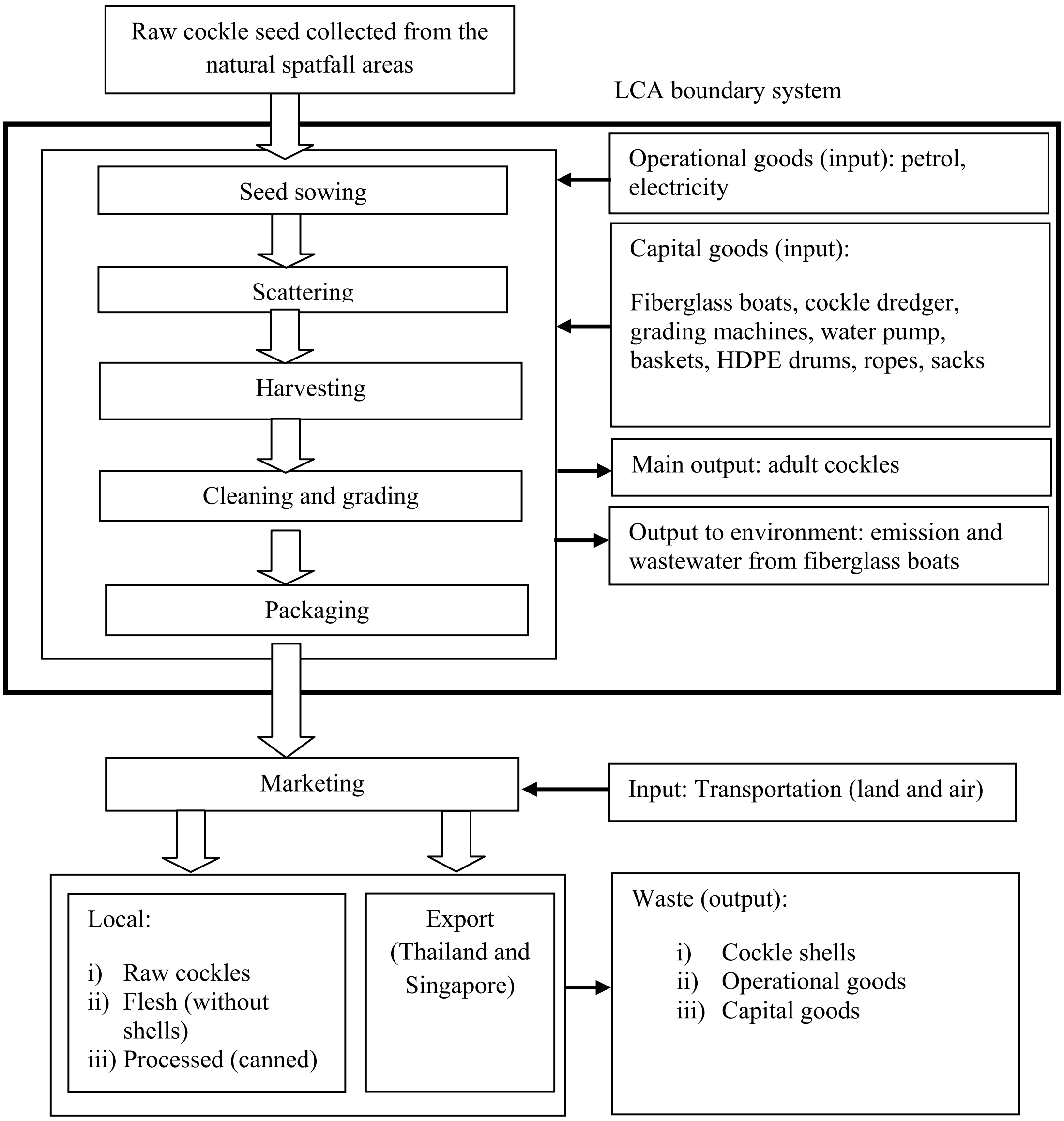

Figure 3. Boundary system from cradle-to-farm-gate for LCA in cockle farming activity

2.4 Data inventory

Data inventory aims to develop flow process and materials involved in a product or system under study (Baumann and Tillman, 2004). Data collection has been conducted based on the ISO 14041: 1998 document to ensure the quality of data. Data inventory was carried out through the survey, water quality sampling, laboratory analysis, and secondary data. All data was grouped, verified by the experts from a related government agency and journal articles, and then selected for its relevance in each of impact category.

Water quality sampling conducted for in situ parameters consists of temperature, pH, conductivity, dissolved oxygen (DO), and total dissolved solid (TDS). Water samples were tested by laboratory analysis for total suspended solid (TSS), chemical oxygen demand (COD), total organic carbon (TOC), nitrate, phosphate, and sulfate.

Table 1 illustrated the details of capital goods for the five main processes in cockle farming activity. Capital goods include the production of equipment and machinery used in cockle farming. Data on the fiberglass boat was assembled from the technical government agency. Fiberglass and plywood production were the main element in the fiberglass boat production. Cast iron represents the primary element in the boat engine production. Fiberglass boats dominated seed sowing, scattering, and harvesting process. Other elements were low alloyed steel, high-density polypropylene (HDPE) drums, polypropylene fiber for ropes and sacks, and a few others. Values (in g) were calculated based on the estimated amount of the main elements used in the production of the particular capital goods. This value was then divided by the functional unit (70 kg). The disposal cycle of each of these capital goods does not include in the system boundary due to the limited information.

Table 1. Capital goods in the five main processes in the LCA system boundary for cockle farming

Process	Capital goods	Inventory (SimaPro 8)	Values (based on 70kg FU)
Seed sowing	Fiberglass boats	Fiberglass*{GLO}*|market|*AllocDef, S*	572 g
	Plywood	Wood chip production, outdoor use (woodchips, dry)	817 g
	Boat engines	Cast iron*{GLO}*|market |*AllocDef, S*	82 g
	Carrier	Aluminium alloy, *AlMg3 {GLO}*	0.1633 g
Scattering	Fiberglass boats	Fiberglass*{GLO}*|market|*AllocDef, S*	572 g
	Plywood	Wood chip production, outdoor use (woodchips, dry)	817 g
	Boat engines	Cast iron*{GLO}*|market |*AllocDef, S*	82 g
	Cockle dredger	Steel, Low-alloy	0.61 g
	Ropes	Polypropylene fiber (PP), crude oil based, mix production	0.172 g
Harvesting	Fiberglass boats	Fiberglass*{GLO}*|market|*AllocDef, S*	572 g
	Plywood	Wood chip production, outdoor use (wood chip, dry)	82 g
	Boat engines	Cast iron*{GLO}*|market |*AllocDef, S*	817 g
	Cockle dredger	Steel, Low-alloy	0.61 g
	Ropes	Polypropylene fiber (PP), crude oil based, mix production	0.172 g
	Baskets	Polypropylene (PP)Injection Moulding E	0.7 g
Cleaning and grading	Cleaning and grading machine	Steel, Low-alloy	2.15 g
	Water pump	Steel, Low-alloy	2.3 g
		PVC Pipe E	3.03 g
Packaging	Weighing machine	Steel, Low-alloy	0.58 g
	HDPE drums	HDPE Resin E	73 g
	Sacks	Polypropylene fiber (PP), crude oil based, mix production	200 g

Table 2 showed the operational goods in the LCA system boundary for this study. Operational goods include of the use of petrol for fiber glass boat and the electricity use during the cleaning and grading phase. The use of petrol and usage of electricity was estimated using data provided by the farmers. The highest use of petrol was recorded during the harvesting process, and the lowest usage was at the seed sowing process.

Table 3 summarized all the inputs and outputs identified within the system boundary. Ecoinvent 3, ELCD, and Industry Data 2.0 databases were used as background data. Electrical energy was used for the running of machine and water pumps during cleaning and grading process. The average electricity use was 100 kWh per month. Based on the functional unit designated for each 70 kg of cockles, the electricity consumption is 0.14 kWh. The transportation component includes only on the use of a fiberglass boat. The value set for this study is based on the maximum weight capacity allowed for a fiberglass boat, that is, 500 kg. Thus, 500 kg/km or 0.5 tons/km are considered as the standard for the transportation component.Water quality data were used as the output to the environment, to represent the wastewater component from the fiberglass boats.

2.5 Impact analysis

Environmental impact was measured using the CML-IA Baseline V3.01 method with a mid-point approach and using SIMAPRO 8 software. The characterization method employed was EU25. Analysis of environmental impacts mainly involves mandatory categories, such as impact category definition, classification, characterization, and impact analysis. Ten impact categories, namely, abiotic depletion (ABD), global warming potential (GWP), ozone layer depletion (OLD), human toxicity (HT), freshwater ecotoxicity (FWT), marine ecotoxicity (MET), terrestrial ecotoxicity (TET), photochemical oxidation (PO), acidification (ACD), and eutrophication (EUT) were selected.

Impact analysis has been carried out based on the mandatory elements as specified in ISO 14042:2000 which were impact category definition, classification, characterization, and impact analysis profiling (Baumann and Tillman, 2004). Other optional elements such as sensitivity analysis, was not carried out for this study as the cockle farming activity involved only a minimum usage of electricity and fully depending on natural food supply for its operation. Other LCA

Table 2. Operational goods in the LCA system boundary for cockle farming

Process	Estimated use (kg)	Values (based on 70kg FU) Petrol, unleaded *{RoW}*|market|*AllocDef, S*
Seed sowing	450 kg	0.053 kg
Scattering	4200 kg	0.49 kg
Harvesting	25,200 kg	2.94 kg

Table 3. Inputs and outputs for the cradle-to-farm LCA study for cockle culture activity.

Input/Output	Components	Values	Database
Input:			
From technosphere			
Plywood production	Fiberglass boats	2451 g	Ecoinvent 3
Glass fiber	Fiberglass boats	1716 g	Ecoinvent 3
Cast iron	Boat engines	246 g	Ecoinvent 3
Steel, low-alloyed	Cockle dredger	1.22 g	Ecoinvent 3
	Shackle chain for cleaning machine	0.58 g	
	Rod cylinder for cleaning machine	0.72 g	
	Inlet and outlet tray for cleaning machine	0.27 g	
	Electrical motor	0.58 g	
	Water pump	2.3 g	
	Weighing machine	0.58 g	
HDPE Resin E	HDPE plastic drum	73.15 g	Industry Data 2.0
Aluminium Alloy,	Cockle seed container	0.1633 g	Ecoinvent 3
Polypropylene (PP) fibers	Ropes	0.344 g	ELCD
Polypropylene (PP) Injection Moulding E	Carrier basket	0.7 g	Industry Data 2.0
Polypropylene (PP) fibers	Sacks	200 g	ELCD
PVC Pipe E	Water pump pipe	0.1 g	Industry Data 2.0
	Water pump hose	2.93 g	
From environment			
Cockle seed	Collected from natural spatfall areas	60 kg	
Water source	River (water is pumped for cockle cleaning process and release to river)	-	
Output:			
To environment			
Chemical oxygen demand (COD)	47.56 mg/L	0.09512 mg	-
Nitrate	1.21 mg/L	0.0121 mg	-
Phosphate	0.17 mg/L	0.0017 mg	-
Sulfate	72.67 mg/L	0.07267 mg	-
Oil and grease	0.2853 mg/L	0.05706 mg	-
To atmosphere:			
Petrol, unleaded	Petrol consumption for boats	3483 g	Ecoinvent 3.

study for aquaculture conducted sensitivity analysis in order to compare the environmental performance based on the scenario modeling; such as changes in feed conversion ratio, electricity sourcing, or different production system which cause changes in the energy use (ISO, 2000; Ayer and Tyedmers, 2009; D'Orbcastel *et al*., 2009; Samuel-Fitwi *et al*., 2013).

3. Results and Discussion

Characterization results led to the potential environmental impactsofcapital and operational goods as shown in Fig. 4. Capital goods dominate the impact of HT (82.20%), ABD (81.72%), EUT (81.36%), FET (79.3%), PO (79.02%),MET(75.06%), TET (59.8%), and GWP (53.15%). Operational goods dominate OLD at 80.24% and ACD at 53%.

Capital goods dominate eight of the ten types of environmental impacts selected in this study. Fig. 5 shows a graph of the potential environmental impact, according to the type of materials for capital goods used in cockle farming. Fiberglass is the material that dominates almost the entire potential environmental impact except for EUT. Fiberglass dominate the ABD impact with the highest proportion of 90.33%, followed by TET and MET at 86.45% and 84.10%, respectively. Meanwhile, the ACD rate caused by fiberglass production is 74.80%. Fiberglass also affects FET, HT, OLD, and GWP at 61%-68%. Fiberglass is the key component in the manufacture of fiberglass boats other than plywood and resin components. In this study, the ratio of theweight of fiberglass and plywood in the manufacture of boats is assumed to equal (1:1). The use of resin is not calculated separately because the content of the resin is considered in the data background obtained from the Ecoinvent 3 database.

Eutrophication impact is dominated by polypropylene material at 60.59%. Polypropylene is the main material for cockle carrier baskets and has been used in all harvesting activities. Apart from fiberglass,polypropylene also caused OLD at

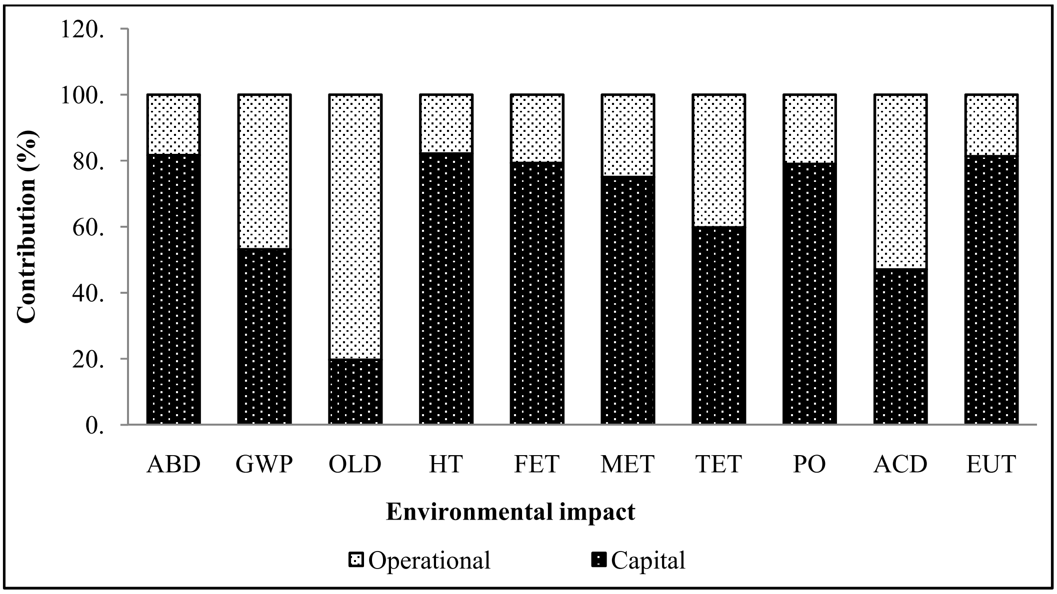

Figure 4. Contribution to the potential of environmental impact of capital and operational goods

a rate of 28.70%. Cast iron is the main material for manufacturing boat engines. Low alloy steel is the primary material for cleaning machines and water pumps. These materials are not significant to any environmental impact. Other materials, such as aluminum and polyvinyl chloride, contribute to all types of environmental impacts at a minimum level.

Fig. 6 shows a graph of environmental impact potential of five processes of cockle farming based on a functional unit of 70 kg cockles. Harvesting process dominates all environmental impacts. However, the most dominated impacts are OLD (62%), GWP (42%), acidification (45%), and PO (37%). This result is attributed to the regular use of petrol on fiberglass boats during harvest season. Fuel combustion exerts various types of gas, such as carbon dioxide, sulfur dioxide, and nitrogen oxide, and causes the release of small particles, such as heavy metals and dust. This process increases

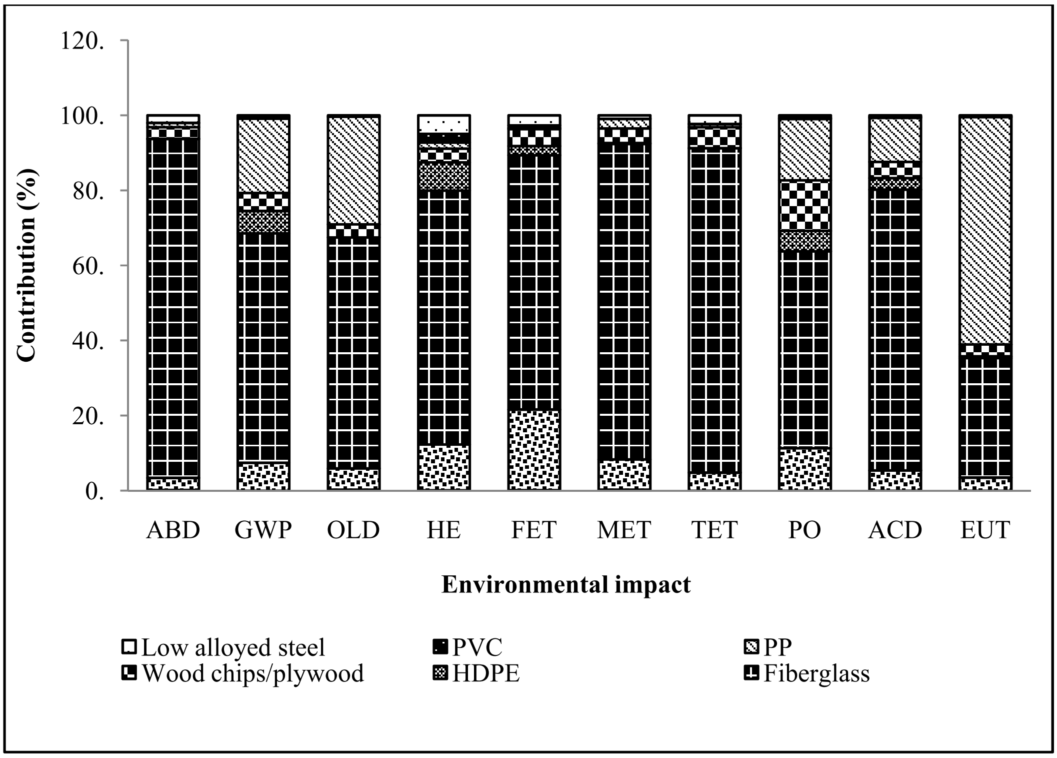

Figure 5. Contribution to the potential of environmental impact based on the type of materials for capital goods used in cockle farming.

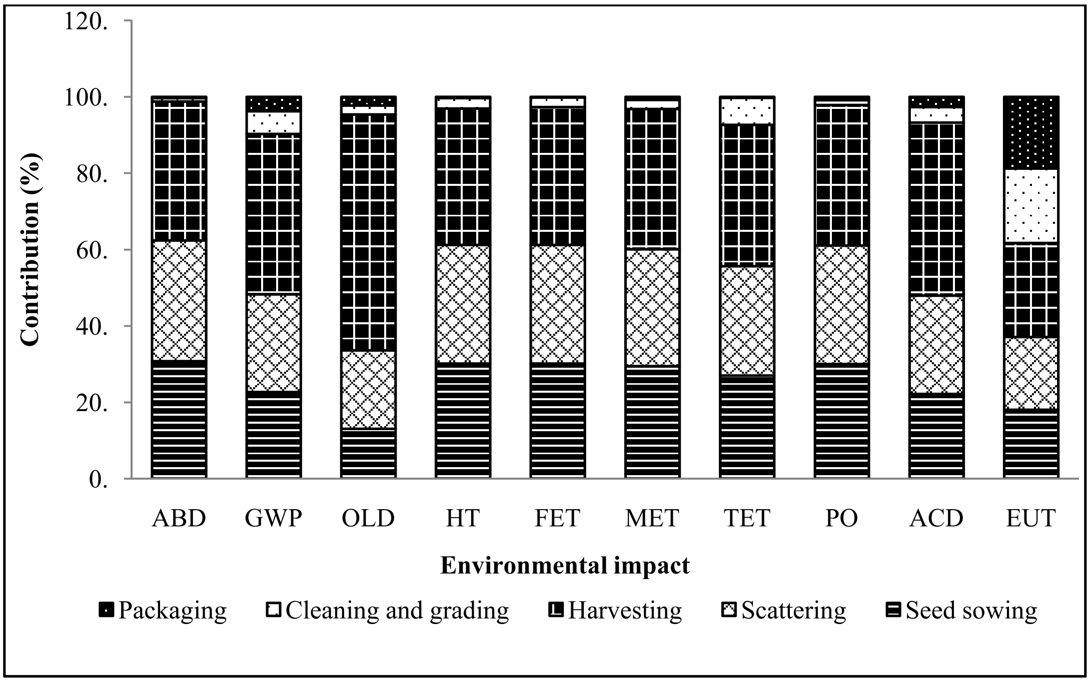

Figure 6. Contribution to the potential of environmental impact by the main processes in cockle farming (functional unit: 70 kg)

chemical reaction in the air and explains its dominance. Eutrophication is also dominated by harvesting process (25%). However, other processes also contribute quite evenly to eutrophication potentials, such as seed sowing (18%), scattering (19%), cleaning and grading processes (20%), and packaging (19%).

Table 4 shows the details of potential environmental impacts contributed by the main processes in cockle farming. Seed sowing, scattering, and harvesting process involved the frequent use of fiberglass boat and resulted in a domination of all impact categories. Given this result, the use of the farming boat is identified as the main activity that contributes to the environmental impact. Harvesting process in a plot involves more than one boat. Each fiberglass boat has a capacity of two farmers at a time. During harvest season, only one farmer is typically sailing a boat to provide more space for cockle harvesting.This condition is the main factor that affects the dominance of fiberglass boats in cockle farming.

Eutrophication can threaten the health of aquatic ecosystems, including the aquaculture systems associated with it. Eutrophication potential for this study is limited to the contribution of the capital goods. Cockle farming system is classified as open aquaculture system (Siti Dina *et al.*, 2015). Therefore, the evaluation of eutrophication could be studied further by considering the influence of natural factors such as the sea oligotrophic conditions and the ability of cockles to prevent eutrophication (Aubin *et al.*, 2009; Gren *et al.*, 2009; Spångberg *et al.*, 2013). Several LCA studies on closed, semi-closed, and open aqua culture systems also consider the ratio of nitrates and phosphates to determine the aquaculture system capacity that generates related environmental impact (Cao, 2012; Spångberg *et al.*, 2013).

Harvesting process also contributes to the higher percentage of OLD (61.8%), GWP (42%) and ACD (45%) respectively. OLD and GWP are both phenomenon due to the presence of greenhouse gasses

Table 4. Main processes in cockle farming and contribution to the potential environmental impact

Processes	Potential environmental impact (%)									
	ABD	GWP	OLD	HT	FET	MET	TET	PO	ACD	EUT
Seed sowing	30.74	22.71	13.13	30.20	30.17	29.53	27.06	30.04	22.25	18.07
Scattering	31.64	25.63	20.49	31.08	31.10	30.58	28.60	31.06	25.74	19.07
Harvesting	36.38	42.0	61.81	35.7	36.08	36.75	37.03	36.79	45.29	24.58
Cleaning and grading	0.893	5.92	2.332	2.7	2.51	2.36	7.07	1.27	4.08	19.58
Packaging	0.310	3.74	2.24	0.31	0.14	0.78	0.24	0.84	2.63	18.71

such as carbon dioxide, methane, and chlorofluorocarbon. GWP caused by fishing activities is commonly associated with the use of the auxiliary boat and fishing vessel that involve petroleum and diesel burning (Thrane, 2006; Vázquez-Rowe *et al*., 2010; Ziegler *et al*., 2003). Aquaculture and fishery sectors have different fishing vessel needs. Fishing vessels for the fishery sector usually consist of various types and sizes and depend on factors, such as the capacity of fishery catches, fishing equipment, and a number of fishing crew. For cockle farming activity, the use of auxiliary boats is also notable because the sites are typically located in coastal areas. However, OLD and GWP for cockle farming activity causes minimal impact compared with farming systems of other fishery species (Ayer and Tyedmers, 2009; Aubin *et al*., 2009; Bosma *et al*., 2011; Iribarren *et al*., 2010).

Acidification and eutrophication are regional environmental impact because both are influenced by the geographical position of a system or product under study in the LCA (Potting *et al*., 1998; Seppälä *et al*., 2004). Acidification represents sulfur and nitrogen, and eutrophication refers to nitrogen and phosphorus contained in a system under study (Huijbregts and Seppälä, 2000; Seppälä *et al*., 2004). LCA researchers have extensively studied the characterization of both impacts by considering the location so that significant details being developed can represent different regions (Gallego *et al*., 2010; Huijbregts and Seppälä, 2001; Seppälä *et al*.,2004).

This study shows that acidification is dominated by the capital goods at 53% in which fiberglass is the material identified as a major contributor. Acidification in marine areas has the potential to destroy shellfish species in the long term. This process is caused by the increasing amount of carbon dioxide in the atmosphere due to climate change (John *et al*., 2005). Acidification can alter the composition and biogeochemical compound cycle in seawater that causes the decreasing rate of calcium carbonate absorption, which ultimately affects the growth of corals and formation of shellfish such as cockles (Doney *et al*., 2009). The process is often caused by excessive nutrients from either rain or acid fertilizers.In conclusion, the impact of soil, freshwater, or ocean acidification is a potential risk to the growth of cockles. Therefore, it is proposed that the proper disposal procedure should be implemented for the fiberglass boat to minimize the acidification potential in cockle farming.

LCA can be carried out in cockle industry in Malaysia based on two approaches. One approach is driven by conservation of cockle farming areas to maintain the production of adult cockles. The domination of fiberglass boat in most of the environmental impact also indicates cockle farming area should have properly designated shipping lanes to reduce to the influence of other transportation such as recreational boats and fishing vessels. This approach involves drafting more holistic management plans for cockle farming areas by considering the influence of global, regional, and local environmental impacts. The other approach is to improve the performance and expand the market for cockles in the Asian region by carrying out LCA within economic and social development contexts. The LCA approach could be expanded to the larger cockle production chain such as marketing process and shell waste management. LCA also potentially assist in evaluating the suitable depuration process which is crucial in shellfish production but still in its infancy in Malaysia. The constant application of LCA approach will eventually lead to a healthy and safe aquaculture production.

4. Conclusions

Capital goods are potential dominant of environmental impacts except for ozone depletion. Operational goods dominate the ozone depletion impact, which is consistent with the assumption that frequent use of fiberglass boat that involves fuel combustion is the main cause of this result. The fiberglass material is a major contributor to the dominance of environmental impact except for eutrophication that is dominated by polypropylene material. Harvesting dominates the overall environmental impactbased on farming approach. LCA should be expanded to cover not only the entire chain of cockle production, but also to put into practice other aquaculture systems in Malaysia.

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References

Aubin J, Papatryphon E, Van der Werf HMG, Chatzifotis S. Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment (LCA). Journal of Clean Production 2009; 17(3): 354-61.

Ayer NW, Tyedmers PH. Assessing alternative aquaculture technologies: life cycle assessment (LCA) of salmonid culture system in Canada. Journal of Clean Production 2009; 17(3): 362-73.

Baumann H, Tillman AM. The hitch hiker's guide to LCA: an orientation in LCA methodology and application. Student litteratur, Lund, 2004; 19-41.

Bosma R, Anh PT, Potting J. Life cycle assessment of intensive striped catfish farming in the Mekong Delta for screening hotspots as input to environmental policy and research agenda.The International Journal of Life Cycle Assessment 2011; 16(9): 903-15.

Cao L. Farming shrimp for the future: a sustainability analysis of shrimp farming in China. Ph.D dissertation. University of Michigan, USA, 2012.

Department of Fisheries Malaysia (DOFM).Annual fisheries statistics book 2014. Department of Fisheries Malaysia. Putrajaya. 2014.

Doney SC, Fabry VJ, Feely RA, Kleypas JA.Ocean acidification: the other CO_2 problem. Annual Review of Marine Science 2009; 1:169-92.

D'Orbcastel ER, Blancheton JP, Aubin J. Towards environmentally sustainable aquaculture: comparison between two trout farming systems using life cycle assessment. Aquacultural Engineering 2009; 40(3): 113-19.

Gallego A, Rodríguez L, Hospido A, Moreira MT, Feijoo G. Development of regional characterization factors for aquatic eutrophication. The International Journal of Life Cycle Assessment 2010; 15(1): 32-43.

Gren IM, Lindahl O, Lindqvist M. Values of mussel farming for combating eutrophication: An application to the Baltic Sea. Ecological Engineering 2009; 35(5): 935-45.

Grönroos J, Seppälä J, Silvenius F, Mäkinen T. Life cycle assessment of finnish cultivated rainbow trout. Boreal Environment Research 2006; 11(5): 401-14.

Huijbregts AJ, Seppälä J.Towards region-specific, european fate factors for airborne nitrogen compounds causing aquatic eutrophication. The International Journal of Life Cycle Assessment 2000; 5(2): 65-67.

Huijbregts AJ, Seppälä J. Life cycle impact assessment of pollutants causing aquatic eutrophication. The International Journalof Life Cycle Assessment 2001; 6(6): 339-43.

Heijungs R, Settanni E, Guinée J. Toward a computational structure for life cycle sustainability analysis: unifying LCA and LCC. The International Journal of Life Cycle Assessment 2013; 18(9):1722-

Iribarren D, Moreira MT, Feijoo G. Life cycle assessment of mussel culture. *In*: Mussel: anatomy, habitat and environmental impact (*Eds*: Lauren EM). Nova Publishers, New York, 2011; 357-78.

ISO 14040. Environmental management-LCA - principles and framework. International Organization of Standardization, Switzerland.1997.

ISO 14041. Environmental management - life cycle assessment - goal and scope definition and inventory analysis. International Organization of Standardization, Switzerland. 1998.

ISO 14042. Environmental management - life cycle assessment - life cycle impact assessment. International Organization of Standardization, Switzerland. 2000.

Jerbi MA, Aubin J, Garnaoui K, Achour L, Kacem A. Life cycle assessment (LCA) of two rearing techniques of sea bass (*Dicentrarchus labrax*). Aquacultural Engineering 2012; 46: 1-9.

John G, Bradshaw J, Chen Z, Garg A, Gomez D, Rogner HH, Simbeck D, Williams R, Toth F, Vuuren DV. IPCC special report on carbon dioxide capture and storage. 2005; 77-103.

Koh SM, Koh PK, Sim KT, Lee YH, Surif S. Proximate analysis and heavy metal concentrations of tissues of cockles (*Anadara granosa*) from several cockle farms in Peninsular Malaysia. Sains Malaysiana. 2011; 40(2); 139-46.

Papatryphon E, Petit J, Kaushik SJ, Van der Werf HMG. Environmental impact assessment of salmonid feeds using life cycle assessment (LCA). Ambio 2004; 33(6): 316-23.

Pathansali D, Soong MK. Some aspects of cockle (*Anadara granosa* L.) culture in Malaya.1958; 26-31.

Pawiro S. Bivalves: global production and trade trends. *In*: Safe management of shellfish and harvest waters (*Eds*: Rees G, Pond K, Kay D, Bartram J, Santo DJ). IWA Publishing, London, UK. 2010; 11-19.

Phong LT, de Boer IJM, Udo HMJ. Life cycle assessment of food production in integrated agriculture-aquaculture systems of the Mekong Delta. Livestock Science 2011; 139(1-20): 80-90.

Potting J, Schöpp W, Blok K, Hauschild M. Site-dependent life cycle impact assessment of acidification. Journal of Industrial Ecology 1998; 2(2): 63-87.

Samuel-Fitwi B, Nagel F, Meyer S, Schroeder JP, Schulz C.Comparative life cycle assessment (LCA) of raising rainbow trout (*Oncorhynchus mykiss*) in different production systems. Aquacultural Engineering 2013; 54: 85-92

Seppälä J, Knuuttila S, Silvo K. Eutrophication of aquatic ecosystems a new method for calculating the potential contributions of nitrogen and phosphorus. The International Journal of Life Cycle Assessment 2004; 9: 90-100.

Shamsuddin L. Akuakultur Pinggir Laut. Dewan BahasadanPustaka, Kuala Lumpur. 1992; 10-12.

Siti Dina RP, Ahmad FM, Abdullah S. LCA for open systems: a review of the influence of natural and anthropogenic factors on aquaculture systems. The International Journal of Life Cycle Assessment 2015; 20(9): 1324-37.

Spångberg J, Jönsson H, Tidåker P. Bringing nutrients from sea to land-mussels as fertiliser from a life cycle perspective. Journal of Cleaner Production 2013; 51: 234-44.

Thrane M. LCA of Danish fish products: new methods and insights. The International Journal of Life Cycle Asessment 2006; 11(1): 66-74.

Tillman AM, Ekvall T, Baumann H, Rydberg T. Choice of system boundaries in life cycle assessment. Journal of Cleaner Production 1994; 2(1): 21-29.

Tookwinas S. Commercial cockle farming in Southern Thailand. International Center for Living Aquatic Resources Management, Philippines. 1985; 1-2.

Vázquez-Rowe I, Moreira MT, Feijoo G. Life cycle assessment of horse mackerel fisheries in Galicia (NW Spain): comparative analysis of two major fishing methods. Fisheries Research 2010; 106(3): 517-27.

Vázquez-Rowe I, Hospido A, Moreira MT, Feijoo G. Best practices in life cycle assessment implementation in fisheries. Improving and broadening environmental assessment for seafood production systems. Trends in Food Science and Technology 2012; 28(2): 116-31.

Ziegler F, Nilsson P, Mattsson B, Walther Y. Life cycle assessment of frozen cod fillets including fishery specific environmental impacts. The International Journal of Life Cycle Assessment 2003; 8(1): 39-47.

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