การประเมินการปล่อยแก๊สเรือนกระจกจากกิจกรรมของฟาร์มกุ้งแบบหนาแน่นชายฝั่งแห่งหนึ่งในจังหวัดฉะเชิงเทรา

Evaluation of greenhouse gas emission from activities of a coastal intensive shrimp farm in Chachoengsao Province

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บทคัดย่อ

งานวิจัยนี้ศึกษาการปล่อยแก๊สเรือนกระจกจากการเพาะเลี้ยงกุ้งขาวแวนนาไมแบบหนาแน่นจาก 3 กระบวนการผลิต ได้แก่ การเตรียมบ่อ การเพาะเลี้ยงและการเก็บเกี่ยว ที่ความหนาแน่น 50,000-60,000 ตัว/ไร่ ในเดือนมีนาคม-พฤษภาคม พ.ศ. 2562 ข้อมูลกิจกรรมได้แก่การใช้พลังงานและสสาร ของเสียและการระบายน้ำทิ้งได้เก็บรวบรวม และนำมาคำนวณเป็นปริมาณแก๊สเรือนกระจกที่ปล่อย ผลการศึกษาแสดงให้เห็นว่าการเพาะเลี้ยง 1 รอบ ปล่อยแก๊สเรือนกระจกเท่ากับ 4.33 กก. คาร์บอนไดออกไซด์เทียบเท่า/กก. ผลผลิต โดยขั้นตอนการเพาะเลี้ยงเป็นขั้นตอนที่ปล่อยแก๊สเรือนกระจกสูงสุดเท่ากับ 3.63 กก. คาร์บอนไดออกไซด์เทียบเท่า/กก. ผลผลิต การใช้ไฟฟ้าจากการเติมอากาศ การใช้เครื่องให้อาหารอัตโนมัติ และแสงสว่าง คิดเป็นร้อยละ 83.58 ของค่าการปล่อยแก๊สเรือนกระจกทั้งหมด หากมีการให้อากาศแบบบางช่วงเวลา และลดจำนวนและขนาดวัตต์ของหลอดไฟฟ้าสามารถทำให้การปล่อยแก๊สเรือนกระจกลดลงได้ร้อยละ 9.88

คำสำคัญ: การเพาะเลี้ยงสัตว์ น้ำ แก๊สเรือนกระจก ฟาร์มกุ้งแบบหนาแน่น

Abstract

This study investigated the GHG emission from 3 processes of white leg shrimp production in an intensive shrimp farm; namely, pond preparation, culturing and harvesting at the density of 50,000-60,000 individuals/rai in March-May 2019. The activity data such as energy and materials use, waste and water discharge were collected and greenhouse gas emission calculated. Results showed that overall GHG emission for 1 crop was 4.33 kgCO_2eq/kg product for which the cultural stage produced the highest amount of 3.63 kgCO_2e/kg. The use of electricity from aeration, auto feeding and lighting in the cultural stage was 83.58% of total GHG emission. If intermittence aeration was applied and the light bulbs were decreased in number and wattage, the total amount of GHG emission could be decreased by 9.88%.

Keywords: Aquaculture**,** Greenhouse Gas, Intensive Shrimp Farm

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Introduction

The problem of global warming from greenhouse gases (GHGs) has become more and more critical. The aquaculture sector is one of the fastest-growing food production systems in the world (Dorber *et al.*, 2020) shrimp aquaculture has undergone a rapid development in the last decades, as it can help to satisfy the increasing food demand of a growing population. However, shrimp production can be accompanied by environmental impacts, such as land cover changes associated with pond construction, or the degradation of coastal areas through pollution. Environmental footprinting, has proven to be a valuable tool for tracing environmental impacts from human consumption back to their location and sector of origin. Here, we focus on the land footprint, which quantifies the area of required land resources to satisfy human consumption (of shrimp production and shrimp farming has been especially condemned all over the world (Ahmed & Glaser, 2016) because of its socio-economic and environmental impacts. Whiteleg shrimp is a valuable and ideal species among Asian shrimp producers. Thailand have been produced whiteleg shrimp with an intensive production system in the coastal areas surrounding the upper gulf of Thailand from 1987 to 1989 (Szuster, 2006). Thailand hosted the world's top ten providers of both freshwater and seawater shrimp products in the year 2019 (Phornprapha, 2020). It has been recognized that intensive shrimp farming is one of the most important and widely used production systems in the aquaculture of Thailand. Chachoengsao province has been reported as having the greatest production of whiteleg shrimp in all of the coastal zones producing 24,803 tons that were 40.43% of the total whiteleg shrimp products in Thailand. The total area was 2,141 rai in 2018 (Department of Fisheries, 2020).

The objectives of this study are (i) to determine materials and energy usage in intensive shrimp processes (ii) to compare greenhouse emissions of each process at the pond preparation stage, cultural stage and harvesting stage of intensive shrimp processing (iii) to propose reduction of GHGs emissions and energy uses in intensive shrimp farm aquaculture.

Methodology

This study used the basic principle of GHG emission calculation by multiplying the activity data with the emission factors (coefficients which quantify the emissions per unit activity). The emission factors were derived from the IPCC 2006 guidelines (IPCC, 2006a ; IPCC, 2006b) and Thailand greenhouse gas organization (TGO, 2020 ; TGO, 2021a ; TGO, 2021b). The activity data were investigated in one crop of the entire shrimp production process of an intensive shrimp farm at Chachoengsao province in 2019. Data were collected at the farm by direct measurement of types and numbers of motor use, light bulb, weight of plastic packages for transportation and by interviewing the farmers about farm practices and chemical use in the farm. In addition, pond water was taken to quantify the chemical oxygen demand (COD). The conversion of organic matter to GHG by microorganisms in sediment was not take into account when calculating emissions. The GHG emissions was reported in terms of kgCO_2eq/kg shrimp harvested. This research was certified by human research ethics (KMUTT-IRB-COE-2019-180).

1. Study Site and General Information

The shrimp pond has an area of about 1.5 rai or 2,400 m^2 and shrimp production is typically 3 crops per year. Data of shrimp production was collected during March-May 2019. The seeding of super post larvae was at size ranges 2-5 cm ; weight of one shrimp was 0.1 to 1 g and the density was 50,000 to 60,000 individuals/rai. The total weight of shrimp after harvesting was 1.8575 tons (1238.33 kg/rai). This study site was changed from rice paddy field to shrimp farm more than 20 years previously, thus it was not considered to be GHG emission from land use change (IPCC, 2006a). In addition, MacLeod *et al.* (2019) also mentioned that landuse change arising from pond construction emits carbon dioxide (CO_2) but it is difficult to quantify and unlikely to be a major source of emissions.

2. Calculation of GHG from Use of Total Energy

Energy uses in aquaculture farms comprise electricity and fuel consumption. Electricity is used for aeration, auto feeding and lighting. The fuel oil is used for water pumping and transportation. Therefore, total GHG emission from energy use is the summation of GHG from electricity and fuel oil.

2.1 Calculation of GHG from Total Use of Electricity Consumption

To determine the electricity consumption, the amount of aeration and associated electricity use was estimated following the method of Boyd and McNevin (2020). Motors were used for aeration and water pumping. The power of each motor was estimated from its horsepower (hp) as shown in equation (1) (Boyd & McNevin, 2020).

$$P = 0.746\ Ai \tag{1}$$

where P=Power of an aerator or pump (kW) and A_i=capacity (hp)

Thus, electricity used for the motor (E_m) can be calculated as equation (2).

$$E_m\ (\text{kWh}) = (100 \times P)\ t/\text{Efficiency} \tag{2}$$

where, t is the time for which the motor was used (h), Efficiency is an efficiency of an electric motor (%)

The efficiency of small motors (1-4 hp) is usually assumed to be 75-79%, and above 90% for a 5 hp motor (Boyd & Mcnevin, 2020). The more powerful motor is more efficient in converting electrical energy input to mechanical energy output. To evaluate the energy use from lighting (E_L), the usage time, numbers and type of light bulb were recorded and calculated following equation 3.

$$E_L\ (\text{kWh}) = nPt \tag{3}$$

where, n is number of the LED bulbs, and P is power of LED bulb (KW)

Total GHGs emission from electricity consumption (GHG_E) can be calculated from the summation of E_m and E_L per amount of shrimp production in one crop as shown in equation (4).

$$GHG_E\ (\text{kgCO}_2\text{e/kg}) = 0.5986\ (E_m + E_L)/\text{kg shrimp} \tag{4}$$

where, 0.5986 is the emission factor of electricity in kgCO_2e/kWh (TGO, 2021a).

2.2 Calculation of GHG from Total Use of Fuel Consumption

Small trucks and some water pumps used fuel oils such as gasohol and diesel. The water pumps used diesel oil for adding water into the pond during preparation and for draining water out during harvesting.

Emission from water pumping (E_p) can be calculated as equation (5).

$$E_p\ (\text{kgCO}_2\text{e}) = EF \times R \tag{5}$$

where EF is emission factor for diesel oil for stationary combustion=2.7076 (kgCO_2e/L) (TGO, 2021a) and R is amount of oil used (Liter)

According to the collected data, two small trucks were used for transportation, for which the GHG emission from transportation (E_T) was computed following equation (6).

$$E_T(\text{kgCO}_2\text{e}) = EF \times [\text{distance (km)} \times \text{rates of energy consumption (L/km)}] \tag{6}$$

where EF is emission factor, which diesel for mobile combustion=2.7403 kgCO_2e/L and for gasohol= 2.2325 kgCO_2e/L (TGO, 2020).

Thus, GHG emission from fuel consumption (GHG_F) can be calculated from equation (7).

$$GHG_F\ (\text{kgCO}_2\text{e/kg}) = (E_P+E_T)/\text{kg shrimp} \tag{7}$$

3. Calculation GHG from Total Use of Raw Materials and Waste

The materials used in the farm were chemicals and shrimp feed so the packaging bags are solid waste. The packaging bags were collected and weighed after they has been emptied of feed, chemicals and shrimp larvae. Water discharge from the shrimp pond to the receiving water was also estimated and calculated as wastewater.

3.1 GHG Emission from the Packaging Bags

High-density polyethylene (HDPE) was used for packaging bags of shrimp feed and chemicals. They are strong, flexible, lightweight and have high moisture resistance. The GHG emission from packaging bags (GHG_B) was calculated from the weight of plastic packages bags in the equation (8).

$$GHG_B \text{ (kg } CO_2e\text{/kg)} = EF \times W \qquad (8)$$

where the emission factor of HDPE is 6.7071 $kgCO_2e/kg$ (TGO, 2021a), W is weight of the plastic packaging bags (kg)

If the plastic bags were recycled, the emission was calculated by equation (9).

$$E_{EOL} = [(1-R_{RL}) \times E_{d,l}] + E_{tw} \qquad (9)$$

where, E_{EOL} is GHG emission during waste management (tCO_2e/ton), $R_{RL=}$Recycling rate for plastic material (0.87), $E_{dl=}$Waste management GHGs emission value (2.3 tCO_2e/ton) and $E_{tw=}$GHGs emission from transport of car (zero emission) (TGO, 2021b).

The GHG emission from dead fish and uneaten food waste from intensive seabass farms was calculated as food waste and it was assumed that they were decomposed the same as at a landfill site in which the emission factor (EF) was 2.53 kg CO_2e/kg (TGO,2021b).

$$E_{df} \text{ or } E_{un} = EF \times W \qquad (10)$$

Where, E_{df}=Emission from dead fish 2.53 ($kgCO_2e/kg$)

$E_{un=}$Emission from uneaten feed 2.53 ($kgCO_2e/kg$)

W=weight of the dead fish or uneaten feed (kg)

3.2 GHGs emission from feed

Ammonia is nitrogen waste produced from feed input. The emission of nitrous oxide (N_2O) from different aquaculture systems could be different significantly, depending on the environmental conditions. Hu *et al.* (2012) stated that nitrification and denitrification processes are

influenced by many parameters such as dissolved oxygen concentration, pH and temperature. N_2O

emission is evaluated from the shrimp production in terms of N_2O production of 1.69 gN_2O-N per kg of production (IPCC 2006 a ; Hu *et al.*, 2012 ; Paudel *et al.*, 2019)this study estimates emission of N 2 O-N from aquaculture in Nepal in 2020 and 2030 to be 1.1 × 10 8 g N 2 O-N (±5.2%. Thus GHGs from feed (GHG_F) can be evaluated from equation (10).

$$GHG_F\text{(kg } CO_2e\text{/kg)} = 1.69 \times \text{kg shrimp production} \times 265 \text{ (GWP of } N_2O) \qquad (11)$$

3.3 GHGs Emission from Discharged Water

The discharged water from the shrimp pond was estimated as wastewater which the shrimp pond depth less than 2 meters. The GHG emission from discharged water (GHG_W) is shown in equation (12) (TGO, 2020).

$$GHG_W \text{ (kg } CH_4\text{)}=0.050 \times [(Wi \times COD/1000)] \qquad (12)$$

where, Wi is wastewater volume (m^3) and COD is Chemical Oxygen Demand (mg/l).

Result and Discussion

The overall input and output of each stage of shrimp farm in this study is shown in Figure 1.

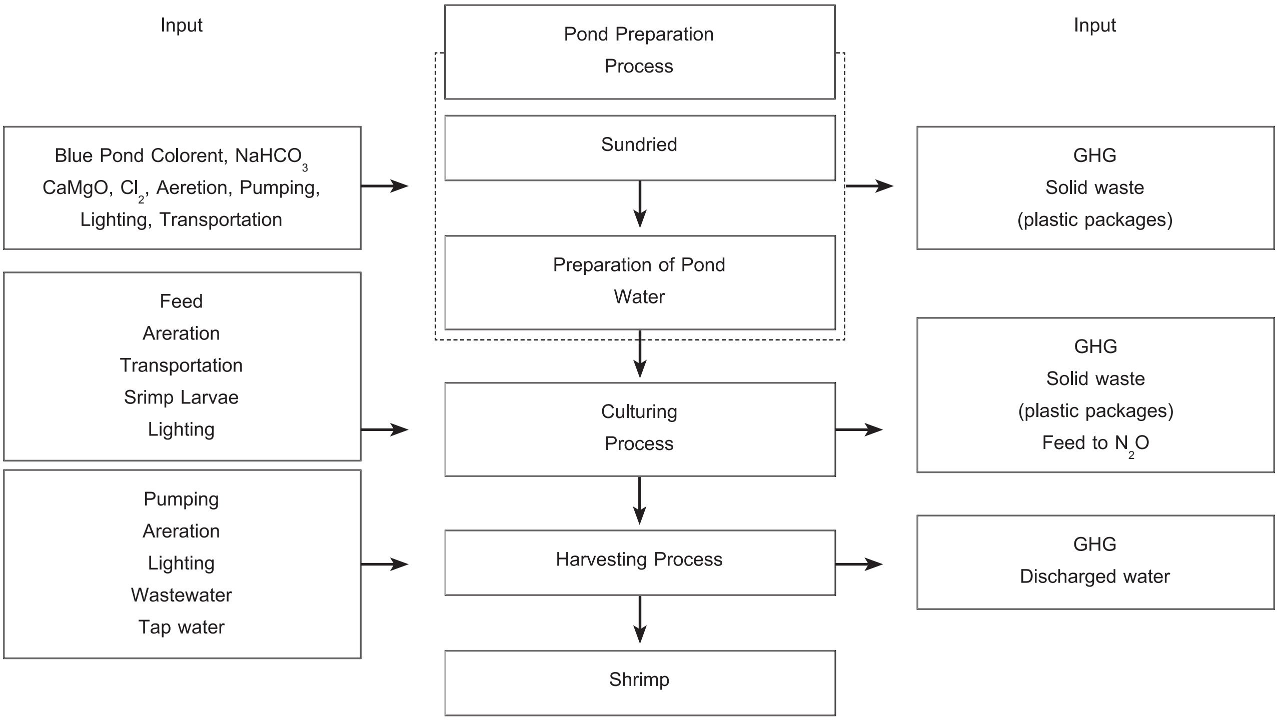

Figure 1 Input and Output Evaluated of Shrimp Production in an Intensive System

Pond preparation started in March 2019 and lasted for 15 days, the cultural stage was 48 days and the harvesting stage was 1 day in May 2019. There was no nursery period in this farm because super post larvae were used for seeding. The duration of the pond cultural stage was 48 days because the shrimps were starting to become infected by white spot syndrome virus so the farmer harvested early. The marketable size was about 30 pcs/kg (FAO,1986) but in this farm, the harvesting size was 49 pcs/kg. The pond preparation stage had been started after shrimp harvesting and the water was pumped out for cleaning accumulated particles from dead plankton, uneaten feed and feces and was then sundried for about 2 weeks. Boyd (2019) stated that sunlight decreases soil moisture, and that it is sufficient to destroy most of the organisms (including pathogens) remaining in the pond after draining. It is necessary to prevent the remaining pathogen from one crop to the next crop after shrimp harvesting and also to maintain a good quality of soil and water in the pond. Calcium magnesium oxide (CaMgO) was applied to the pond floor before adding the water for killing the germs. A mixture of calcium carbonate ($CaCO_3$) and slaked lime or hydrated lime [$Ca(OH)_2$] was normally used to increase the pH level and to reduce the turbidity which enables optimum photosynthesis (Chanda *et al.*, 2019). The shrimp pond in this study did not have applied hydrated lime or calcium carbonate. Then, water was pumped into the pond and the chemicals were applied, such as the blue pond colorant, sodium bicarbonate ($NaHCO_3$), CaMgO, chlorine, and potassium permanganate ($KMnO_4$). The application of calcium and magnesium in the pond gave the essential elements for aquatic plants and animals (Boyd, 2015). The CaMgO did not emit CO_2 and it was used instead of a mixture of $CaCO_3$ and $Ca(OH)_2$. Adding carbonates to soils in the form of lime (calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$) leads to CO_2 emissions as the carbonate limes dissolve and release bicarbonate (HCO_3^-), which evolves into CO_2 and water (IPCC, 2006a)

The harvesting stage was only one day in duration. The volume of water (Wi) of the pond at full capacity was approximately 3600 m^3. During the cultural stage, there was no water exchange. However, water was aerated by using aerators. In the harvesting stage, the aerated water was gradually drained out. Then cleaning the pond by spraying the water using 1 hp motor for 4 hours. The remaining of 1.5 m^3 of water was left in the pond. The feed conversion ratio (FCR) that is kg dry weight of feed divided by kg wet weight of shrimp was 1.07.

1. GHG Emission during Pond Preparation Stage

In the pond preparation stage, the energy used comprised aeration, transportation, pumping and lighting. Total greenhouse gas emission from this stage is shown in Table 1. Boyd & McNevin (2020) stated that many types of mechanical aerators were used in aquaculture farming. Among them, the floating electric aerators with steel paddlewheels were the main means of aeration, and the other types of aerators were vertical turbine, diffuser, and venturi aerators. The aerators used in this farm were used for 4 hours in the daytime and for 4 hours at the nighttime. In the daytime, three motors were used (2 for 2 hp motors and 1 for 5 hp motor), whereas 4 motors (3 for 2 hp motors and 1 for 3 hp motor) were used in nighttime. The total electricity consumed for 15 days of aeration was 871.9 kWh.

Table 1 GHG Emission from Pond Preparation Stage

Sectors	Energy & Material use	GHG Emission (kgCO$_2$e/kg)
Aeration	871.9(kWh)	0.2810
Lighting	54(kWh)	0.0174
Pumping	90(liters)	0.1310
Transportation (diesel)	0.889 (liters)	0.0013
(gasohol)	0.889 (liter)	0.0011
Plastic	0.004(ton)	0.0007
Total		**0.4327**

Small trucks were use only once for carrying the chemicals from the chemical shop to the farm during the pond preparation stage. The distance between the chemical shop (Tha lay Thong) and the farm was 4 km and the fuel consumption of the small trucks was 0.11 L/km. Another energy use was water pumping for 4 hours for which the engine diesel oil consumption was 60 liters/rai. Moreover, the energy was consumed for 20 individual 18-Watt LED bulbs were used for lighting (7.00 pm.-5 am). The energy consumption for electricity was 3.6 kWh/day.

Waste generation from this stage is plastic bags from the chemical used for water adjustment which is the lowest GHG contribution as shown in Table 1. The highest emission was aeration (64.92%), followed by water pumping (30.34%) lighting (4.02%) and transportation (0.55%).

2. GHG Emission from the Culturing Stage

The material used for the culturing stage was chemicals and feedstock. The total plastic packaging bags was 88 bags or 11 kg. In this study, the farmers sold all the plastic bags as recycled material. Therefore, the GHGs emission from plastic bags was 1.79 kgCO$_2$e/ton.

The production of shrimp after harvesting was 1857.5 kg/crop, therefore, the amount of N$_2$O emission from the cultural stage was 0.004932 kg N$_2$O/ton of shrimp or 1.31 kg CO$_2$e/ton shrimp.

The energy used in the culture stage was for aeration, lighting, transportation, and an auto feeding machine. The aerators in this farm were operated for 24 hours/day during the cultural period. In the daytime, two 2 hp motors and one 5 hp motor were operated. There were three 2 hp motors and one 3 hp motor opened at nighttime. Also, 3 hp submerged aerators with 16 heads were used for twenty-four hours in the pond. The total electricity consumption for aeration during the whole culture stage of 48 days was 10910 kWh. For lighting, 20 light bulbs of 18-Watt were used with a total of 172.8 kWh during this stage. The electricity consumption of a 1 hp pump for the auto feeding was 134.3 kWh for 30 days and the efficiency of the pump was 79% thus the electricity consumption for the auto feeder was 170 kWh. Two small trucks were used for going to a shop. A small truck using diesel was used 3x and another small truck using gasohol as a fuel was used 7x. The diesel fuel energy used was 0.889 liters and gasohol fuel energy used was 2.667 liters for transportation Therefore, the total emission for the culture stage was 3.63 $kgCO_2e/kg$.

Total greenhouse gas emission from the culturing stage of the shrimp farm is shown in Table 2. The highest emission was aeration (96.94%), followed by lighting (1.44%) and auto feeding (1.42%).

Table 2 GHG Emission from Culturing Stages

Sectors	Energy & Material used	GHG Emission ($kgCO_2e/kg$)
Aeration	10910 (kWh)	3.5158
Lighting	172.8 (kWh)	0.0556
Auto feeding	170 (kWh)	0.0547
Transportation (gasohol)	2.667 (liters)	0.0045
(diesel)	0.889 (liter)	
N_2O emission	0.0049 (kgN_2O/ton)	0.0013
Plastic waste	0.011 (ton)	0.0017
Total		**3.634**

3. GHG Emission from Harvesting Stage

During the harvesting stage, the pond water was aerated and the volume of 3598.5 m^3 was discharged. The average COD concentrations was 63.38 mg/l.

Shrimps were caught in the pond and transferred to the customers' vehicles which carried them to the market. Therefore, the energy used for harvesting did not include that of transportation of shrimps. During the harvesting time, the surface aeration pumps were closed at 2.30 am and submerged aeration was closed at 3.00 am. Hence, the electricity consumption was less than at other stages. After the shrimps were caught, the water pump was used for cleaning the pond. In addition, 3,000 liters of tap water were used for cleaning the pipes and submerged aerators. Total GHGs emission from the harvesting stage of shrimp farm was 0.272 $kgCO_2e/kg$. The highest emission of GHG was water discharge (63.2%), followed by water pumping (32.63%) and aeration (3.53%). The emission from lighting is 0.43% as shown in Table 3.

The total amount of GHG emission from pond preparation, culturing and harvesting were 0.43, 3.63 and 0.27 $kgCO_2e/kg$, respectively. A comparison of three stages of GHGs emissions from the intensive shrimp farming process of this present study and other researches is shown in Table 5.

Table 3 GHGs Emission from Harvesting Stage

Sector	Energy & Material used	GHG Emission ($kgCO_2e/kg$)
Aeration	29.75 (kWh)	0.010
Lighting	3.6(kWh)	0.0012
Pumping (electric)	3.78 (kWh)	0.0012
(diesel)	60 (liter)	0.087
Wastewater Discharge	11.4 (kg)	0.1719
Tap water	3 m^3	0.0005
Total		**0.2718**

Table 4 shows the GHG emissions from aquaculture production. It was found that the GHG emissions varied depending on the farm practices and species cultivated. GHG emission of this study corresponded with the results of Seeprom & Phoochinda (2017). Results from Haditomo *et al.* (2020) revealed a lower GHG emission from Vannamei shrimp farms in Indonesia than in Thailand. The GHG emission was also estimated from activity data same as this present study but it did not include the pond preparation period and transportation. In addition, the value of 2.37 $kgCO_2e/kg$ was an average value from 9 farms in which the range was 1.05-4.67 $kgCO_2e/kg$. The report from Robb *et al.* (2017) expressed the lower GHG emissions of fish farms as being lower than emissions of shrimp farms. This was because cultivation of tilapia, carps and catfish does not require 24 hours aeration.

Table 4 GHG Emission from Various Aquacultural Farms

Location	Description	GHG Emission ($kgCO_2e/kg$)					Reference
		Pond Preparation	Culture	Harvesting	Transportation	Total	
Chacheongsao Thailand	Activity data analysis (1.86 tons/1.25 rai/ 64 days)	0.43	3.63	0.27		4.33	This present study
Suphan Buri, Thailand	Activity data analysis (600kg/5rai/ 67 days)	1.85	2.25	0.02	0.26	4.38	Seeprom & Phoochinda (2017)
Indonesia	Activity data (cradle-to-gate). Average value of traditional, intensive and super-intensive farms					2.37	(Haditomo *et al.*, 2020)
Bangladesh-Nile tilapia India-Indian major carps Viet Nam-striped catfish	Life cycle assessment (aquaculture LCA model v1.1) intensive system					1.58 1.84 1.37	(Robb *et al.*, 2017)

4. Proposed Sustainable Aquaculture Practices

The results revealed that the use of electricity was the main GHG emission. Thus, if a solar cell can be applied, the GHG emission would also decrease. Solar cells are clean energy so there is no GHG emission. It was reported that the capital cost for installation was 170,000 Baht/2 rai for daytime operation of white leg shrimp culture. The payback period for solar cell application was 11 years and lifetimes were 20-25 years (Lertsatitthankorn *et al.*, 2020). However, a reserve battery is necessary for aeration during nighttime. The cost of solar cell installation is not attractive so intermittent aeration would reduce energy consumption and operational cost. The aeration time might reduce during the daytime because the dissolved oxygen content of the water is gradually increased from the early morning hours by photosynthesis. Moreover, the dissolved oxygen level is higher than the saturation level in the early afternoon (Kepenyes & Váradi, 1984). The pond preparation process was started in March, therefore the daytime length was longer and the intensity of sunlight for the photosynthesis process was very efficient in producing oxygen. Mohanty (2001) mentioned that from the view of economics of the culture operation, the aeration time can be restricted to 9 h/day at 1-15 days, 11 h/day at 16-30 days, 13 h/day at 31-45 days. 15 h/day at 46-60 days of culture stage and at the various stocking densities of the average survival rate of *P. monodon* shrimp was not extremely large. In the pond preparation stage, the temperature of water was 30.3 °C and the dissolved oxygen was 5.84 mg/l. Rahman *et al.* (2020) mentioned that the good quality of dissolved oxygen (DO) amount was 4 or 5 mg/l or higher. Thus, the aeration time can be decreased by 1 h/day during pond preparation stage because the DO level was enough and there were no seeded shrimp in the pond. As for culture stage, there were submerged and surface aerators. The submerged aerators should be operated for 24 hours to avoid adverse conditions at sediment water interface because black tiger shrimp live on the bottom, whereas white leg shrimp feed on the bottom. However, 2 hp and 5 hp surface aerators can be turned off after 3 hours (11 A.M to 2 A.M) as this period has high dissolved oxygen, so the aeration times reduced were from 24 hours/day to 21 hours/day. Tien *et al.* (2019) mentioned that there is a greater need for aerators at night than daytime so the aerators were not turned off at night because daytime has oxygen from photosynthesis but high oxygen consumption for respiration during nighttime. This will reduce electricity use by 9.88% and will also save on cost. However, turning off the surface aerators may result in higher water temperature than when they are operating, and the bottom sediment may be floated as the submerged aerators were turned on. However, dissolved oxygen should be monitored in pond water when the surface aerators were turned off because it may not be applicable for some farms with a long period of shrimp culture (90-120 days), particularly when no submerged aerators are applied. Other indirect activities for reduction of the GHG emissions are planting trees such as mangrove trees in the area and decreasing the uneaten feed. It was reported that *S alba* could absorb carbon dioxide of 57.6 tons CO_2/ha (Putra *et al*., 2019). If there is no uneaten feed in the pond, there will be low organic matter in the pond, consequently low COD in discharged water. In addition, the FCR will decrease. The dissolved oxygen concentration should be monitored to improve management of aeration (Boyd & Mcnevin, 2020). Furthermore, a biofloc technology system would produce higher levels of water quality and shrimp performance, that could reduce GHG emissions from the wastewater discharge of the shrimp farm (Krummenauer *et al*., 2014).

Conclusion

Intensive aquaculture can create job opportunities and develop its related sector, although it has been recognized as one of the GHG emission sources for Agriculture, Forestry and Other Land Use Sector (AFOLU). GHG emissions from pond preparation, culturing and harvesting were 0.432, 3.863 and 0.276 kgCO_2eq/kg, respectively. The highest GHG emission came from the use of electricity at the cultural stage. The electricity used accounted for 92% of the total GHG emissions. Thus, to mitigate the GHG emissions, the use of intermittent aeration and decrease in the number of light bulbs were proposed for farm trials.

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