Greenhouse gases emission estimation from Indonesia *Litopenaeus vannamei* shrimp production

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Abstract. Aquaculture's role in contributing to fish production in Indonesia becomes increasingly important as capture fisheries production has decreased over the last decades. On the other side, aquaculture contributes to global green house gas emissions during several of its activity stages. For Indonesia, however, information on greenhouse gas (GHG) emissions from its aquaculture industry are scarce and therefore, research on this particular aspect needs to be more deeply explored. The main purpose of this study was to conduct carbon inventory in selected aquaculture systems in Indonesia. The scope of this research was the cradle-to-gate assessment of GHG emissions from *Litopenaeus vannamei* production. The specific objective of the study was to undertake a preliminary life-cycle assessment (LCA) of the GHG emissions arising from the production of three cultivation systems of *L. vannamei* shrimp production in Indonesia: traditional and intensive shrimp ponds in Central and West Java, and six intensive shrimp hatcheries in East Java. The data were collected from June to August 2019 using questionnaires to guide in-depth interview at the farming systems studied. Using business-as-usual and mitigation scenarios for carbon emission simulated up to 2024 energy use and total shrimp production were predicted in terms of optimistic, moderate and pessimistic scenarios. The most significant source of increased carbon emissions comes from electricity energy use attributed to paddle wheel, pumping and lighting. Planned scenario depends on the policies taken by the government and existing stakeholders.
Key Words: baseline analysis, carbon emission, *Litopenaeus vannamei,* aquaculture production.

Introduction. Indonesia is the largest archipelago in the world and it is home to some of the most frequent fish consumers in the world. Historically, this fish consumption need has been satisfied by the productive fishing waters surrounding the nation, but over the last decades unsustainable fishing practices, poor management, overfishing and conflicts among fisheries sectors/communities have resulted in an impeded supply of wild fish (BSI 2011; Muawanah et al 2012).

Indonesia is the world's second largest fish producer after China, contributing to around 7% of the global capture fish production (FAO 2020). Since the mid of 1980s global capture fisheries landings have stagnated, but the contribution of aquaculture to the world's fish production has linearly and consistenly increased since 1950s (FAO 2020). This global trend is also reflected in the national fish production in Indonesia, where the role of aquaculture as a source of fish protein has become increasingly important over the past decades (MMAF 2018). Aquaculture as an industry provides various aquatic food products, generates incomes from marine and coastal livelihoods and contibutes to national foreign exchange earnings. Shrimp industry creates jobs, however, shrimp farming have environmental issues and requires high energy supply (Tien et al 2019). Despite its various contributions to the economics and dietary needs of people in the world, aquaculture contributes to GHGs emissions during several stages such as fish-farming, transportation, processing and storage (Robb et al 2017). For instance, the adding up of GHGs from aquaculture to the atmosphere comes from the stocking density and the high quantity of different inputs added into the aquaculture ponds for the profitable culture of species (Pathak et al 2013).

The carbon emission inventory is a method of distribution and measurement of CO_2 emissions for all sectors, including in aquaculture. Gasses that trap heat in the atmosphere are called greenhouse gasses (GHGs) (Definition courtesy of IPCC AR4). These GHG emissions are usually indicative of related changes in droughts, sea levels, and the frequency of severe weather events, as well as economic impacts (Tol 2009). The impact of GHGs on ecosystem is greater than previously projection. These emissions add considerably to existing estimates of land-use carbon gas emissions such as tropical deforestation (including in seagrass and mangrove forest) (Adi et al 2020).

Further information about GHG emissions from the aquaculture industry still needs to be explored deeper. To assess carbon emission from industries, including aquaculture, a systematic carbon inventory assessment is required (Hiraishi et al 2013). Understanding the sources of GHGs and their drivers is essential for understanding and planning the need for mitigation and adaptation actions. The research aimed to undertake a preliminary life-cycle assessment (LCA) of the greenhouse gas (GHG) emissions arising from intensive shrimp ponds (in Central and West Java) and intensive shrimp hatchery (in East Java).

Material and Method

General description of the method. The data were collected from June to August 2019 in West Java, Central Java and East Java, using questionnaires to guide the in-depth interviews. The GHGs inventory was implemented by calculating the energy use of the farming system and inputs added to the aquaculture ponds such as fertilizer and artificial feed. The inventory result was then used to develop an emission baseline scenario by projecting the emission inventory result using a business-as-usual scenario (BAU). Finally, mitigation scenario for reducing the emission was developed by reducing the sources of the GHGs emissions according to policies related to energy and aquaculture sectors in Indonesia.

Scope of the study. The scope of this research was the cradle-to-gate assessment of the GHG emissions from *Litopenaeus vannamei* production (Figure 1), which for aquatic food products for human consumption is from fisheries or broodstock management to the incoming gate of the retail or food service (BSI 2012).

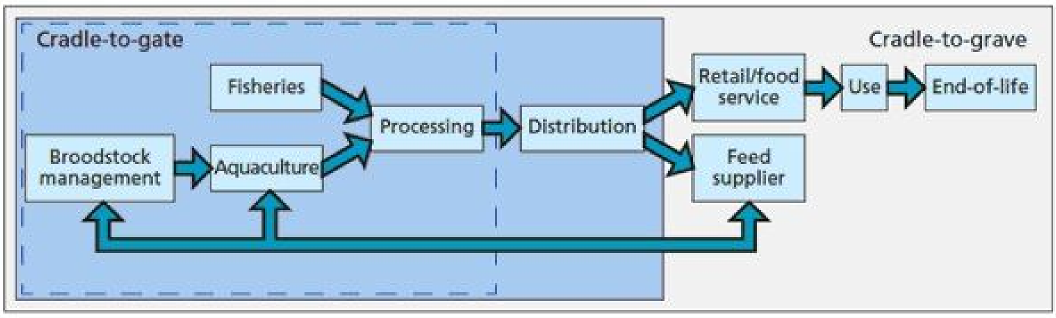

Figure 1. The scope of the study which is the cradle-to-gate assessment shown as the chain process inside the dashed line (Source: BSI 2012).

In this study, sources of GHG emissions on farm in *L. vannamei* culture are limited to electricity usage (the main energy source), generators (reserves of energy sources), the use of artificial feed and fertilizer. Artificial feed is from uneaten feed comparing with feed converted to shrimp meat. The N content in the remaining portion of artificial feed that is not converted to shrimp meat will in part be converted to N_2O. Similarly, the use of fertilizers in ponds is not all absorbed by phytoplankton. The N waste load from fertilizer which is not absorbed by phytoplankton will be partially converted to N_2O.

This research is limited to the measurement of farm GHG emissions. The GHG emissions from the land procurement, transportation, and processing of artificial feed have not been taken into consideration in this report.

Green house gases estimation. Based on the literature review, questionnaires were developed and served as the main survey tool for the data collection and in-deep interview. The questions were grouped into a few sections. The calculation of GHG emissions on *L. vannamei* intensive farming was carried out using the following assumptions:

1. Electricity costs are adjusted to each group rate (Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia No. 23/2016);
2. CO_2 GHG emissions from electricity amounting to 1.05 kg e (equivalent) GHG kWh^{-1}:
    - this value is based on the study of Budi & Suparman (2013) who conducted a study of CO_2 emissions of several coal power plants in Indonesia, including the Banten Power Plant, Indramayu Power Plant and Rembang Power Plant,
    - the results of the study show that CO_2 emissions from coal power plants studied were in the range of 1.002 to 1.136 kg kWh^{-1} with an average value of 1.05 kg kWh^{-1},
    - therefore, the value of the emissions is used as a reference assumption because Indonesia relies heavily on coal-fired power plants as electricity suppliers in Indonesia, especially in Java;
3. The heating value of diesel fuel is $36x10^{-6}$ TJ (tera joule) per liter, and 1 TJ of diesel fuel produces (Ministry of Environment 2012):
    a. CO_2 emissions of 74,100 kg e GHG,
    b. CH_4 emissions of 10 kg e GHG,
    c. N_2O emissions of 0.6 kg e GHG.
4. Protein in artificial feed is assumed to contain 16% N. While the proportion of feed converted to meat is assumed to be 17%, the rest is not consumed by around 15%, it is used for metabolism and it is secreted into the environment (48%), and it is excreted in stools of about 20% (Supono 2017). Conversion of N to N_2O in culture media was 1.8% (Hu et al 2012; Robb et al 2017). According to the study of Hu et al (2012), N_2O emissions in water bodies of aquaculture pond are sourced from nitrification and denitrification processes;
5. N levels are absorbed by algae (including phytoplankton) by 25%, so the N waste load from fertilizer is 75% (MacLeod 2015; Boyd 2018).

Analysis method. This study used a quantitative analysis by developing a measurable and objective GHG emission measurement approach. Nevertheless, qualitative analysis is still conducted to explore and understand the complexity of issues related to GHG emissions, including the use of case study methods. The use of mixed methods is the development of quantitative and qualitative approaches, because the two research approaches are both useful and important, so they can complement each other (Williams 2007). Statistical analyses (regression) were performed using Excel software.

Results and Discussion. Administratively, the farming systems studied are located in 3 provinces: Central Java, East Java and West Java. The three provinces are among the most densely populated provinces (more than 800 ind per km^2) compared with Indonesia population which has a density of 140 ind per km^2 (www.bps.go.id). Pond cultivation is relatively developed along the north coast of Java, both in Central Java, East Java and West Java. In addition, ponds on the southern coast of Java also began to develop, although not as much as on the north coast of Java.

General description of vannamei shrimp business. Vannamei shrimp farming is experiencing growth in several locations surveyed. After the intensive extortion of the tiger shrimp farming business, many ponds were left abandoned or changed functions to extensive or traditional cultivation with low stocking density. The traditional fishpond farmers tend to use polyculture patterns. In the three provinces, semi-intensive system with modest pond production was more dominant than intensive pond production. Pond cultivation in a simple and semi-intensive system in Java predominantly use shrimp and milkfish as the cultivated species. Some farmers also maintain tilapia in ponds. In the cultivation process, the use of artificial feed and energy is relatively low and productivity is also low. Whereas intensive and super intensive systems are usually used for shrimp farming as it has high sale value and requires very large capital (Henriksson et al 2017; Tran et al 2017).

The development of pond land needs to calculate the environment carrying capacity so as not to worsen environmental damage. Hiraishi et al (2013) suggested developing pond land in Indonesia should consult with local governments and must report to the Ministry of Marine Affairs and Fisheries (MMAF). Before 1996, shrimp production in Indonesia was dominated by black tiger or tiger shrimp (*Penaeus monodon*). In the mid-1990s, tiger shrimp farming did experience many disease problems. Many tiger shrimp business operators went bankrupt and closed their ponds (Arief et al 2015; Supono 2017). After the bankruptcy of the tiger prawn cultivation business, some of the ponds were not used or converted into extensive and traditional cultivation businesses. Several traditional pond farmers tend to use polyculture patterns, including shrimp and milkfish. Some farmers also cultivate tilapia in ponds. In extensive cultivation, the use of artificial feed and energy is relatively low.

Vannamei shrimp cultivation experienced growth in several locations surveyed. Vannamei shrimp's origin is from the eastern Pacific waters. Then, vannamei shrimp was legally first introduced into Indonesia in 2001 based on the Decree of the Minister of Marine Affairs and Fisheries No. 41/2001 (Wijayanto et al 2017). After the introduction of vannamei shrimp in Indonesia, gradually some of the former intensive tiger shrimp ponds began to be used for intensive vannamei shrimp cultivation (Supono 2017).

Estimation of aquaculture production and area until 2030. According to fish model of FAO (2018), by 2030 Indonesia aquaculture production (non aquatic plant) will reach 8,253,000 ton. Based on least square analysis between total non-aquatic plant aquaculture production with aquaculture production 2005 to 2016 (R^2 = 0.98) it shows aquaculture production by 2030 will reach 5,380,775 ton (Figure 2).

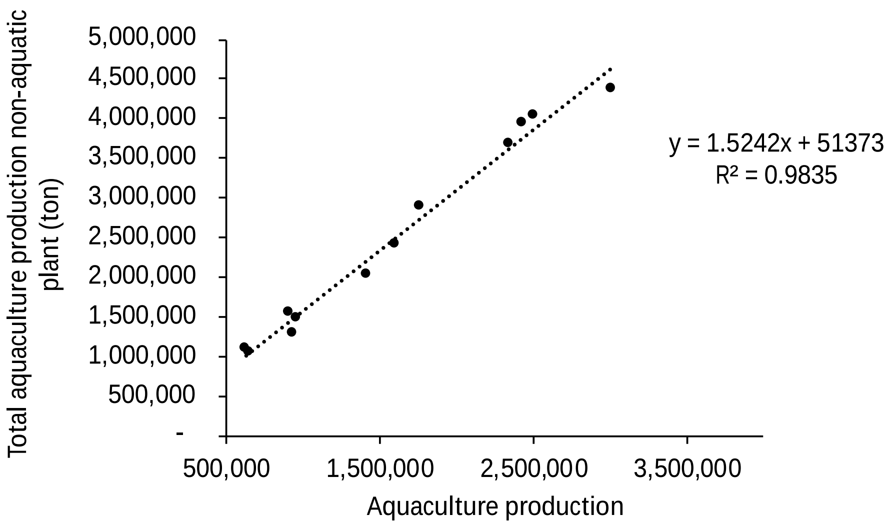

Figure 2. Relationship total non aquatic plant aquaculture production with aquaculture production.

Based on least square analysis between pond area and aquaculture production of 2005 to 2016 (R^2 = 0.35) it shows that pond area will increase by 2030 reaching 1,158,080 ha. It is estimated pond area will increase 483,945 ha between 2017 to 2030 (Figure 3).

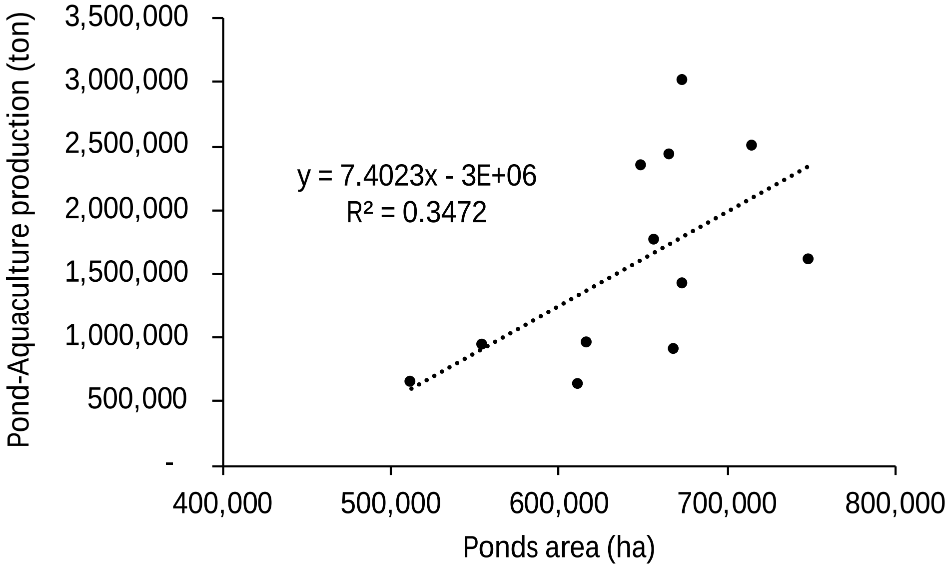

Figure 3. Relationship between aquaculture production and pond area.

Figures 2 and 3 are basically showing that fish ponds and aquaculture production are expected to increase up to 2030. This prediction should give alarming signals at least to two important environmental issues: the potential mangrove-to-pond conversion and the increase of GHGs emission from aquaculture sector.

Development of Indonesia vannamei shrimp production. There are two types of shrimp that are cultivated in Indonesia, namely vannamei shrimp and tiger shrimp. Actually, vannamei shrimp is not native to Indonesian waters. While tiger prawns is indeed found in Indonesian waters. Therefore, vannamei shrimp hatchery in Indonesia still depends a lot on broodstock imports from the USA. Vannamei shrimp production nationwide is experiencing a positive trend for the past decades. As an illustration, in 2011 vannamei shrimp production amounted to 246.420 tons per year and became 421.089 tons in 2015 (MMAF 2016). By using the forecasting method, it can be projected that vannamei shrimp production in 2019 could reach 773.808 tons (Table 1).

Table 1

The development of vannamei shrimp production

Years	*Vannamei shrimp production (ton)*	*Estimated intensive vannamei shrimp pond production (ton)*			*Vannamei shrimp seed production (million)*
		Assumption 5%	*Assumption 10%*	*Assumption 15%*	
2011	246.420	12.321	24.642	36.963	21.998
2012	251.763	12.588	25.176	37.764	21.594
2013	390.278	19.514	39.028	58.542	31.375
2014	442.380	22.119	44.238	66.357	29.952
2015	421.089	21.054	42.109	63.163	40.735
2016	490.274	24.514	49.027	73.541	55.400
2017	570.826	28.541	57.083	85.624	75.344
2018	664.613	33.231	66.461	99.692	102.467
2019	773.808	38.690	77.381	116.071	139.356

Note: Vannamei shrimp production in 2016-2019 is the result of forecasting.

The positive growth development of vannamei shrimp production has positive correlation with vannamei shrimp seed production that has also experienced positive growth (MMAF 2016). In principle, increasing production of vannamei shrimp seeds tends to follow market demand from the farmers. Shrimp seed production and shrimp farming production play important roles in the socioeconomics of the coastal areas (Hai et al 2015). The main contributor to shrimp seed production in Indonesia is from Lampung. In Lampung, there are indeed several large-scale shrimp farming companies. Whereas the second ranking contributor to national shrimp seeds is East Java, including Situbondo Regency as a production center for shrimp hatcheries (MMAF 2016).

Estimated GHG cultivation of vannamei shrimp on farm. The average value of intensive and super intensive vannamei shrimp farming business produces GHG emissions of 2.37 kg e GHG per kg of vannamei shrimp harvested (Table 2). These results do not take into accounting emission that is released due to land use change (LUC), transportation and production of artificial feed which also has a relatively large contribution to GHG emissions (Robb et al 2017).

Table 2

Resume of GHG emissions in vannamei shrimp intensive pond

Pond sites	*Estimated GHG Emissions (kg e GHG per kg of vannamei shrimp harvest)*
A	4.67 (99.97% from total energy)
B	1.32 (99.91% from total energy)
C	3.49 (99.96% from total energy)
D	2.02 (99.87% from total energy)
E	1.22 (99.90% from total energy)
F	3.08 (99.95% from total energy)
G	2.55 (99.95% from total energy)
H	1.05 (99.89% from total energy)
I	1.96 (99.94% from total energy)
Average	2.37

As a comparison, the results of GHG emission studies on aquaculture in Bangladesh, India and Vietnam can be seen in Table 3.

Table 3

Comparison studies GHG emission on aquaculture in Bangladesh, India and Vietnam

Research object	*GHG emission intensity (kg CO_2 e / kg weight of live fish)*		
	Without LUC	*With LUC*	*LUC contribution*
Bangladesh - Nile tilapia	1.58	1.81	0.23
India - Indian major carps	1.84	2.12	0.28
Vietnam - striped catfish	1.37	1.61	0.24

LUC = land use change (Robb et al 2017).

The results indicate that the intensive and super intensive cultivation of vannamei shrimp has resulted in relatively high GHG emissions. This is due to the high energy consumption. Intensive shrimp rearing requires a paddle wheel that must be run 24 hours (Baliao 2004). The oxygen sources in shrimp farms contribute 80% of farm electric power (Tien et al 2019). But high oxygen levels in vannamei shrimp pond can improve the environment, including reducing total bacteria, virus, and disease, and increasing feed efficiency that generate the optimal growth (Rahmawati et al 2020). This is different from other types of cultivation such as catfish, tilapia and carp which do not require a 24 hours paddle wheel works.

While the main energy source of intensive shrimp farming business in Indonesia is electricity from PLN (State Electricity Company), while diesel generators are rarely used unless electricity is experiencing problems. Electricity is considered relatively economical for businesses, including shrimp farmers. On the other hand, electricity sources in

Indonesia are mostly supplied by PLTU (steam power plants), especially in large islands, including the Java-Bali electricity grid. The power plant uses coal as fuel to heat seawater which then becomes the driving force for turbine power plants (Budi & Suparman 2013). The selection of coal was carried out because of budget savings considerations despite the high carbon emissions which contributed to global warming (Sengupta 2018). As an illustration, the average emission factor of power plants in Indonesia in 2015 was 0.867 $kgCO_2\ kWh^{-1}$, projected to increase to 0.934 $kgCO_2\ kWh^{-1}$ in 2017 with the operation of many new coal-fired power plants. Furthermore, the emission factor is predicted to decrease in 2024 to 0.758 $kgCO_2\ kWh^{-1}$ with the operation of PLTP and PLTA (Cahyadi 2015). Therefore, the reduction in the use of coal in national energy sources is expected to significantly reduce GHG emissions.

Based on the results of the analysis it can be seen that the main source of GHG emissions from intensive scale vannamei shrimp farming is the energy use, particularly from electricity and generators. On the contrary, the source of GHG emissions from fertilizer, feed and other factors tends to be insignificant. The contribution of GHG emissions from vannamei shrimp hatching (Table 4) tends to be insignificant when converted to vannamei shrimp production because on average only 0.000000048 kg of GHG per seed shrimp (1 kg of vannamei shrimp seeds are 0.048 kg e GHG). Therefore, energy efficiency is a critical success factor for the development of a more environmentally friendly vannamei shrimp hatchery related to GHG emissions.

Table 4

Resume of GHG emissions in vannamei shrimp hatchery

Hatchery	*Estimated GHG emissions (kg e GHG per vannamei shrimp seed)*
1	0.000000080
2	0.000000068
3	0.000000020
4	0.000000050
5	0.000000022
Average	0.000000048

Note: the source of emissions calculated only from energy, whereas from fertilizers and feed is assumed to be insignificant; if a seed is assumed that the weight of PL 10-12 vannamei shrimp seeds is 0.001 g.

Estimated development of vannamei shrimp culture GHG emissions*.* By using the estimation results of GHG, both rearing and hatching stages of vannamei shrimp, it is possible to estimate the development of GHG emissions in intensive scale and vannamei shrimp hatcheries. An overview of the development of GHG emissions can be seen in Table 5, Figure 4 and Figure 5.

It can be seen that there is an increasing trend of GHG emissions in vannamei shrimp culture in Indonesia, especially in intensive ponds and hatcheries. Calculations have not been made for semi-intensive and traditional ponds. It is recommended to manage GHG emission in vannamei shrimp ponds as a top priority compared to vannamei shrimp hatcheries. The present calculation does not take into account GHG emissions from LUC. In the case of aquaculture in India, Bangladesh and Vietnam, it is estimated that the value of GHG emissions related to changes in land use is 0.23 to 0.28 kg CO_2 e per kg of live fish. Meanwhile, according to a study by Sidik & Lovelock (2013), intensive shrimp ponds in Bali have released carbon from the mangrove area into the atmosphere with a value of around 4.37 kg CO_2 per m^2 per year.

The results of this study do not taken into account GHG emissions from the process of producing artificial feed and from transportation. Referring to Robb et al (2017), GHG emissions from fish feed (excluding LUC) can reach 0.64 to 0.80 kg CO_2 e per kg of live fish produced, where this value is the largest contributor to GHG in aquaculture fish that are minimal or do not use paddle wheels. The GHG value of fish feed (excluding LUC) is still lower than the intensive GHG vannamei shrimp pond (on farm) which has an average emission value of 2.37 kg CO_2 e per kg of live shrimp produced.

Table 5

Estimated GHG emissions of Indonesian vannamei shrimp cultivation

Years	*Shrimp production (tons)*	*Shrimp production from intensive ponds (tons)**	*Shrimp seeds production (million seeds)*	*GHG emissions intensive shrimp pond (tons e GHG)*	*GHG emissions shrimp hatchery (tons e GHG)*
2011	246.420	24.642	21.998	58.484	1.06
2012	251.763	25.176	21.594	59.752	1.04
2013	390.278	39.028	31.375	92.626	1.51
2014	442.380	44.238	29.952	104.992	1.44
2015	421.089	42.109	40.735	99.938	1.96
2016	490.274	49.027	55.400	116.358	2.66
2017	570.826	57.083	75.344	135.476	3.62
2018	664.613	66.461	102.467	157.735	4.93
2019	773.808	77.381	139.356	183.651	6.70

Note: * Assumption: 10% from vannamei shrimp ponds production.

Figures 4 and 5 show the development of national production of intensive vannamei shrimp culture and vannamei shrimp seeds, respectively. The figures are plotted along with the resulted GHG emissions from the respective aquaculture systems analyzed. It can be clearly seen that the GHGs emission from the vannamei shrimp aquaculture is linearly increasing with the aquaculture production. It is expected that climate change mitigation action on aquaculture practice / industry can 'flatten' this linear increase in GHG emission despite the increase in production.

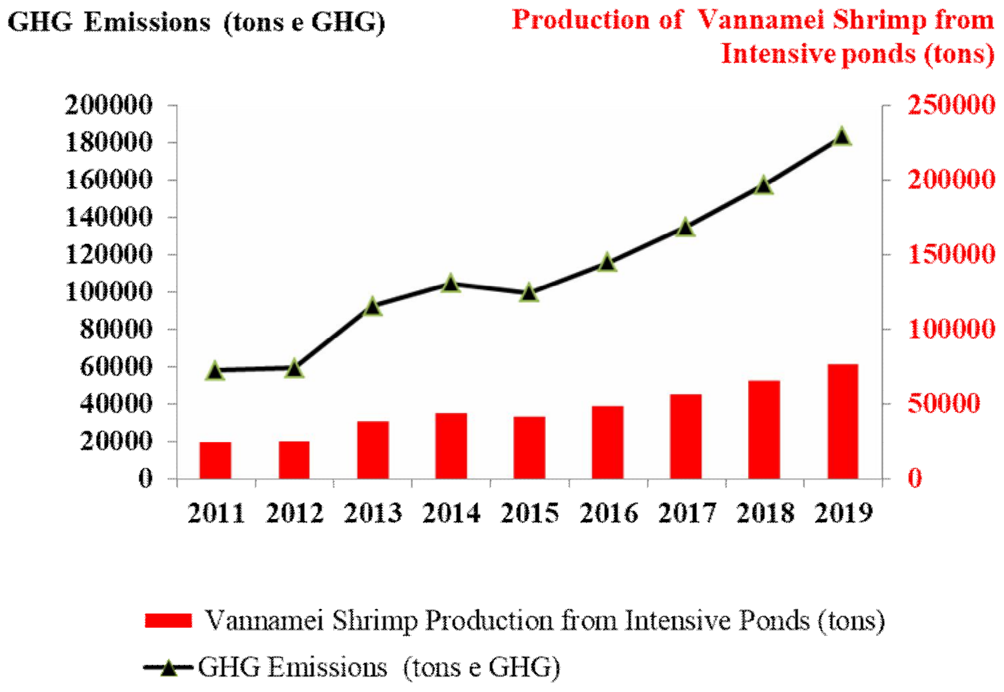

Figure 4. Estimated GHG intensive vannamei shrimp culture in Indonesia.

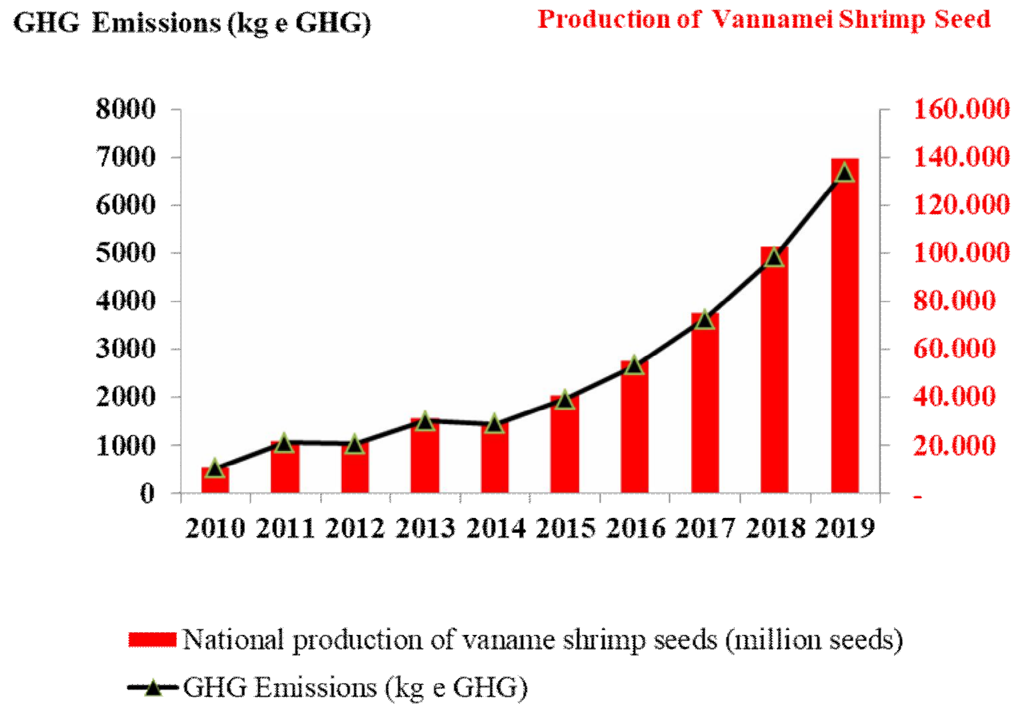

Figure 5. Estimated GHG intensive vannamei shrimp seeds production in Indonesia.

Alternative efforts to reduce vannamei shrimp GHG emissions. The relatively high GHG emissions in the vannamei shrimp farming business encourage the need to reduce emissions. Based on this study some mitigation actions that can be attempted include:

- energy efficiency, both for electricity and generator set. It is because the contribution of energy component in GHG emissions of the shrimp farming is very significant, which can reach 99% (on farm, excluding feed production, transportation and LUC) of the total energy used in the farming system. Although this efficiency is not very significant in terms of operational cost, the GHGs emission reduction will be significant;
- the use of energy sources which is more efficient and environmentally friendly for lighting, for example by using solar energy. However, it is estimated that the energy use for supporting operational activities (lighting, and offices) is not very significant, which is around 5% of the total energy use, only reducing GHG emissions from 2.37 kg e GHGs to 2.25 kg e GHGs;
- the use of technology for water pumps and waterwheels which is more environmentally friendly, for example by using wind power and solar energy. The current challenge is the roles of electric pump and paddle wheels have not been able to be replaced with wind and solar power technology from the operational cost perspective. According to Tien et al (2019), innovative aeration systems using renewable energy can provide both economic and environmental benefits:
- the development of feed technology and the control system of artificial feed with lower FCR (feed conversion ratio) and lower protein content but which are still able to support shrimp growth;
- the application of biofloc technology that can reduce GHG emissions, control water quality and improve FCR;
- increasing crop productivity, because of the higher the productivity, the lower the level of emissions per kg of shrimp harvested.

Conclusions. The source of GHG emissions from vannamei aquaculture are electricity use, diesel fuel, CH_4, N_20, artifical feed and fertilizer. The most significant source of carbon emissions comes from electricity energy, mainly contributed by the use of wheel, pumping and lighting. Producing one kg of vannamei shrimp with post larva size of 10-12 from intensive hatchery would release 0.048 kg GHGe to the atmosphere. Additionally, producing 1 kg of vannamei shrimp from intensive pond would have impact on the release of 2.37 kg GHGe to the atmosphere. Based on this study, mitigation scenario for vannamei shrimp aquaculture in Indonesia should be focused on the efficiency of energy and artificial feed use and the potential use of more environmentally friendly energy sources. The success of this strategy depends on the policies taken by the government and the awareness of existing stakeholders on environmental and climate change issues.

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