CARBON MASSFLOW OF PACIFIC WHITE SHRIMP, GIANT FRESHWATER PRAWN AND GIANT PERCH MEAT PRODUCTION FROM FISHERY FARM TO DEVELOP CARBON FOOTPRINTS IN TRANG, SONGKHLA AND PHATTHALUNG PROVINCES, THAILAND

Watcharaporn Tantipanatip

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การถ่ายเทมวลคาร์บอนของการผลิตเนื้อกุ้งขาวแวนนาไม เนื้อกุ้งก้ามกราม และเนื้อปลากะพงขาวจากการทำฟาร์มประมง เพื่อพัฒนาค่าคาร์บอนฟุตพรินท์ในจังหวัดตรัง สงขลา และพัทลุง ประเทศไทย

นางสาววัชราภรณ์ ตันติพนาทิพย์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาชีววิทยาสิ่งแวดล้อม
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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การถ่ายเทมวลคาร์บอนของการผลิตเนื้อกุ้งขาวแวนนาไม (*Penaeus vannamei*) เนื้อกุ้งก้ามกราม (*Macrobrachium rosenbergii*) และเนื้อปลากะพงขาว (*Lates calcarifer*) จากการทำฟาร์มประมงเพื่อพัฒนาค่าคาร์บอนฟุตพรินท์ ได้ทำการศึกษาทางภาคใต้ของประเทศไทยในเขตพื้นที่จังหวัดตรัง พัทลุง และสงขลา ในระหว่างเดือนตุลาคม พ.ศ. 2554 ถึงเดือนกันยายน พ.ศ. 2555 โดยการสำรวจอัตราการถ่ายเทมวลคาร์บอนจากอาหารสัตว์น้ำไปสู่ตัวกุ้งขาวแวนนาไม กุ้งก้ามกราม และปลากะพงขาว รวมทั้งอัตราการปล่อยคาร์บอนจากการใช้พลังงานไฟฟ้า น้ำมันเชื้อเพลิง และแก๊สปิโตรเลียมเหลวในฟาร์มเลี้ยงสัตว์น้ำแต่ละชนิดในการศึกษาครั้งนี้ได้สำรวจและสอบถามข้อมูลประมงจากเกษตรกรเจ้าของฟาร์มเลี้ยงกุ้งขาวแวนนาไมทั้งสิ้น 280 ฟาร์ม และโรงเพาะฟัก 26 ฟาร์ม ฟาร์มเลี้ยงกุ้งก้ามกรามจำนวน 100 ฟาร์ม โรงเพาะฟัก 19 ฟาร์ม และตลาดจำนวน 24 แห่ง ฟาร์มเลี้ยงปลากะพงขาวจำนวน 220 ฟาร์ม โรงเพาะฟัก 21 ฟาร์ม และตลาดจำนวน 20 แห่ง พร้อมทั้งนำตัวอย่างมาวิเคราะห์หาปริมาณการถ่ายเทมวลคาร์บอนทั้งระบบของการผลิตเนื้อสัตว์น้ำ ผลการศึกษาการถ่ายเทมวลคาร์บอนจากอาหารสัตว์น้ำไปสู่ตัวสัตว์น้ำผ่านการกินอาหาร พบว่าอาหารปลากะพงขาวมีปริมาณคาร์บอนสูงกว่าอาหารกุ้งขาวแวนนาไมและอาหารกุ้งก้ามกราม คือ 0.0077±0.0008 0.0076±0.0026 และ 0.0038±0.0028 กก.คาร์บอน/กก.สัตว์น้ำ/วัน ตามลำดับ สำหรับประสิทธิภาพในการตรึงคาร์บอนมาสะสมไว้ในตัวปลากะพงขาวคือ 0.0075±0.0008 กก.คาร์บอน/กก.สัตว์น้ำ/วัน ซึ่งมีค่าเฉลี่ยสูงกว่ากุ้งขาวแวนนาไมและกุ้งก้ามกราม โดยมีค่าเท่ากับ 0.0063±0.0027 และ 0.0032±0.0024 กก.คาร์บอน/กก.สัตว์น้ำ/วัน ตามลำดับ นอกจากนี้ อัตราการปล่อยคาร์บอนจากตัวสัตว์น้ำพบว่ากุ้งขาวแวนนาไมมีการปล่อยคาร์บอนจากตัวกุ้งมากที่สุดคือ 0.0013±0.0004 กก.คาร์บอน/กก.สัตว์น้ำ/วัน รองลงมาคือกุ้งก้ามกรามมีค่าเท่ากับ 0.0006±0.0005 และปลากะพงขาวมีค่าเท่ากับ 0.0002±0.0000 กก. คาร์บอน/กก.สัตว์น้ำ/วัน ในขณะเดียวกัน อัตราการปล่อยคาร์บอนจากการใช้พลังงานในการผลิตเนื้อปลากะพงขาวมีค่าเฉลี่ยสูงสุดเท่ากับ 32.0434±16.6597 กก.คาร์บอน/กก.สัตว์น้ำ/วัน ขณะที่การปล่อยคาร์บอนจากการใช้

พลังงานในการผลิตเนื้อกุ้งก้ามกรามและเนื้อกุ้งขาวแวนนาไม มีค่าเฉลี่ยเท่ากับ 25.2120±12.2669 และ 19.7928±14.3007 กก.คาร์บอน/กก.สัตว์น้ำ/วัน ตามลำดับ ดังนั้น ผลการศึกษาการถ่ายเทมวลคาร์บอนทั้งระบบพบว่ากระบวนการทำฟาร์มเพาะเลี้ยงและการผลิตเนื้อปลากะพงขาวก่อให้เกิดผลกระทบต่อสิ่งแวดล้อมสูงกว่าการทำฟาร์มเพาะเลี้ยงและการผลิตเนื้อกุ้งก้ามกรามและเนื้อกุ้งขาวแวนนาไม นอกจากนี้ พบว่าการปล่อยคาร์บอนจากฟาร์มเลี้ยงสัตว์น้ำสามารถก่อให้เกิดผลกระทบต่อสิ่งแวดล้อมได้ ซึ่งส่วนใหญ่เกิดจากการใช้พลังงานภายในฟาร์มประมงและการใช้พลังงานน้ำมันเชื้อเพลิงสำหรับกระบวนการขนส่ง ผลการศึกษาครั้งนี้จึงสามารถสรุปได้ว่าการผลิตอาหารประเภทเนื้อสัตว์น้ำจากการทำฟาร์มประมงเป็นอีกภาคหนึ่งที่ก่อให้เกิดปัญหาสิ่งแวดล้อมได้

สาขาวิชาชีววิทยา
ปีการศึกษา 2557

ลายมือชื่อนักศึกษา____________
ลายมือชื่ออาจารย์ที่ปรึกษา____________
ลายมือชื่ออาจารย์ที่ปรึกษา____________
ลายมือชื่ออาจารย์ที่ปรึกษา____________

WATCHARAPORN TANTIPANATIP : CARBON MASSFLOW OF PACIFIC WHITE SHRIMP, GIANT FRESHWATER PRAWN AND GIANT PERCH MEAT PRODUCTION FROM FISHERY FARM TO DEVELOP CARBON FOOTPRINTS IN TRANG, SONGKHLA AND PHATTHALUNG PROVINCES, THAILAND. THESIS ADVISOR : ASST. PROF. NATHAWUT THANEE, Ph.D. 195 PP.

CARBON MASSFLOW, PACIFIC WHITE SHRIMP, GIANT FRESHWATER PRAWN, GIANT PERCH, MEAT PRODUCTION, FISHERY FARM

The studies of carbon massflow of Pacific white shrimp (*Penaeus vannamei*), giant freshwater prawn (*Macrobrachium rosenbergii*) and giant perch (*Lates calcarifer*) meat production from fishery farms to develop the carbon footprints were conducted in Trang, Songkhla and Phatthalung provinces, southern Thailand during October, 2011 to September, 2012. The main objectives of this study were to investigate the rate of carbon massflow from aquatic food to aquatic animals, and to study carbon emission from the use of electricity, diesel and liquefied petroleum gas in aquaculture farms. Total 280 shrimps, 100 prawns and 220 fish farm owners, 26 shrimps, 19 prawns and 21 fish hatcheries including 24 prawns and 20 fish markets were surveyed and interviewed. The carbon content, carbon fixation and carbon emission of meat production of studied animals were also analyzed. The results of the assessment of the carbon massflow from aquatic food to aquatic animals by food consumption showed that giant perch received higher carbon from aquatic food than Pacific white shrimp and giant freshwater prawn which were 0.0077±0.0008, 0.0076±0.0026 and 0.0038±0.0028 kg.C/kg.aquatic animal/day, respectively. The carbon fixation in giant perch was 0.0075±0.0008 kg.C/kg.aquatic animal/day, which had higher average carbon fixation than Pacific white shrimp and giant freshwater prawn at 0.0063±0.0027 and 0.0032±0.0024 kg.C/kg.aquatic animal/day, respectively. Furthermore, the results showed that Pacific white shrimp emitted the highest carbon value at 0.0013±0.0004 kg.C/kg.aquatic animal/day, followed by giant freshwater prawn at 0.0006±0.0005 and giant perch at 0.0002±0.0000 kg.C/kg.aquatic animal/day. In the same time, the giant perch meat production had the highest carbon emission from energy consumption compared with giant freshwater prawn and giant perch meat productions at 32.0434±16.6597, 25.2120±12.2669 and 19.7928±14.3007 kg.C/kg.aquatic animal/day, respectively. Therefore, carbon emission from giant perch meat production had higher environmental impacts than from giant freshwater prawn and Pacific white shrimp meat productions. Additionally, the environmental impacts were mainly caused by energy use, farm-level effluents and transportation. Also, it can be concluded that aquatic meat production from aquaculture farming system is an important source of environmental impacts.

School of Biology

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Watcharaporn Tantipanatip

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LIST OF ABBREVIATIONS

C	=	Carbon content
C_{input} or C-input	=	Average carbon content in aquatic food and average of carbon input in form of energy consumption
$C_{fixation}$ or C-fixation	=	Average carbon content which was fixed in aquatic animal body.
$C_{emission}$ or C-emission	=	Average carbon emissions from energy consumption of aquatic meat production
$C_{emitted}$ or C-emitted	=	Average carbon emitted in the form of aquatic animal faeces including CO_2 and CH_4 from faeces, digestion and respiration
C_{output} or C-output	=	Average carbon content was in the form of aquatic animal faeces.
FCR	=	Feed conversion ratio is a measure of the amount of feed eaten per unit of bodyweight gain or carcass weight gain.
GWP	=	Global warming potential
GHG	=	Greenhouse gas
CO_2	=	Carbon dioxide
CH_4	=	Methane
N_2O	=	Nitrous oxide

LIST OF ABBREVIATIONS (Continued)

LPG	=	Liquefied petroleum gas
kWh	=	Kilowatt-hour is a unit of energy equivalent to one kilowatt (1 kW) of power expended for one hour (1 h) of time.
kg	=	Kilogram is the base unit of mass in the International System of Units (SI).
Kcal	=	Kilocalorie
KJ	=	Kilojoule
°C	=	Degree Celsius

CHAPTER I

INTRODUCTION

1.1 General introduction to global warming

The global warming which is caused by the increasing concentrations of greenhouse gases (GHGs) into the atmosphere is a major environment problem. The agricultural and aquacultural activities contribute about 20% of the total GHGs emissions, accounting for 45-50% of methane (CH_4) and 20-70% of nitrous oxide (N_2O) emissions (OECD, 2000), also increased about 31% of the total GHGs emissions in 2007 (IPCC, 2007).

The carbon cycle is an important biogeochemical cycles for human life because carbon is the primary element of living things, both plants and animals. Carbon and oxygen combine chemically to form carbon dioxide gas (CO_2), which is harmful to the respiratory system of humans and animals. The amount of CO_2 is released into the atmosphere by fossil fuel burning and many sources have suggested that there will be a continuing increased of CO_2 in atmospheric. The CO_2 is an important GHGs resulting in the global warming, increasing yearly (Lenntech, 2009) as shown in Figure 1.1.

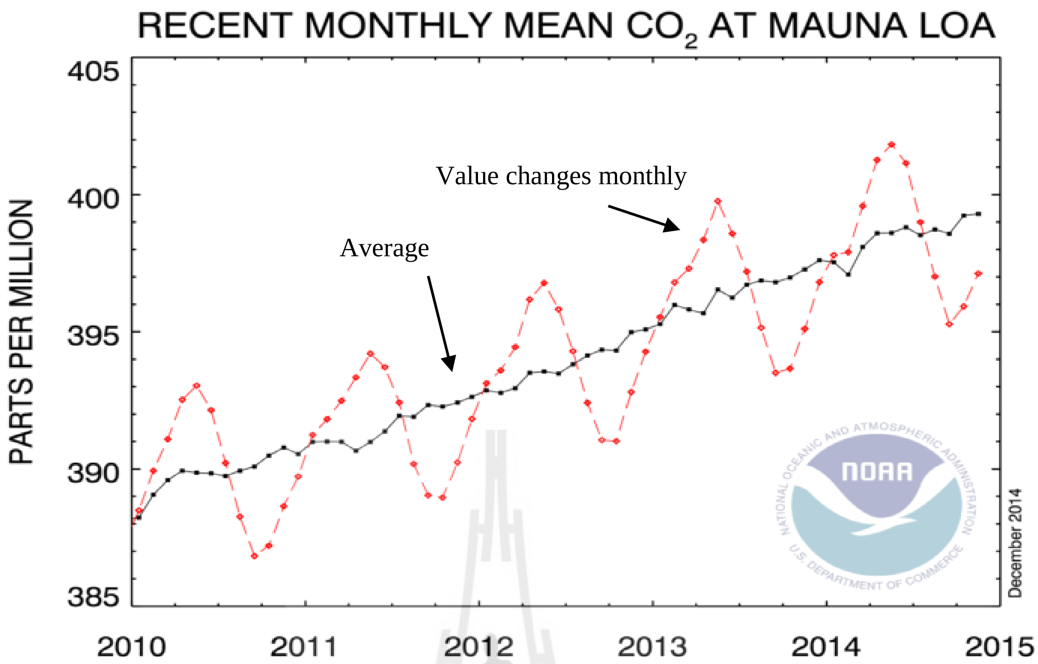


Figure 1.1 The tendency of increase of CO_2 in atmosphere. (Source: NOAA, 2009)

The Intergovernmental Panel on Climate Change (IPCC) in England in 1995 concluded that global climate change has been mainly caused by GHGs, which most of them have been released from human activities. The solutions of these problems are that we have to reduce some activities which cause an increase of the GHGs. The IPCC (1995) predicted that in 2100 the sea level will be raised up about 3 feet higher than the present level and the environment will be changed. The declining of forests, the distribution and increase of the pathogens, air pollution and heat wave occur throughout the world. Agriculture and aquaculture products will be affected by drought, flood and the storm and become increasingly violent. Polar iceberg melting has caused higher sea level, flooding and more extreme weather; result in decreasing areas of land use. The IPCC (2007) was argued that GHGs emissions must be reduced considerably from their present levels in order to avoid climate change of a magnitude that will have serious negative consequences for the society (IPCC, 2007; Stern, 2006).

The increased concentration of CO_2 in the atmosphere has already led to increasing of CO_2 concentrations in the ocean (Kortzinger, Mintrop, and Duinker, 1998; Sabine et al., 2004). The accumulations of CO_2 in the surface water due to the increasing of CO_2 in atmosphere have probably already caused a decrease of almost 0.1 pH units (Haugan and Drange, 1996). The estimates of future atmospheric and oceanic CO_2 concentrations suggest that pH will be decreased about 0.4 pH units in the surface water and that unabated CO_2 emissions may produce pH changes in the ocean over the coming centuries that were greater than experienced in the past 300 million years (Caldeira and Wickett, 2003). Such effects are related to the large changes in seawater chemistry (i.e. pH reductions of ~0.5-1.0 pH units) and may cause mortality for nearby infaunal deep-sea communities (Barry et al., 2004) or affect the growth marine planktons (Kurihara, Shimode, and Shirayama, 2004; Riebesell, 2004).

The aquatic ecosystems have potential processes to fix carbon depending on the types and conditions of the systems, especially in the ability in fixing the carbon into the form of meat products from each species of animal life. Once frozen carbon is fixed in the form of biomass in fish and shrimp meat products, they are converted back into CO_2 due to the process of digestion and respiration. Therefore, the carbon fixation in this issue is to extract carbon from atmospheric to semi-permanent sources in form of fish and shrimp meat from a net carbon accumulation (net carbon production) is equal to the rate of accumulation volume of carbon between the growth stages of aquatic animals. Also, the amount of carbon for the average time (time averaged C stocks) is expressed as a weight measurement of carbon per time (van Noordwijk, Cerri, Woomer, Nugroho, and Bernoux, 1997). The definition of carbon fixation shows that the emission of CO_2 to the atmosphere is mitigated by the carbon fixation in form of fish and shrimp meat products.

1.2 Introduction of aquaculture

Aquaculture is a fast growing sector in the global seafood industry as it offers possibilities to accommodate increasing consumer's demand for seafood products. Seafood is a source of protein of increasing importance in the world. In developing countries, more than half of the human intake of protein comes from seafood. Aquaculture production grew at about 10% per year since 1985. There is a reasonable prediction that per-capita seafood consumption will increase about 1.5 kg per year by 2025. Both population growth and increased individual consumption indicate that seafood products will be gradually more important as an additional food source, and aquaculture will play an important role in that consumption as natural fish and shrimp stocks continue to decline (Diana, 2009; FAO, 2009).

Asia plays the leading role in fishery farming, accounting for almost 80% of world fish and shrimp culture, mainly from China and Thailand. Rapid growth of fish and shrimp farming in Thailand has led to an economic boom in coastal provinces of the eastern and southern regions and stimulated related industries and businesses. The industries associated with fishery farming include such as aquatic feed production, capture and supply of wild broodstock by fishermen, hatchery production of immature of aquatic animal, nursery operations, manufacture and sale of fishery farming equipment, live and pelleted feed processing, cold storage plants, fish and shrimp processing, and exporting companies. Increase of farmed fish and shrimp production is achieved with intensification of farming systems, often characterized by increased material inputs, energy demands, and effluent discharge (Prein, 2007).

The expansion of aquaculture has drawn criticisms on environmental, economic and social sustainability. These criticisms include pressure on natural resources such as water, energy, feed, eutrophication, depletion of biodiversity, conversion of sensitive land, introduction of invasive species, genetic alteration, and disease transmission to wild stocks (Diana, 2009). Therefore, increasing attention to environmental responsibility of fish and shrimp farming underscores the urgent need to understand the environmental footprints from different production systems to better manage them to promote more sustainable aquaculture.

1.3 Life cycle assessment methods to evaluate sustainability

Life cycle assessment (LCA) is a suitable methodology of the environmental assessment of seafood products according to a life-cycle approach by compiling an inventory of relevant inputs and outputs of the product systems. The using of LCA has proved to be suitable when analyzing the performance of food products to identify key environmental issues in support of the development of eco-labeling criteria (Mungkung, Udo de Haes, and Clift, 2006). Furthermore, the carbon footprint for food products is expected to increase due to the relevant contribution of food GHGs emissions to global atmosphere (Garnett, 2008; Garnett, 2009).

The carbon footprint involves the estimate of GHGs emissions associated with a product along its supply chain, even including use, end-of-life recovery and disposal

(EPLCA, 2007). According to Carbon Trust (2008), the term “product carbon footprint” refers to the GHGs emissions of a product across its life cycle, from raw materials through production, distribution, consumer using, disposal and recycling. Major greenhouse gases are CO_2, CH_4 and N_2O, with families of gases including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

Thailand is committed to several international agreements and principles that involve the fisheries and aquaculture industry: the Kyoto Agreement to reduce the emissions of GHGs, the Precautionary Principle to achieve sustainable management of the natural resources, and the UN Regulations concerning ocean fisheries, and requirements on biological diversity (CF-Thailand, 2008).

Food is a vital human need that provides not only essential nutrition but is also a key part of our social life. However, the food production chain from primary production (agriculture and aquaculture) to consumers and beyond, also has caused various environmental impacts since it is a great consumer of both energy and natural resources (Foster et al., 2006; Edwards-Jones et al., 2008). Agriculture and aquaculture have emitted GHGs, making them the second largest GHGs contributing sector after energy (Davis and Sonesson, 2008). A growing demand for food requires the greater use of irrigation and fertilizer for production, which in turn increases the demand for energy. It also induces changes in land use, a process that inevitably leads to CO_2 emissions (Sinden, 2009). Food production and food consumption are consequently of critical importance in the current and future development of GHGs emissions. The current consumption pattern has been motivating an increasing interest to report the environmental performance of food products.

The purposes of this study were to compare the resource and energy consumption of a commercial-sized hatchery, farm and market, using an existing Pacific white shrimp (*Penaeus vannamei*), giant freshwater prawn (*Macrobrachium rosenbergii*) and giant perch (*Lates calcarifer*) facility as a base case. The key parameters used in the analysis include direct and indirect energy use and carbon emissions. Clear documentation of the energy and resource consumption of a wide range of production systems will be useful for policy, planning, and regulation of aquaculture development.

The benefits include direct evaluation of fishery farming systems to advise regulation and environmental impact mitigation measures for policy makers, to guide fish and shrimp farmers toward implementing good aquaculture practices, and to inform consumers in their awareness and choice for more sustainable consumption. Moreover, these results are expected to be useful to undertake future carbon footprint studies of seafood products.

1.4 Research objectives

The objectives of this study were:

1.4.1. To study carbon massflow from aquatic food to the last aquatic consumers through the food chain.

1.4.2. To study carbon emission from energy use in the production of aquatic animals (Pacific white shrimp, giant freshwater prawn and giant perch) in Thailand.

1.4.3. To develop carbon footprint of these aquatic meat products from aquaculture farms in Thailand.

1.4.4. To compare carbon emission among Pacific white shrimp, giant freshwater prawn and giant perch production.

1.5 Scopes and limitation of the study

The study on carbon massflow of fish and shrimp meat production was conducted in Trang, Songkhla and Phatthalung provinces. The samples included hatchery farms, aquaculture farms, markets and aquatic animals such as Pacific white shrimp (*Penaeus vannamei*), giant freshwater prawn (*Macrobrachium rosenbergii*) and giant perch (*Lates calcarifer*). All aquaculture farms were divided according to the size of farm. The samples were collected in 12 months during October, 2011 to September, 2012.

The aquatic animals for each type had to exist in farms. The varieties of animals in the same species were not considered. They were in mature stages for meat collection. This study was emphasized on types and amount of food consumed. All aquatic animals were registered with the Department of Fisheries in each province. Data evaluation and analysis were conducted as the systems are in equilibrium stages using carbon massflow concept. The steps of food production and carbon transfer are shown in Figure 1.2.

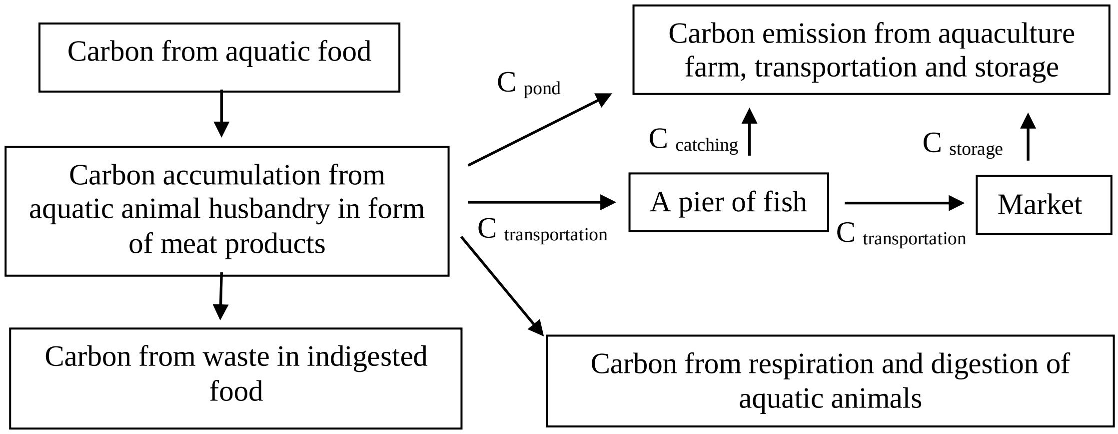


Figure 1.2 The steps of aquatic production and relationship of carbon transfer.

CHAPTER II

LITERATURE REVIEW

2.1 Ecosystems and system relationship

An ecosystem is an interesting system of living organisms and basically an energy-processing and nutrient-regenerating system. It has two major parts, the biotic and the abiotic. The biotic part consists of all interacting organisms living in the area and the community. The abiotic part embraces the physical environment which the organisms of the community interact. The biotic and abiotic exchange energy and materials. Populations are the subsystems through which the system functions. The relationship between biotic and abiotic components leads to the ecosystem equilibrium (Odum, 1971).

2.2 Carbon cycles in ecosystems

The carbon cycle, the carbon massflow between organisms, are occurring of the process photosynthesis, respiration and digestion. In addition, there is the combustion of fuel and decay of limestone, as shown in Figure 2.1 that releases CO_2 into the atmosphere and has caused greenhouse effects around the world (Smith, 1974).

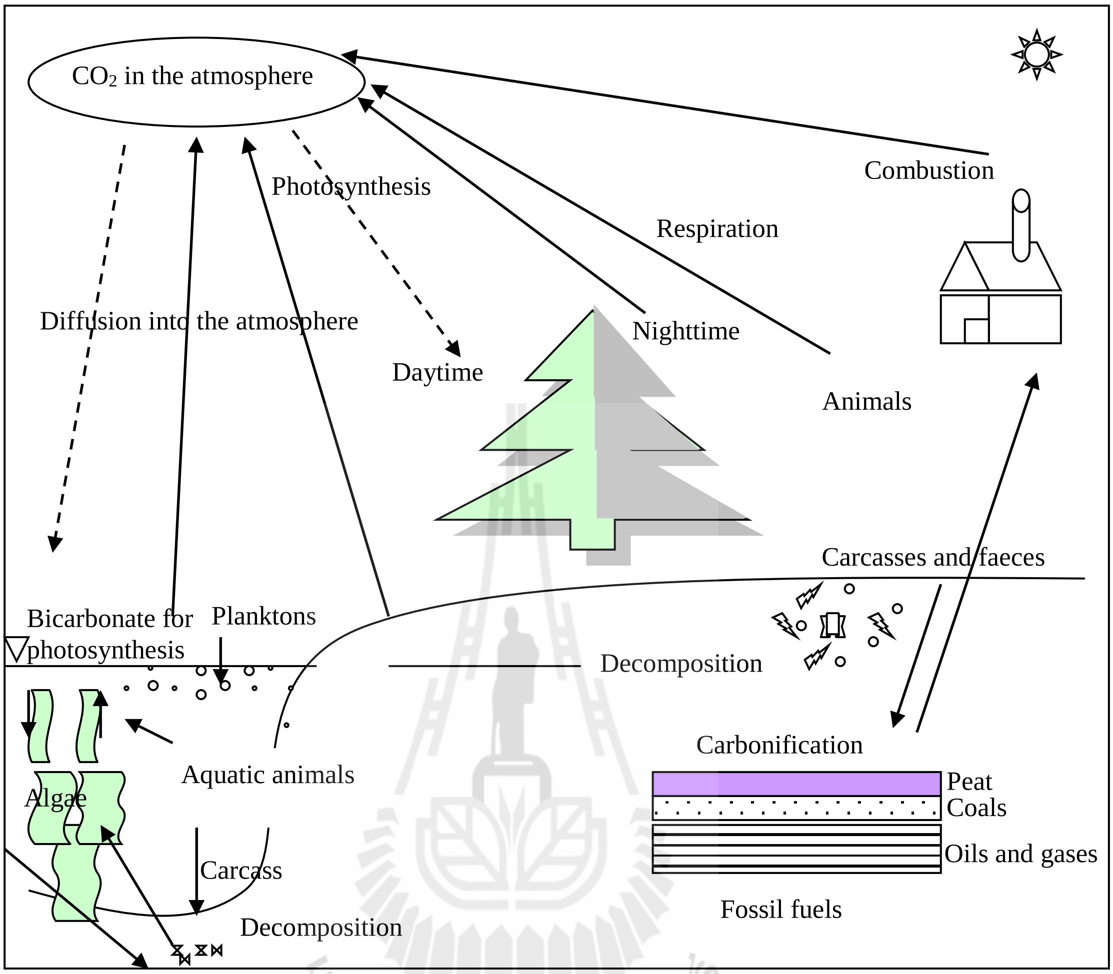


Figure 2.1 The carbon massflow in the ecosystem through the photosynthesis, respiration, decomposition and burning of fuel (Smith, 1974).

The oceans have around 36,000 gigatonnes of carbon, mostly in form of carbonate or bicarbonate ion. The inorganic carbon is important in its reactions within the water. This carbon exchange becomes important in controlling pH in the ocean and can also vary as a source for carbon. The carbon has readily exchanged between the atmosphere and the ocean, which has participate of reactions are locally in equilibrium:

Solution = CO_2 (atmospheric) ⇌ CO_2 (dissolved)

Conversion to carbonic acid = CO_2 (dissolved) + H_2O ⇌ H_2CO_3

First ionization = H_2CO_3 ⇌ H^+ + HCO_3^- (bicarbonate ion)

Second ionization = HCO_3^- ⇌ H^+ + CO_3^{2-} (carbonate ion)

The CO_2 and other atmospheric gases (e.g. nitrogen and the inert gases) are dissolved in surface waters. Dissolved gases are in equilibrium with the gas in the atmosphere. The CO_2 is reacted with water in solution to form the weak acid and carbonic acid. The carbonic acid dissociates are hydrogen ions and bicarbonate ions. The hydrogen ions and water are reacted with most common minerals (silicates and carbonates) altering the minerals. The products of weathering are predominantly clays (a group of silicate minerals) and soluble ions such as calcium, iron, sodium, and potassium. The bicarbonate ions also remain in solution.

In addition, CO_2 has dissolved into water and has concentrations at the different temperatures, as listed in Table 2.1. This information indicates that the amount of CO_2 in water is inversely proportional to water temperature.

The increases of CO_2 and other GHGs in the atmosphere are changing several features of the world’s climate, oceans, coasts, and freshwater ecosystems. These have affected the fishery and aquaculture such as air, sea surface temperatures, rainfall, sea level, acidity of the ocean, wind patterns, and the intensity of tropical cyclones (FAO, 2009).

Table 2.1 The concentrations of dissolved CO_2 in water at various temperatures.

Temperature (ºC)	Dissolved CO_2 (mg/l)
0	1.10
5	0.91
10	0.76
15	0.65
20	0.56
25	0.48
30	0.42

Source: Boyd, 1995.

2.3 Introduction of aquaculture farming

2.3.1 Seafood production and sustainability

Aquaculture is of great importance worldwide, serving as an alternative source to traditional food production systems to help accommodate expansion of the human population. According to the latest Food and Agriculture Organization of the United Nations (FAO) assessment, global aquaculture production has increased by 20 million tons (62%) in less than a decade from 2000 to 2008 (FAO, 2012). In 2008, the global aquatic production had grown to 55 million metric tons. Aquaculture is fastest growing of food production in the world in 1970, which had average compounded growth of 9.2% per annum (FAO, 2009). Most production occurs in Asia, mainly China and Thailand (Fuchs, Martin, and An, 1999).

The fishery farming industry has great economic and social importance. In addition, aquaculture can help to reduce pressure on overexploited wild stocks, in terms of natural resource protection. But aquaculture system has also been criticized for generating negative impacts on the environment, aquatic ecosystems, and human lives in coastal areas (Diana, 2009), due to poor planning and management as well as a lack of appropriate regulations. Fish and shrimp aquaculture itself may have several adverse environmental impacts.

The effluents from fish and shrimp ponds typically enriched in suspended solids, nutrients and biochemical oxygen demand often contribute to eutrophication of receiving waters (Folke, Kautsky, and Troell, 1992; Dierberg and Kiattisimkul, 1996; Paez-Osuna, Guerrero-Galvan, and Ruiz-Fernandez, 1998), deterioration of the benthos (Findlay, Watling, and Mayer, 1995; Paez-Osuna, 2001), introduction of genetic material into compromised conspecific populations (Youngson and Verspoor, 1998; Fleming et al., 2000), the discharge of pharmaceuticals and other chemicals into the environment (Hastein, 1995), and land modification and the depletion of wild stocks through broodstock (Naylor et al., 2000; Mungkung, Udo de Haes, and Clift, 2006). Diseases in farms and hatcheries are caused by the invasion of protozoa, fungi, viruses and bacteria (Folke, Kautsky, and Troell, 1992; Paez-Osuna, 2001; Naylor and Burke, 2005) including competition for land and water with other food production sectors (Costa-Pierce, 2010).

Other environmental impacts of aquaculture have been reported such as salt water intrusion due to active pumping of groundwater into coastal ponds, disposal of sediments from culture ponds with accumulated nutrients and other chemicals. Growing awareness of environmental problems during recent years has led to increasing demand for environmental performance information from different fishery farming systems.

2.3.2 Aquaculture in Thailand

Asians have been farming fish and crustaceans in coastal areas using traditional techniques for at least 3000 years (Stickney, 1979). The intense traditional forms of aquaculture that supported local food production are being replaced by the resource intensive, high intensity systems that cater to international seafood markets (Stonich, Bort, and Ovares, 1997). The fishing activities in Thailand are usually divided into two main blocks: commercial fishing and aquaculture. The commercial fishing comprises coastal, offshore and deep-sea fisheries such as fish, cephalopod, crustacean and the other marine organism landings, whereas aquaculture encompasses two farming subsections are extensive and intensive aquaculture. Fish and shrimp are the most valuable aquatic species currently being produced using high intensity aquaculture techniques and the total value of global fish and shrimp production were approximately $7 billion USD in 2000 (FAO, 2002).

The aquatic farming industry generates significant socio-economic benefits to Thailand. Progressively more intensive aquatic farming systems have been applied to satisfy the increasing global demand as well as to maintain the status of leading aquatic animal producer. To support the intensive farming systems, hatching and nursing of immature from marine broodstock at hatcheries have been developed to support higher stocking density. Production of feed with high protein content has also been carried out to promote the aquatic animal's growth. Aeration systems have additionally been introduced to facilitate higher oxygen transfer for supporting higher density of stocking in intensive farming systems.

Shrimp farming has grown from traditional, small-scale businesses in Southeast Asia into the global industry. The technological advances have led to growing shrimp at ever higher densities. Broodstock is shipped worldwide. Virtually all shrimp farms are penaeids and just two species of shrimp are *Penaeus vannamei* (Pacific white shrimp or vannamei white shrimp) and *Penaeus monodon* (giant tiger prawn) account for 80% of all shrimp farms. These industrial monocultures are very susceptible to diseases, which have caused several regional wipe-outs of shrimp populations. The increasing ecological problems are repeated disease outbreaks and criticism from both NGOs and consumer countries led to changes in the industry in 1990s and generally stronger regulation by the governments (Stonich, Bort, and Ovares, 1997).

The boom of Thai shrimp farming has been triggered by growing demand mainly from international markets in USA, EU and Japan. Increase of export-oriented shrimp production is achieved with intensification of farming systems by large commercial companies, which have greater farm size, material inputs, energy demands, and effluent discharge (Prein, 2007). Nevertheless, the environmental implications of intensive shrimp farming systems have raised serious concerns about the sustainability of the current farming practices. The environmental performance of shrimp production is increasingly becoming a commercial concern due mainly to the consumer demand for environmentally-friendly products. At the same time, ability to compete in international markets is essential for Thailand to remain as one of the major world shrimp exporter.

2.4 Technology development in aquaculture farm

Traditional aquaculture can be classified by stocking density, feeding management and capital investment; whereof the aquacultural farming in Thailand has been developed gradually. The pattern of practice and management can be explained as follows (FAO, 2006; Mungkung, Udo de Haes, and Clift, 2006):

2.4.1 Extensive farming

This is the original aquatic culture system of aquaculture farming in the Inner Gulf area of Thailand. Farm practices were based on natural seed supply, the conversion of rice fields with the construction of high dikes around it and the installation of a sluice gate to receive seawater containing aquatic seed, nutrients and retain them in pond.

2.4.2 Semi-intensive farming

In this system, farm management is improved and hatchery seed is used. The dimensions of fishery farms change with semi-intensive systems; the area is reduced to 20-30 rais, often equipped with water storage. The seawater is drained into the ponds by a pushing pump, which handles the higher quantity of seawater more easily. In addition, feed is applied so that the yield of aquatic increases to 60-100 kg/rai in 4 month period.

2.4.3 Intensive farming

The development of intensive culture was made possible by large scale production of seed by the Department of Fisheries and the private sector. The large, shallow semi-intensive ponds were converted to 1-5 rais in area, water depths were increased to 2-2.5 m and stocking rates were up to 50-100 pieces/sq.m. In intensive farms, heavy feeding rates are applied and after 100 days of culture the pond bottom is to form anaerobic conditions, with low dissolved oxygen levels and high concentrations of toxic gases such as hydrogen sulfide, ammonia, nitrite and carbon dioxide. In intensive systems, the chemical condition of the water and dissolved gases may be a serious threat to aquatic animal health. Dissolved oxygen levels in the water column have to be kept at over 5 ppm and dissolved oxygen is supplied by paddle wheel or air jet machine. Water is also exchanged at a rate of 10% fresh seawater per day.

2.4.4 Super-intensive farming

Super-intensive farming takes even greater control of the environment and can produce yields of 20,000-100,000 kilograms per hectare per year. Thailand has some super-intensive fishery farms. A super-intensive farm in the United States once produced at the rate of 100,000 kilograms per hectare per year, one of the most advanced shrimp farms in the world using super-intensive production techniques. Since production costs per kilogram are low, these systems have sparked considerable interest and probably represent the future of aquatic farming.

Extensive systems with lowest unit production have been replaced by semi-intensive and intensive systems. Aquaculture mostly takes place in both semi-intensive and intensive systems in developing countries, while it remains intensive in developed countries (Diana, 2009). Semi-intensive is considered a way of remedying environmental problems associated with intensive farming systems.

2.5 Factors affecting aquatic animal production

2.5.1 Food

As farms evolve from low to high stocking densities, the quality of food becomes very important. The most of extensive farms do not have food at all; aquatic food on naturally occurring food organisms in the pond. Other extensive farms use a small amount of food and fertilizer to stimulate a natural food chain. On semi-intensive farms, most of the food is consumed by aquatic animals and less is available to serve as a stimulant to the natural food web. Therefore, the quality of food is more important because the aquatic animals get most of their nutrition from it. On super-intensive farms, where bacterial flocks develop, the aquatic animal graze on the flocks, also the protein levels in the foods can be reduced.

Food can represent over 50% of the production costs on aquaculture farms and make a mighty contribution to the sludge on the bottom in the pond such as shrimp's habit of slowly nibbling food particles causes substantial nutrient losses even if the pellets of good quality. Within an hour, shrimp food can lose more than 20% of its crude protein, about 50% of its carbohydrates and 85-95% of its vitamin content. As much as 77% of the nitrogen and 86% of the phosphorus compounds in shrimp food are wasted. The waste either accumulates on the pond bottom or discharged into the environment. Instead of increasing pellet stability beyond a couple of hours, foods should include attractants so they are consumed within 20 or 30 minutes.

In general, shrimp farming usually has a high feed conversion ratio (FCR = feed fed/shrimp weigh gain), which means 2 kg of feed is consumed to produce 1 kg of shrimp. Further growth of shrimp farming with high FCR requires more fishmeal and hence more marine caught fish, which could cause even higher biodiversity loss. Furthermore, food is a major contributor to the emissions and the result also depends on whether the food is dried with diesel oil or natural gas/LNG. Natural gas is becoming more commonly used and a transition to natural gas reduces the CO_2 emissions about 20%, the NO_x emissions by 80-90%, and the sulphur emissions completely compared to heavy oil. The use of natural gas will be leaded to a reduction in CO_2 equivalents about 6-7% (Mungkung, Udo de Haes, and Clift, 2006).

2.5.2 Farm size

The scale of production, processing and distribution systems may also be relevant in assessing the energetic efficiencies of seafood production technologies. The relationship of farm size to productivity has long been debated, with conflicting reports of comparative energy efficiency in small versus large farms. Farm size may affect energy use in contradictory ways, depending on whether farms are in developing or industrialized countries (Kiers et al., 2008; Woodhouse, 2010). In industrialized contexts, most farmers rely on mechanization, and larger farms may be able to utilize their equipment more fully (Shahin, Jafari, Mobli, Rafiee, and Karimi, 2008), thereby increasing fuel efficiency per unit output.

Apart from farm size, the energy productivity on farms is highly sensitive to climate, water availability, soil type, and management practices. Foods produced on regional farms close to the consumer may be less energy efficient than the same foods produced in a more conducive region elsewhere.

2.5.3 Transportation

The fisheries and aquaculture are making a minor but significant contribution to GHGs emissions during fishing operations, transportation, processing, and storage of aquatic products.

The average of fuel used to CO_2 emissions for capture fisheries is estimated about 3 teragrams of CO_2 per million tonnes of fuel used. Cochrane concluded that good fisheries management can substantially improve fuel efficiency for the sector (Pelletier et al., 2009). Overcapacity and excess fishing capacity mean fewer fish caught per vessel that is lower fuel efficiency.

2.6 The study of life cycle assessment (LCA) in aquaculture activity

2.6.1 Overview of LCA methodology

LCA provides a standardized methodology to quantify and evaluate the environmental impact of products with regard to a number of environmental impact categories (ISO, 2006a; 2006b). A typical LCA includes the major stages of a products life including raw material extraction, manufacturing, use and end-of-life.

The fisheries and aquaculture activities have GHGs emission during production operations, transportation, processing and storage of aquatic animal production. There are significant differences in the emissions associated with the sub-sectors and the species targeted or cultured. The primary mitigation route for energy consumption, through fuel and raw material use, management of distribution, packaging, and other supply chain components will be contributed to decreasing the sector carbon footprint. Furthermore, the international studies show that several fishery activities have an energy consumption that is far from sustainable. The emissions of GHGs along the food chain from hatchery to the consumers are further analyzed to find the dominating sources.

Aquaculture ponds are contributed to carbon emissions through management inputs to produce aquatic animals (Boyd, Tucker, McNevin, Bostick, and Clay, 2007). The carbon sequestration capacity of aquaculture ponds could be used as carbon reduction credits against carbon emissions from aquaculture production. The net carbon sequestration (carbon emissions sequestration) by aquaculture operations could be traded as carbon credits.

2.6.2 Assessing sustainability of aquaculture using LCA

Environmental, economic and social issues have created much concern over how to produce aquatic animals in a more environmentally benign, economically profitable and socially acceptable manner. Planning for more sustainable and profitable fish and shrimp aquaculture requires qualitative or quantitative examinations of different alternatives in terms of their environmental impacts, economic benefits and social influence. As a result, there is increasing demand for environmental information regarding seafood products.

There are many methods proposed for examining sustainability and efficiency of food production systems, including LCA, nutrient dynamic modeling and socio-economic analysis (Bartley, Brugere, Soto, Gerber, and Harvey, 2007). LCA has been proven suitable for quantifying a subset of the environmental impacts associated with fisheries and aquaculture production (Pelletier et al., 2007; Diana, 2009).

Thus, LCA can be used to quantify potential environmental burdens throughout the life cycle of fish and shrimp production. It can be used to calculate the energy and material usage in an overall process. LCA can also provide a framework for evaluating environmental performance and identifying the major processes in energy use, as well as global warming, acidification and eutrophication impacts.

2.6.3 LCA applications in aquaculture products

LCA has studies on seafood provides multiple indicators regarding the environmental performance of this type of products (Ziegler, Nilsson, Mattsson, and

Walther, 2003; Hospido and Tyedmers, 2005; Thrane, 2006; Ellingsen and Aanondsen, 2006; Pelletier and Tyedmers, 2007; Ziegler and Valentinsson, 2008; Aubin, Papatryphon, van der Werf, and Chatzifotis, 2009; Ayer and Tyedmers, 2009; Pelletier and Tyedmers, 2010). Nevertheless, LCA is a less developed and standardized tool for assessing local ecological and socio-economic impacts. Those impacts could be described quantitatively on the functional unit basis or qualitatively (Pelletier et al., 2007).

The global warming impact category is among the most common categories assessed. However, the current trends in the communication of the climate change indicate the convenience of using LCA standards alone to perform the calculation of product carbon footprints (SETAC, 2008). Process LCA are sums the impacts of each activity directly or indirectly involved in the production, transportation, storage, retail, consumption and disposal of products. For example, the industrially fish and shrimp meat produced, these activities might include the production and application of aquaculture chemicals for feed, transportation of feed to farm, energy use in farming systems, transportation, catching, and refrigeration.

Papatryphon, Petit, Kaushik, and Van der Werf (2004) assessed the environmental impacts associated with the different feed for rainbow trout production in France by LCA. The functional unit was the amount of feed required for the production of one metric ton of rainbow trout. To allow comparison on an equivalent basis, the four analyzed feeds were considered in term of a normalized nutrient profile (40% crude protein, 26% fat, 19.5 kJ/g digestible energy). The assessment revealed that use of fishery resources and nutrient emissions at the farm contributed most to the potential environmental impacts of salmonid aquafeeds. Improvements in feed composition and management practices seem to be the best ways to improve the environmental profile of aquafeeds.

Mungkung, Udo de Haes, and Clift (2006) conducted an environmental LCA of the shrimp farming in Thailand, which included hatchery, farming, processing, distribution, consumption, and waste management phases. The functional unit was a standard consumer-package size containing 3 kg of block-frozen shrimp. The system used wild-capture broodstock in the hatchery. The impacts assessed were abiotic depletion potential, global warming potential, ozone depletion potential, human toxicity potential, freshwater toxicity potential, marine toxicity potential, terrestrial toxicity potential, acidification potential, photochemical oxidant creation potential, and eutrophication potential. The main impacts of shrimp culture were marine toxicity, global warming, abiotic depletion and eutrophication. The fishery farming was the key life cycle stage contributing to the impacts. Those impacts arose mainly from the using of energy, shrimp feed and burnt lime. The transport of post-larvae from a non-local source to farms also resulted in significantly higher impacts.

Application of LCA to Finnish cultivated rainbow trout production was conducted by Gronroos, Seppala, Silvenius, and Makinen (2006). The analyzed processes include raw material production for feed, feed manufacturing, packaging materials production, package manufacturing, hatchery, fish farming, and slaughtering. Environmental impact categories included climate change, acidification, aquatic eutrophication, and depletion of fossil fuels. The environmental performance of production methods with different feeds, feed coefficients, and pollution reduction measures were assessed. The results revealed that atmospheric emissions (originating mainly from raw material production, manufacturing and transportation of feed) made only a minor contribution to the total environmental impacts caused by production of rainbow trout in Finland.

Ziegler and Valentinsson (2008) used LCA to evaluate the overall resource use and environmental impacts caused by production of Norway lobster (*Nephrops norvegicus*) with creeling and conventional trawling. The inventory covered the entire chain, starting with the production of supply materials and the fishery itself, through seafood auctioning, wholesaling, retailing, and to the consumer. The functional unit was 300 g of edible meat, corresponding to 1kg of whole, boiled Norway lobsters.

The total energy use by Alabama catfish aquaculture estimated for pond construction and delivery of offal from the processing plant was 15.47 MJ/kg.foodsize fish harvested, while CO_2 emissions resulting from energy use was 1.459 kg.CO_2/kg.foodsize fish harvested. Farm operations accounted for about 40% of energy used and nearly 50% of CO_2 emissions associated with Alabama catfish aquaculture. Carbon sequestration by sediments in ponds averaged 0.944 kg.CO_2/kg.fish (Boyd, Polioudakis, and Viriyatum, 2010).

The LCA was applied to evaluate the environmental performance for intensive and semi-intensive shrimp farming systems in Hainan province, China. The environmental impact categories included global warming, acidification, eutrophication, cumulative energy use, and biotic resource use. The results indicated that intensive farming had significantly higher environmental impacts per unit production than semi-intensive farming in all impact categories. These impacts were mainly caused by feed production, electricity use, and farm-level effluents. By averaging over intensive (15%) and semi-intensive (85%) farming systems, 1 metric ton (t) live-weight of shrimp production in China required 38.3±4.3 GJ of energy and 3.1±0.4 t of CO_2.eq. In 2008, the estimated total electricity consumption was 1.1 billion kWh, the energy consumption was 49 million GJ, and greenhouse gas emissions from Chinese white leg shrimp production about 4 million metric tons (Ling, James, Gregory, and Qiuming, 2011).

At the same time, the Carbon Trust (2008) has started developing a carbon labeling approach for products in cooperation with various stakeholder groups and put efforts into the development of a standard methodology for the estimation of the carbon footprints of goods and services in Thailand (Sinden, 2009).

2.6.4 Using LCA for certification and eco-labeling

There is an increased focus on environmental impacts from food production among consumer organizations, retailers, non-governmental organizations (NGOs) and authorities. In particular, climate change and GHGs are the agenda, including to CO_2 accounting for various foodstuffs such as seafood. According to the agenda, the Dutch groceries sold only Marine Steward - ship Council (MSC) - certified seafood in 2011. In Norway, World Wildlife Fund (WWF) launched a campaign on February in 2008 about sustainable seafood, and the Norwegian Ministry of Children and Equality are considering a possible system for climate labeling of food. The Wal-Mart, the world's biggest supermarket retailer, decided in 2006 to purchase only sustainable seafood. The German Metro Group, number three world food retailer, cooperated with the WWF in order to buy sustainable seafood.

Demand for eco-labeled seafood products has increased rapidly in many developed countries. In developing countries, conditions often differ regarding availability of the necessary data, and therefore many seafood producers feel that demand for eco-labels is a trade barrier that stops them from exporting their products.

Seafood generally has carbon footprint, although this depends very much on how the fish is caught as LCA suggests that 75-90% of energy use is related to harvesting. For example, per tonne of deep-sea fish including important commercial species such as cod has fuel use for ships that can vary between 230-2,724 l. For pelagic species including herring and mackerel, those values are lower at 19-159 l/t. The highest fuel use is entailed in shrimp fisheries, with per-tonne fuel use varying between 331-2,342 l (Tyedmers, 2002). These values affect emissions per calorie of food, which vary between 0.085 kg.CO_2.eq/1000 kcal for mackerel and 109 kg.CO_2.eq/1000 kcal for lobster (LCA Food, 2003). The average ton of Atlantic herring landed in 2000 had the combustion of approximately 90 l/t of diesel and resulted in the GHG emissions of approximately 280 kg.CO_2.eq/Mt. The electricity generation to store frozen Atlantic herring and transportation from Nova Scotia to Maine would yield total of about 7.5 million kilograms CO_2.eq.

The carbon footprint is estimated for tuna fishing at the retail level in Manila about 0.80-0.90 kg per kg of fish. The increasing of carbon emission is incurred during handling, storage and transport of the fishery. By comparison, the estimates of the carbon footprints of each kg of other protein sources and staple foods are 1.43-1.75 kg for beef, 1.27-1.35 kg for pork, 1.42 kg for poultry and 0.23 kg for rice. It should be noted that footprint values do not reflect the additional equivalent climate change impacts of the sizeable CO_2 emissions generated in the production of these other food sources.

Estimation of the carbon footprint of tuna catching by using purse seine gear is based on fuel usage data. Hospido and Tyedmers (2005) reported that the average fuel consumption of 0.44 l/kg for nine Spanish vessels targeting Skipjack and Yellowfin tuna. The average of diesel fuel consumption was 0.37 l/kg in the Indian Ocean, 0.44 l/kg in the Atlantic and 0.53 l/kg in the Pacific.

The emission factor for electricity was calculated of 0.5 kg.CO_2/kWh using the GREET model (Wang, 1999). For the process heat, the factor of 0.086 kg.CO_2/MJ using either diesel or fuel; on-site electricity production using a diesel generator is assumed to give a carbon footprint of 0.8 kg.CO_2/kWh. Based on these assumptions, the partial carbon footprint is estimated at 0.63-1.38 kg.CO_2 per kg of product.

2.7 The carbon massflow concept

The Office of Natural Resources and Environmental Policy and Planning (1994) stated the calculation for the amount of GHGs emission as follow:

$$\text{GHGs emission} = CO_2 \text{ from energy consumption} + CO_2 \text{ from destroyed forest} + CH_4 \text{ from rice plantation} + CH_4 \text{ from fishery} \quad (2.1)$$

and then ton-carbon unit is changed to ton-CO_2 through multiplying by 3.667 (3.667 is the ratio of the CO_2 molecular mass divided by the carbon molecular mass.)

Amount of CH_4 emission from fishery (ton equivalent to CO_2)

= CH_4 emission of each aquatic animal species × number of fishery (2.2)

and then ton-methane is changed to ton-CO_2 through multiplying by 21 (21 is the ratio of the global warming potential (GWP) of CH_4.)

Ministry of Science, Technology and Environment (MoSTE) (2000) reported the GHGs emissions of Thailand in 1994 as shown in Table 2.2.

Table 2.2 The greenhouse gases emission of Thailand in 1994.

Gases	Volume of gas emissions (tons)	GWP	CO_2 equivalent (tons)	Percent (%)
CO_2	202,458.05	1	202,458	70.69
CH_4	3,171.35	21	66,598	23.25
N_2O	55.86	310	17,317	6.06
Total			286,373	100.00

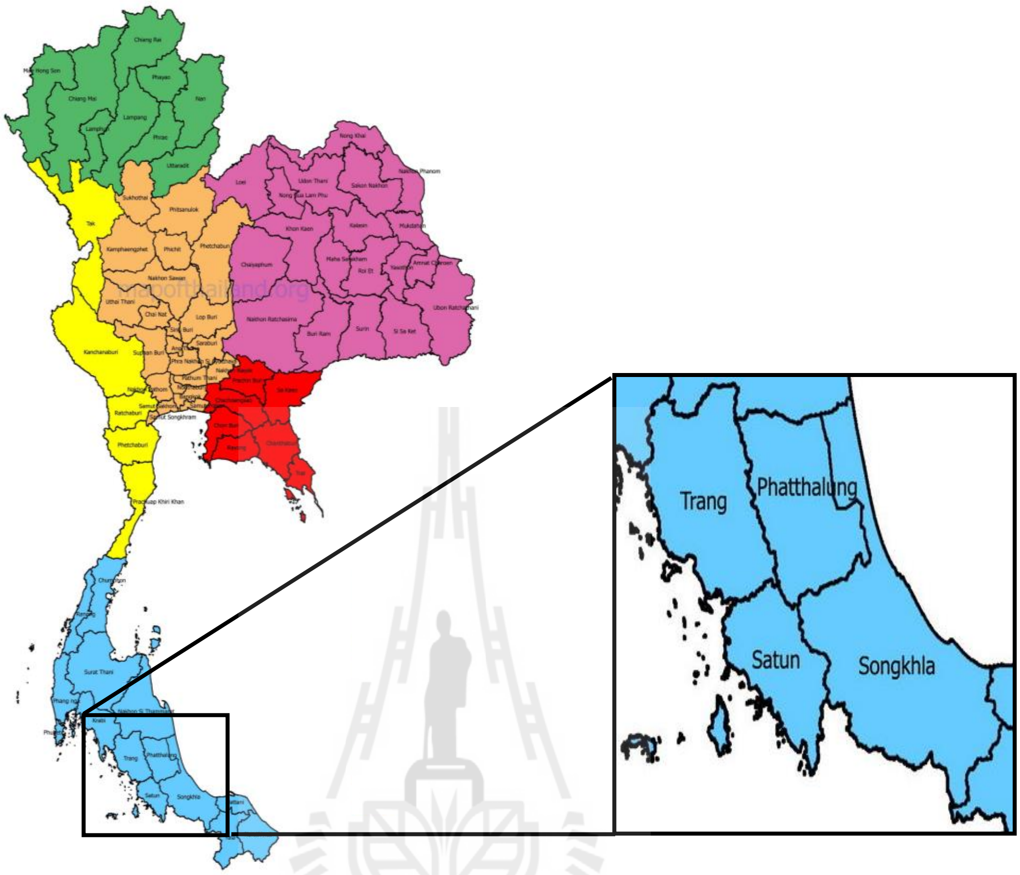
Note: GWP = Global Warming Potential (MoSTE, 2000).

CHAPTER III

MATERIALS AND METHODS

3.1 Selected areas

The study on carbon massflow of aquatic meat production to develop the carbon emission coefficient from aquaculture farms had been conducted in southern part of Thailand. Trang, Songkhla and Phatthalung provinces were the selected areas of this study which represent aquatic meat production in Thailand based on the data of Department of Fisheries (2005) as shown in Figure 3.1. These provinces have large areas and provide many aquaculture farms and aquatic production (Department of Fisheries, 2010).



(a) (b)

Figure 3.1 The study sites. (Source: Map of Thailand, 2010)

3.2 The number of samples

The samples were hatcheries, aquaculture farms, markets and aquatic animals such as Pacific white shrimp (*Penaeus vannamei*), giant freshwater prawn (*Macrobrachium rosenbergii*) and giant perch (*Lates calcarifer*) which were collected during October, 2011 to September, 2012 to investigate the rate of carbon massflow in Trang, Songkhla and Phatthalung provinces. Therefore, the sample size was calculated of approximately average population size at error not exceeding 5% (APHA, AWWA, WEF, 1992) by using the determination of the random sample size of Krejcie and Morgan (1970) to calculate the number of samples in this study as shown in Table 3.1.

Table 3.1 Determination of the random sample size of Krejcie and Morgan (1970).

N	S	N	S	N	S
10	10	95	32	260	155
15	14	100	80	270	159
20	19	110	86	280	162
25	24	120	92	290	165
30	28	130	97	300	169
35	32	140	103	320	175
40	36	150	108	340	181
45	40	160	113	360	186
50	44	170	118	380	181
55	48	180	123	400	196
60	52	190	127	420	201
65	56	200	132	440	205
70	10	210	136	460	210
75	14	220	140	480	214
80	19	230	144	500	217
85	24	240	148	550	225
90	28	250	152	600	234

Note: N is total of population size.

S is sample size.

Table 3.1 Determination of the random sample size of Krejcie and Morgan (1970) (Continued).

N	S	N	S	N	S
650	242	1600	310	5000	357
700	248	1700	313	6000	361
750	256	1800	317	7000	364
800	260	1900	320	8000	367
850	265	2000	322	9000	368
900	269	2200	327	10000	373
950	274	2400	331	15000	375
1000	278	2600	335	20000	377
1100	285	2800	338	30000	379
1200	291	3000	341	40000	380
1300	297	3500	246	50000	381
1400	302	4000	351	75000	382
1500	306	4500	351	100000	384

Note: N is total of population size.
S is sample size.

Moreover, the formula of Yamane (1973) was used to calculate the number of samples in this study as follow:

$$n = \frac{N}{1 + Ne^2} \tag{3.1}$$

Where:

n = Sample size

N = Population size

e = The error of sampling (0.05)

These calculated samples of the number of hatcheries, aquaculture farms, markets and aquatic animals in each province are shown in Tables 3.2 - 3.13, respectively (Modified from Thanee, Dankittikul, and Keeratiurai, 2009a, 2009b, 2009c).

Table 3.2 The calculated samples of the number of aquaculture farm, hatchery and market for Pacific white shrimp (*Penaeus vannamei*).

Province	The size of farm						Hatchery		Market	Animal	
	<5 rais and feed		5 - 10 rais and feed		>10 rais and feed						
	N	S	N	S	N	S	N	S	S	N	S
Trang	395	106	156	42	19	5	9	9	-	159,384,000	219
Phatthalung	41	11	19	5	-	-	-	-	-	55,314,000	23
Songkhla	219	59	182	49	12	3	18	17	-	69,453,960	158
Total	**655**	**176**	**357**	**96**	**31**	**8**	**27**	**26**	**-**	**284,151,960**	**400**

Source: Department of Fisheries, 2010

Note: N is total of population size.

S is sample size.

Rai is equivalent to 0.0016 square kilometer (km^2).

Table 3.3 The calculated samples of the number of aquaculture farm, hatchery and market for giant freshwater prawn (*Macrobrachium rosenbergii*).

Province	The size of farm						Hatchery		Market		Animal	
	<1 rais and feed		1 - 5 rais and feed		>5 rais and feed							
	N	S	N	S	N	S	N	S	N	S	N	S
Trang	7	4	5	4	-	-	3	3	5	5	36,188	29
Phatthalung	17	14	23	16	3	2	9	8	6	6	255,683	112
Songkhla	38	28	35	26	8	6	9	8	13	13	715,718	190
Total	**62**	**46**	**63**	**46**	**11**	**8**	**21**	**19**	**24**	**24**	**1,007,588**	**331**

Source: Department of Fisheries, 2010

Note: N is total of population size.

S is sample size.

Table 3.4 The calculated samples of the number of aquaculture farm, hatchery and market for giant perch (*Lates calcarifer*).

Province	The size of farm						Hatchery		Market		Animal	
	<1 rais and feed		1 - 5 rais and feed		>5 rais and feed							
	N	S	N	S	N	S	N	S	N	S	N	S
Trang	36	15	28	12	-	-	6	6	5	5	37,303	53
Phatthalung	43	18	-	-	-	-	5	5	5	5	23,501	35
Songkhla	196	83	194	82	24	10	11	10	11	10	371,842	312
Total	**275**	**116**	**222**	**94**	**24**	**10**	**22**	**21**	**21**	**20**	**432,646**	**400**

Source: Department of Fisheries, 2010

Note: N is total of population size.

S is sample size.

Table 3.5 The number of aquaculture farm and Pacific white shrimp (*Penaeus vannamei*) in Trang province.

Amphoe	The size of farm											
	<5 rais and feed				5 - 10 rais and feed				>10 rais and feed			
	Aquatic animal		Farm		Aquatic animal		Farm		Aquatic animal		Farm	
	N	S	N	S	N	S	N	S	N	S	N	S
Kantang	30,544,000	42	144	38	22,840,000	31	48	13	3,140,000	5	9	2
Sikao	24,960,000	35	82	22	19,020,000	26	30	8	-	-	2	1
Wang Wiset	9,140,000	12	36	10	-	-	10	3	-	-	-	-
Yan Ta Khao	6,260,000	9	27	7	1,440,000	2	27	7	-	-	-	-
Palian	10,980,000	15	66	18	9,620,000	13	22	6	-	-	-	-
Hat Samran	12,120,000	16	40	11	7,600,000	11	19	5	1,720,000	2	8	2
Total	**94,004,000**	**129**	**395**	**106**	**60,520,000**	**83**	**156**	**42**	**4,860,000**	**7**	**19**	**5**

Note: N is total of population size.

S is sample size.

Table 3.6 The number of aquaculture farm and Pacific white shrimp (*Penaeus vannamei*) in Phatthalung province.

Amphoe	The size of farm											
	<5 rais and feed				5 - 10 rais and feed				>10 rais and feed			
	Aquatic animal		Farm		Aquatic animal		Farm		Aquatic animal		Farm	
	N	S	N	S	N	S	N	S	N	S	N	S
Pak Phayun	16,800,000	7	28	7	26,800,000	11	13	3	-	-	-	-
Pa Bon	5,834,000	2	13	4	5,880,000	3	6	2	-	-	-	-
Total	**22,634,000**	**9**	**41**	**11**	**32,680,000**	**14**	**19**	**5**	**-**	**-**	**-**	**-**

Note: N is total of population size.

S is sample size.

Table 3.7 The number of aquaculture farm and Pacific white shrimp (*Penaeus vannamei*) in Songkhla province.

Amphoe	The size of farm											
	<5 rais and feed				5 - 10 rais and feed				>10 rais and feed			
	Aquatic animal		Farm		Aquatic animal		Farm		Aquatic animal		Farm	
	N	S	N	S	N	S	N	S	N	S	N	S
Mueang Songkhla	968,000	2	13	3	960,000	2	6	2	-	-	-	-
Khuan Niang	1,936,000	4	22	6	2,170,000	5	14	4	-	-	-	-
Sathing Phra	7,006,000	16	42	11	5,784,000	13	32	8	1,000,000	2	4	1
Singhanakhon	4,474,000	10	36	10	3,724,000	8	38	10	-	-	-	-
Krasae Sin	2,441,500	6	32	8	3,514,000	8	34	9	204,000	1	3	1
Ranot	13,069,580	30	74	21	17,376,640	40	58	16	4,826,240	11	5	1
Total	**29,895,080**	**68**	**219**	**59**	**33,528,640**	**76**	**182**	**49**	**6,030,240**	**14**	**12**	**3**

Note: N is total of population size.

S is sample size.

Table 3.8 The number of aquaculture farm and giant freshwater prawn (*Macrobrachium rosenbergii*) in Trang province.

Amphoe	The size of farm											
	<1 rais and feed				1 - 5 rais and feed				>5 rais and feed			
	Aquatic animal		Farm		Aquatic animal		Farm		Aquatic animal		Farm	
	N	S	N	S	N	S	N	S	N	S	N	S
Kantang	7,125	6	3	2	-	-	-	-	-	-	-	-
Mueang Trang	7,088	6	2	1	3,375	3	1	1	-	-	-	-
Palian	6,075	4	2	1	-	-	-	-	-	-	-	-
Ratsada	-	-	-	-	12,525	10	4	3	-	-	-	-
Total	**20,288**	**16**	**7**	**4**	**15,900**	**13**	**5**	**4**	**-**	**-**	**-**	**-**

Note: N is total of population size.

S is sample size.

Table 3.9 The number of aquaculture farm and giant freshwater prawn (*Macrobrachium rosenbergii*) in Phatthalung province.

Amphoe	The size of farm											
	<1 rais and feed				1 - 5 rais and feed				>5 rais and feed			
	Aquatic animal		Farm		Aquatic animal		Farm		Aquatic animal		Farm	
	N	S	N	S	N	S	N	S	N	S	N	S
Pak Phayun	16,035	7	13	10	14,325	6	14	10	5,325	3	3	2
Bang Kaeo	-	-	-	-	48,113	21	2	1	-	-	-	-
Khao Chaison	4,763	2	2	2	78,600	34	4	3	-	-	-	-
Khuan Khanun	5,213	2	2	2	83,310	37	3	2	-	-	-	-
Total	**26,010**	**11**	**17**	**14**	**224,348**	**98**	**23**	**16**	**5,325**	**3**	**3**	**2**

Note: N is total of population size.
S is sample size.

Table 3.10 The number of aquaculture farm and giant freshwater prawn (*Macrobrachium rosenbergii*) in Songkhla province.

Amphoe	The size of farm											
	<1 rais and feed				1 - 5 rais and feed				>5 rais and feed			
	Aquatic animal		Farm		Aquatic animal		Farm		Aquatic animal		Farm	
	N	S	N	S	N	S	N	S	N	S	N	S
Ranot	19,424	5	18	13	196,613	52	16	12	43,463	11	5	4
Krasae Sin	8,370	2	10	8	286,920	76	14	11	-	-	-	-
Khuan Niang	6,840	2	6	4	49,500	13	2	1	50,850	14	3	2
Singhanakhon	6,188	2	4	3	47,550	13	3	2	-	-	-	-
Total	**40,822**	**11**	**38**	**28**	**580,583**	**154**	**35**	**26**	**94,313**	**25**	**8**	**6**

Note: N is total of population size.

S is sample size.

Table 3.11 The number of aquaculture farm and giant perch (*Lates calcarifer*) in Trang province.

Amphoe	The size of farm											
	<1 rais and feed				1 - 5 rais and feed				>5 rais and feed			
	Aquatic animal		Farm		Aquatic animal		Farm		Aquatic animal		Farm	
	N	S	N	S	N	S	N	S	N	S	N	S
Kantang	5,072	7	18	8	5,784	8	16	7	-	-	-	-
Sikao	7,464	11	14	6	11,640	17	10	4	-	-	-	-
Palian	5,130	7	4	1	2,213	3	2	1	-	-	-	-
Total	**17,666**	**25**	**36**	**15**	**19,637**	**28**	**28**	**12**	**-**	**-**	**-**	**-**

Note: N is total of population size.

S is sample size.

Table 3.12 The number of aquaculture farm and giant perch (*Lates calcarifer*) in Phatthalung province.

Amphoe	The size of farm											
	<1 rais and feed				1 - 5 rais and feed				>5 rais and feed			
	Aquatic animal		Farm		Aquatic animal		Farm		Aquatic animal		Farm	
	N	S	N	S	N	S	N	S	N	S	N	S
Pak Phayun	17,875	40	31	13	-	-	-	-	-	-	-	-
Khao Chaison	5,626	13	12	5	-	-	-	-	-	-	-	-
Total	**23,501**	**53**	**43**	**18**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Note: N is total of population size.

S is sample size.

Table 3.13 The number of aquaculture farm and giant perch (*Lates calcarifer*) in Songkhla province.

Amphoe	The size of farm											
	<1 rais and feed				1 - 5 rais and feed				>5 rais and feed			
	Aquatic animal		Farm		Aquatic animal		Farm		Aquatic animal		Farm	
	N	S	N	S	N	S	N	S	N	S	N	S
Ranot	7,868	7	42	18	71,000	60	55	23	2,436	2	2	1
Krasae Sin	9,826	8	36	15	40,320	34	29	12	-	-	-	-
Singhanakhon	16,270	14	60	25	30,958	30	48	20	20,256	12	12	5
Mueang Songkhla	25,549	21	58	25	134,543	108	62	27	12,816	16	10	4
Total	**59,513**	**50**	**196**	**83**	**276,821**	**232**	**194**	**82**	**35,508**	**30**	**24**	**10**

Note: N is total of population size.
S is sample size.

3.3 Analytical methods

The data were collected directly from the owner's aquaculture farms. Data were collected using detailed questionnaires filled out and with interview different aquatic meat productions of aquaculture farms during January, 2011 to December, 2012. Questionnaires comprised a wide range of operational aspects and energy inputs for aquaculture farms (consumption of electricity, petroleum and liquefied petroleum gas (LPG)) as well as aspects related to transportation. The questionnaires were based on inventory data for life cycle analysis (Tyedmers, 2002; Pelletier and Tyedmers, 2010).

The sample properties were analyzed in the laboratory; they were aquatic foods, faeces, aquatic meat products, and water samples from aquaculture farms in each province, at Suranaree University of Technology and Rajamangala University of Technology Srivijaya, Trang Campus. The samples in aquaculture farms were collected randomly by sampling method (Modified from Cavana, Delahaye, and Sekaran, 2000) which were as follows:

3.3.1 The samples of aquatic foods, aquatic meat products, and faeces from aquaculture farms of each province were analyzed as:

- The weight and type of the samples were collected by the convenience sampling methods (Cavana, Delahaye, and Sekaran, 2000).

- The moisture content of total solid was studied followed the method of Manlay et al. (2004).

- The volatile solids and fixed solids were determined by the method of APHA, AWWA, WEF (1992).

3.3.2 Carbon content analysis:

- The carbon contents were analyzed by using LECO CHN628 Series Elemental Analyzer and Gas Analyzer Respiration Trial System. The LECO CHN628 Series Elemental Analyzer is used to determine nitrogen, carbon/nitrogen, and carbon/hydrogen/nitrogen in organic matrices. The instrument utilizes a combustion technique and provides a result within 4.5 minutes for all the elements being determined. The samples were tested by incinerating at temperatures up to 1,050ºC with pure oxygen to ensure the complete combustion of all organic samples. Additionally, the instrument features custom Windows-based software operated through an external PC to control the system operation and data management. At the same time, the studies of carbon emission in the form of CO_2 and CH_4 from the digestion of aquatic animals and faeces were measured by Gas Analyzer Respiration Trial System (Manlay et al., 2004).

- The formula of John and Alan (1992) and Tanthunwet (2008) were used to study the carbon emission in the form of CO_2 from the respiration of aquatic animals in this study as follows:

(1) Bicarbonate alkalinity:

$$HCO_3^- \text{ (mg.CaCO}_3\text{/l)} = \frac{T - 5.0 \times 10^{(pH - 10)}}{1 + 0.94 \times 10^{(pH - 10)}} \quad (3.2)$$

Where:

T = Total alkalinity (mg.$CaCO_3$/l)

(2) Carbonate alkalinity:

$$CO_3^{2-}\ (mg.CaCO_3/l) = 0.94 \times B \times 10^{(pH - 10)} \quad (3.3)$$

Where:

B = Bicarbonate alkalinity (mg/l).

(3) Hydroxide alkalinity:

$$OH^-\ (mg.CaCO_3/l) = 5.0 \times 10^{(pH - 10)} \quad (3.4)$$

(4) Free carbon dioxide:

$$CO_2\ (mg/l) = 2.0 \times B \times 10^{(6 - pH)} \quad (3.5)$$

Where:

B = Bicarbonate alkalinity (mg/l)

(5) Total carbon dioxide:

$$Total\ CO_2\ (mg/l) = A + 0.44(2B + C) \quad (3.6)$$

Where:

A = Free carbon dioxide (mg/l)

B = Bicarbonate alkalinity (mg/l)

C = Carbonate alkalinity (mg/l)

3.3.3 Calculations of energy used and carbon contents were as follows:

- The carbon input (C-input) from aquatic food for feeding to the biomass of Pacific white shrimp, giant freshwater prawn and giant perch were analyzed.

- The carbon emission rate (C-emission) was analyzed from energy used in aquaculture farms and dry faeces, as well as the C-emission in the form of CO_2 and CH_4 for digestion and respiration of fish and shrimp.

- The carbon fixation rate (C-fixation) was studied from aquatic meat products.

- The efficiencies in the carbon using of Pacific white shrimp, giant freshwater prawn and giant perch were studied.

- The proportion of impacts on the environment compared to the same C-fixation and the amount of carbon in the same aquatic food was calculated.

- The amounts of electricity, petroleum and liquefied petroleum gas (LPG) used for hatchery operations, aquaculture farm operations, catching, storage of the frozen aquatic meat products, and processing plant or markets were studied.

- The amounts of energy used for transportation such as fingerling and post larvae, aquatic food and LPG to aquaculture farms, including aquatic product transportation to the processing plant or markets were also calculated.

- Estimates of energy used and carbon contents for each task were summed and presented as kilogram (kg) of energy used per kilogram of aquatic product per farm size (rai) (kg of energy used/kg of aquatic product/rai), and kilogram of carbon contents per kilogram of aquatic product per day (kg.C/kg of aquatic product/day), respectively. The scopes of studies are shown in Figure 3.2.

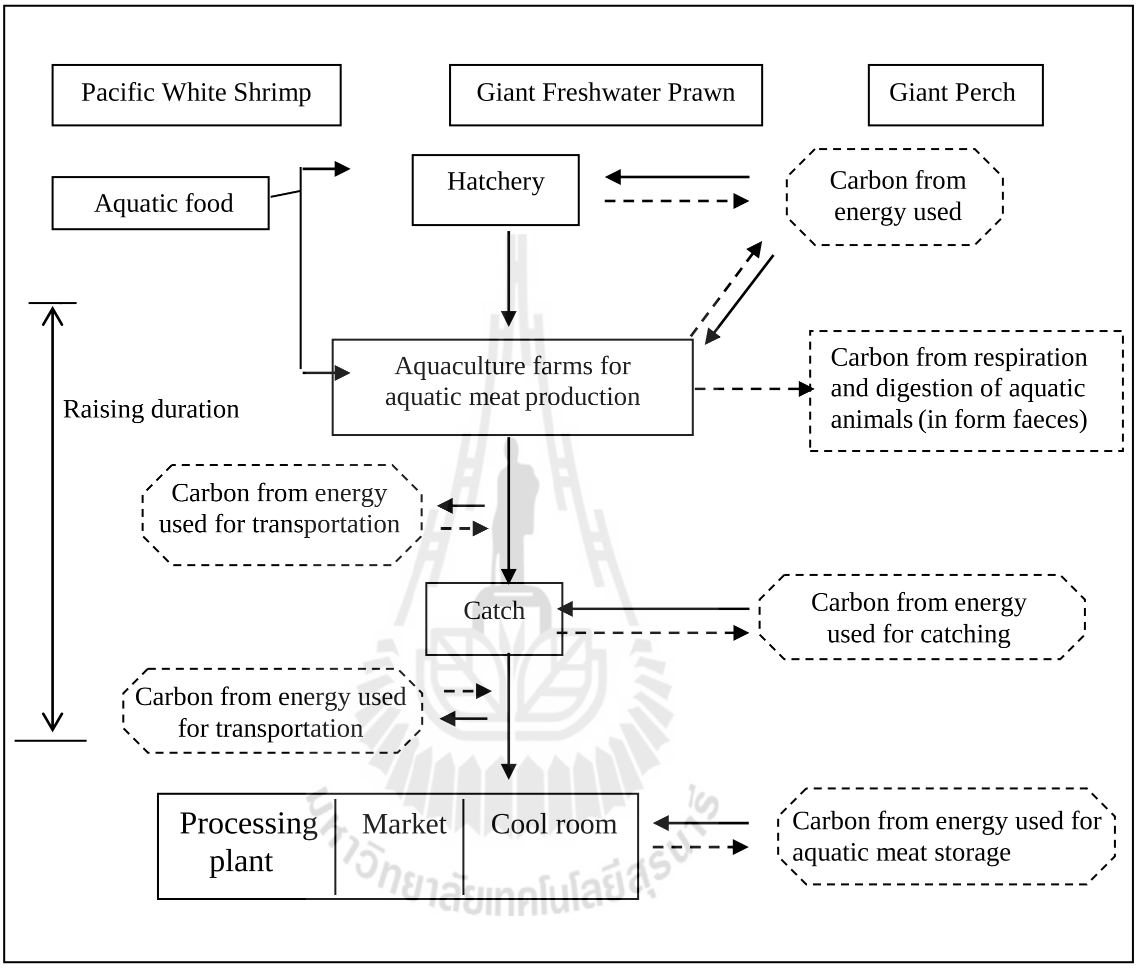


Figure 3.2 The scope of study on carbon massflow and carbon emission from aquatic meat production in Trang, Songkhla and Phatthalung provinces.

- The data of carbon content from the laboratory was used as source to study the average of carbon from aquaculture activities (kg.C/kg of aquatic product/day) and to find the carbon transfer rate from aquatic food to aquatic animals. The carbon emission in the form of CO_2, CH_4 and faeces were investigated through the carbon massflow concept (UNECE, 2004). Thus, the carbon emission was shown in the formula 3.7.

$$E_{total} = n_{animal} \times (EF_{metabolic} + EF_{spreading} + EF_{energy\ equivalent}) \quad (3.7)$$

Where:

E_{total} = The total of carbon emission (kg.C/day).

n_{animal} = The number of aquatic animals.

$EF_{metabolic}$ = Carbon emission from the respiration of aquatic animals (kg.C/kg of aquatic product/day).

$EF_{spreading}$ = The carbon emissions from faeces of aquatic animals (kg.C/kg of aquatic product/day).

$EF_{energy\ equivalent}$ = The carbon emissions from energy used in aquatic meat production such as fuel used for transportation, electrical used in hatcheries, aquaculture farms and markets including electric used for frozen aquatic meat products (kg.C/kg of aquatic product/day).

3.4 Data analysis

All data of all carbon contents which relate to food production such as carbon in aquatic food (C-input), carbon in aquatic meat (C-fixation), carbon in faeces, as well as carbon in the form of CO_2 and CH_4 for the digestion and respiration of aquatic animals, and carbon in the form of energy used for aquatic production (C-emission) was analyzed. The results were explained the ratio of C-emission to C-fixation in form of food production and was explained the environmental impacts from carbon emission for aquaculture farming. So, the analyses of some important processes were as follows:

3.4.1 The carbon emission rate (C-emission) was total carbons that secreted in form:

- Carbon from faeces (C-output) and carbon in the form of gasses such as CO_2 and CH_4 from the respiration and digestion (C-emission) per time were:

$$C_{\text{emission from aquatic animal}} = (\text{C in dry faeces} + \text{C in form of } CO_2 \text{ and } CH_4 \text{ from fresh faeces} + \text{C in form of } CO_2 \text{ and } CH_4 \text{ from respiration and digestion of aquatic animal}) \text{ per time} \quad (3.8)$$

- Carbon from total energy used in hatcheries, aquaculture farms, catching, transportation, processing plants or markets, and storage of aquatic meat products were:

$$C_{\text{emission from energy used}} = (C_{\text{hatchery}} + C_{\text{farm}} + C_{\text{catching}} + C_{\text{transportation}} + C_{\text{processing plants or markets}} + C_{\text{storage}}) \text{ per time} \quad (3.9)$$

3.4.2 The carbon fixation rate (C-fixation) from aquatic food to aquatic animals by food’s weight and aquatic animal’s weight were compared to time as shown as follow:

$C_{fixation}$ = (C in aquatic food – C in dry faeces – C in form of CO_2 and CH_4 from fresh faeces – C in form of CO_2 and CH_4 from respiration and digestion of aquatic animal) per time (3.10)

3.4.3 The comparison of the efficiency in the carbon fixation was considered in form of aquatic meat of each aquatic animal to consider that which kind of aquatic animal was more suitable for aquatic meat production. So, the aquatic animal should have higher efficiency in carbon fixation than other aquatic animals was as follow:

$$C_{fixation\ efficiency} = (C_{aquatic\ food} - C_{emission}) \div C_{aquatic\ food} \quad (3.11)$$

3.4.4 The analysis was made for ranking the importance of each aquaculture kind for the production of Pacific white shrimp, giant freshwater prawn and giant perch meat which showed the least impact on environment. The comparison of the carbon from aquatic food, carbon emission from aquatic animals and energy used within the aquaculture farms for catching, transportation, storage of aquatic animals products, including carbon fixation in aquatic meat were:

$$\text{Ratio of environment impact compared to the same level of } C_{fixation} = \frac{\text{Carbon emitted}}{\text{Carbon fixed}} \quad (3.12)$$

$$\text{Ratio of environment impact compared to the amount of aquatic food} = \frac{\text{Carbon emitted}}{\text{Carbon in aquatic food}} \quad (3.13)$$

Where:

Carbon emitted	=	Carbon from respiration, digestion and faeces from aquatic animals.
Carbon fixed	=	Carbon from aquatic meat.
Carbon in aquatic food	=	Carbon from artificial diet.

3.5 Statistical analysis

Statistical analysis was performed using SPSS Version 18. The data subjected to analysis of variance (ANOVA) of the various parameters were used to compare the differences among aquaculture groups, and the differences between means were evaluated by Duncan’s Multiple Range Test (Steel and Torrie, 1980).

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 The investigation of aquaculture farms in Trang, Songkhla and Phatthalung provinces

The importantly economic aquaculture has been produced in many areas of Trang, Songkhla and Phatthalung provinces, especially Pacific white shrimp (*Penaeus vannamei*), giant freshwater prawn (*Macrobrachium rosenbergii*) and giant perch (*Lates calcarifer*). This study was conducted during October, 2011 to September, 2012. The results and discussions are as follows.

4.1.1 Pacific white shrimp (*Penaeus vannamei*) farming in Trang, Phatthalung and Songkhla provinces

The samples for this study were the groups of 280 Pacific white shrimp farms and 400 shrimps, which were implemented in a range of different farm sizes (less than 5 rais, 5-10 rais and more than 10 rais). So, the samples of 153 farms and 219 shrimps, 16 farms and 23 shrimps, 111 farms and 158 shrimps were chose and collected from Trang, Phatthalung and Songkhla provinces, respectively. Total of 26 hatcheries which represented different hatchery types were visited from Trang and Songkhla provinces to ensure data quality.

Hatchery systems range from specialized, small or medium size, often inland, backyard hatcheries to large and environmentally controlled installations. In general, Hatcheries sell two products: nauplii (newly hatched, first stage larvae) and post larvae (which have passed through three larval stages). Nauplii are sold to specialized hatcheries that raise them to the post larval stage.

Shrimp juveniles were purchased by farmers between 10 and 30 days after moulting to the post larvae stage (PL 10-30), but usually between 12 and 15 days (PL 12-15), from several provinces such as Songkhla, Krabi, Phang-Nga, Phuket, Trang, Satun, Phatthalung and Chumphon, etc. Nevertheless, this study surveyed the shrimp hatcheries in Trang and Songkhla provinces only. At the same time, the stocking densities range from 100,000 to 150,000 individual/rai, which is the appropriate density for the Pacific white shrimp culture (Limsuwan, Chanratchakool, Turnbull, and Smith, 1995).

Primary data on Pacific white shrimp farms were collected through a series of questionnaires filled out by 280 farms owners in Trang, Phatthalung and Songkhla provinces. The survey yielded primary data on pond area, culture periods, pond preparation, shrimp stocking and shrimp food use per one production cycle were investigated. Additionally, the energy used as inputs into the Pacific white shrimp farming facilities was gained from different sources, electricity, fuel and LPG, which are presented in Tables 4.1 - 4.4. Some of the farms used renewable sources of energy but were not reported in the output data.

Table 4.1 Type of energy consumption within Pacific white shrimp farms in Trang, Phatthalung and Songkhla provinces.

Province	Type of energy use	Lighting	Water pumps	Aeration	Automatic feeder
Trang	Electricity	✓	✓	✓	✓
	Diesel		✓	✓	
	LPG			✓	
Phatthalung	Electricity	✓	✓	✓	
	Diesel		✓	✓	
	LPG			✓	
Songkhla	Electricity	✓	✓	✓	✓
	Diesel		✓		
	LPG				

The study of shrimp food in Pacific white shrimp farming did not cover the feed brands used; later verification revealed that several farmers used different brands during one production cycle. As a result, the feed conversion ratio (FCR), the amount of feed used to raise a kilogram (kg) of shrimp accounting for all forms of feed loss, for several individual farms could not be related to a specific feed used. The study of the Pacific white shrimp farming systems had an average FCR of 1.34±0.98 for Trang, 5.20±3.68 for Phatthalung, and 0.93±0.20 for Songkhla provinces. This made it less relevant to include this variability in the further calculations.

Table 4.2 Farm-level inputs and outputs for the production of 1 kg live-weight of Pacific white shrimp (*Penaeus vannamei*) in Trang province (mean±SD).

Item	Unit	The size of farm		
		<5 rais	5-10 rais	>10 rais
Pond area	rai	3.24±0.88	6.14±1.50	11.60±0.55
Shrimp production	kg/rai/year	3,890.99±1,867.29	3,060.85±1,225.83	3,190.91±630.78
Feed consumed	kg/rai/year	7,374.77±6,947.54	5,548.74±2,730.87	4,451.50±1,795.62
FCR	kg/kg	1.71±1.14	1.42±1.40	0.89±0.39
Electricity use	kWh/kg.shrimp/rai	0.021±0.037	0.006±0.005	0.004±0.001
Diesel use	l/kg.shrimp/rai	0.033±0.066	0.006±0.009	0.000±0.000
LPG use	kg/kg.shrimp/rai	0.080±0.130	0.043±0.080	0.000±0.000

Table 4.3 Farm-level inputs and outputs for the production of 1 kg live-weight of Pacific white shrimp (*Penaeus vannamei*) in Phatthalung province (mean±SD).

Item	Unit	The size of farm	
		<5 rais	5-10 rais
Pond area	rai	1.68±0.96	5.10±0.55
Shrimp production	kg/rai/year	5,109.09±2,429.86	2,866.67± 963.79
Feed consumed	kg/rai/year	7,745.45±5,702.88	3,865.20± 1,575.91
FCR	kg/kg	9.34±7.18	1.05±0.18
Electricity use	kWh/kg.shrimp/rai	0.036±0.028	0.610±0.308
Diesel use	l/kg.shrimp/rai	0.113±0.115	0.430±0.962
LPG use	kg/kg.shrimp/rai	0.016±0.054	0.968±2.164

Table 4.4 Farm-level inputs and outputs for the production of 1 kg live-weight of Pacific white shrimp (*Penaeus vannamei*) in Songkhla province (mean±SD).

Item	Unit	The size of farm		
		<5 rais	5-10 rais	>10 rais
Pond area	rai	3.50±1.02	6.54±0.67	8.78±1.49
Shrimp production	kg/rai/year	3,830.28±928.87	4,268.25±1,314.88	4,792.24±769.24
Feed consumed	kg/rai/year	5,179.67±1,607.10	6,177.58±1,584.47	6,674.57±2.72
FCR	kg/kg	0.90±0.27	0.90±0.23	0.99±0.10
Electricity use	kWh/kg.shrimp/rai	0.049±0.029	0.021±0.011	0.012±0.001
Diesel use	l/kg.shrimp/rai	0.004±0.004	0.002±0.001	0.001±0.000
LPG use	kg/kg.shrimp/rai	0.000±0.000	0.000±0.000	0.000±0.000

On-farm material, shrimp food and energy inputs showed substantial differences per kg live-weight of Pacific white shrimp produced by each farm size. Overall, the Pacific white shrimp farming had consistently higher on-farm energy and shrimp food use. Higher stocking density and water exchange rates also required more electricity; LPG and fuel oil were used for aeration and water pumping in farm. Moreover, shrimp food conversion ratio (FCR) is another pivotal environmental performance driver. Since FCR is directly related to biotic resource use and nutrient retention, lower FCR reduces cumulative impacts of shrimp production. Pelletier et al. (2009) reported that FCR was influenced mostly by feed composition, feeding management and feed quality such as stability in water. If feed composition was the same and feed remained stable longer in water, appropriate feeding regimes would reduce feed loss and dramatically lower FCR.

Additionally, the amount of shrimp food required to produce 1 kg of Pacific white shrimp in Trang, Phatthalung and Songkhla provinces were 1.81, 1.45 and 1.44 kg, respectively. Corresponding to the studies of Cao, Diana, Keoleian, and Lai (2011), this study reported that the amount of feed required producing one tonne of shrimp varied from 1,600 kg in intensive farming to 907 kg in semi-intensive farming systems.

4.1.2 Giant freshwater prawn (*Macrobrachium rosenbergii*) farming in Trang, Phatthalung and Songkhla provinces

Field studies were conducted involving a total of 100 giant freshwater prawn farms and 331 prawns of the different farm sizes (i.e., less than 1 rais, 1-5 rais, and more than 5 rais). The collected samples were 8 farms and 29 prawns from Trang, 32 farms and 112 prawns from Phatthalung including 60 farms and 190 prawns from

Songkhla provinces. Total 19 hatcheries and 24 markets were explored in Trang, Phatthalung and Songkhla provinces.

Larval rearing typically occurred in 12% brackish water and hatcheries were either flow-through or recirculating. Inland hatcheries produced brackish water by mixing freshwater with seawater transported from the coast, brine trucked from salt pans or artificial seawater. The brackish water derived from the mixture of seawater, brine or artificial sea salts with freshwater for use in prawn hatcheries should be 12-16 ppt with a pH of 7.0 to 8.5 and a minimum dissolved oxygen level of 5 ppm. Some hatcheries were integrated with nursery and grow-out facilities. Although some farmers stocked grow-out ponds with young PL, many either purchased larger juveniles or reared PL in their own nursery ponds before transferring to grow-out ponds from Trang, Phatthalung and Songkhla provinces.

The cultural management in the giant freshwater prawn farming was used by the owner's prawn farms. The most common culture included stocking with PL, 10-25 days old, and utilizing a nursing period with high stocking densities in order to use land, water and labor more efficiently. The nursing period ranged from 30-90 days. Alternatively, some farmers chose to directly stock PL or juveniles, ranging from 3-29 grams, into grow-out ponds. Two different harvest methods were used, batch and combined. In the more common combined method, farmers culled only marketable sized prawns, beginning 5 months after PL were stocked and 2 months after juveniles were stocked. Prawns stunted by dominants were then allowed to grow and were harvested on a 30-45 day basis. After 8 months, ponds were drained, harvested entirely and prepared for the next crop. The less common batch method allowed prawns to grow to a medium market size and then ponds were drained, harvested and prepared for another crop.

Primary data for giant freshwater prawn farms were collected using detailed questionnaires filled out and with interviews of the owners of 100 grow-out farms. Aggregated operational material or energy inputs and production associated with the giant freshwater prawn farm's operations were collected to ensure clarity and consistency in reported data. Therefore, the survey yielded primary data on pond area, culture periods, pond preparation, prawn stocking, prawn food use, water management and the use of energy such as electricity, fuel and LPG (Tables 4.5 - 4.8).

Table 4.5 Type of energy consumption within giant freshwater prawn farms in Trang, Phatthalung and Songkhla provinces.

Province	Type of energy use	Lighting	Water pumps	Aeration
Trang	Electricity	✓	✓	
	Diesel		✓	
	LPG			✓
Phatthalung	Electricity	✓	✓	
	Diesel		✓	
	LPG			✓
Songkhla	Electricity	✓	✓	✓
	Diesel		✓	
	LPG			✓

Table 4.6 Farm-level inputs and outputs for the production of 1 kg live-weight of giant freshwater prawn (*Macrobrachium rosenbergii*) in Trang province (mean±SD).

Item	Unit	The size of farm	
		<1 rais	1-5 rais
Pond area	rai	0.46±0.25	3.10±0.60
Prawn production	kg/rai/year	1,008.21±570.03	998.21±285.01
Feed consumed	kg/rai/year	354.97±284.68	549.63±270.74
FCR	kg/kg	17.42±1.63	17.09±0.61
Electricity use	kWh/kg.prawn/rai	0.007±0.006	0.000±0.000
Diesel use	l/kg.prawn/rai	3.605±6.212	0.139±0.081
LPG use	kg/kg.prawn/rai	0.391±0.781	0.148±0.016

Table 4.7 Farm-level inputs and outputs for the production of 1 kg live-weight of giant freshwater prawn (*Macrobrachium rosenbergii*) in Phatthalung province (mean±SD).

Item	Unit	The size of farm		
		<1 rais	1-5 rais	>5 rais
Pond area	rai	0.50±0.24	2.26±0.69	5.65±0.21
Prawn production	kg/rai/year	908.13±282.09	883.40±19.95	880.00±28.28
Feed consumed	kg/rai/year	328.60±155.89	204.31±85.98	57.21±16.62
FCR	kg/kg	17.87±5.22	10.53±3.11	12.12±8.51
Electricity use	kWh/kg.prawn/rai	0.056±0.012	0.346±0.263	0.014±0.001
Diesel use	l/kg.prawn/rai	4.933±7.885	9.234±4.105	1.103±0.076
LPG use	kg/kg.prawn/rai	0.425±1.153	0.000±0.000	0.000±0.000

Table 4.8 Farm-level inputs and outputs for the production of 1 kg live-weight of giant freshwater prawn (*Macrobrachium rosenbergii*) in Songkhla province (mean±SD).

Item	Unit	The size of farm		
		<1 rais	1-5 rais	>5 rais
Pond area	rai	0.54±1.04	2.38±0.84	5.94±0.52
Prawn production	kg/rai/year	13,515.56±15,937.48	950.90±175.96	712.53±194.39
Feed consumed	kg/rai/year	12,548.66± 12,028.39	287.20±183.01	800.41±428.99
FCR	kg/kg	17.44±8.08	10.79±3.55	10.27±3.49
Electricity use	kWh/kg.prawn/rai	0.007±0.018	0.002±0.003	0.001±0.001
Diesel use	l/kg.prawn/rai	0.498±0.694	0.034±0.050	0.128±0.044
LPG use	kg/kg.prawn/rai	0.335±0.840	0.058±0.202	0.000±0.000

The study of prawn food in the giant freshwater prawn farming did not cover the food brands used; several farmers used different brands and mainly used aquatic food for giant tiger prawn (*Penaeus monodon*). The studies of giant freshwater prawn farming systems had an average FCR of 17.26±1.12 for Trang, 13.51±5.61 for Phatthalung, and 12.83±5.04 for Songkhla provinces.

The results of 100 giant freshwater prawn farms in this study showed substantial differences per kg live-weight of giant freshwater prawn produced in each farm size. Giant freshwater prawn farming had consistently higher on-farm prawn food and the use of energy for aeration and water pumping. Water pumps and aeration were the largest user of fuel oil and LPG. At the same time, the amount of prawn food required to produce 1 kg of giant freshwater prawn was 0.63, 0.42 and 0.22 kg for Songkhla, Trang and Phatthalung provinces, respectively.

4.1.3 Giant perch (*Lates calcarifer*) farming in Trang, Phatthalung and Songkhla provinces

This study was investigated in 220 giant perch farms and 400 fish in three differently sized farms, the farm size less than 1 rais, 1-5 rais, and more than 5 rais. So, the samples accounted for 27 farms and 53 fish, 18 farms and 35 fish, 175 farms and 312 fish, including 21 hatcheries and 20 markets from Trang, Phatthalung and Songkhla provinces, respectively.

While giant perch fingerlings are still collected from the sea, most seed supply is through hatchery production. Hatchery production technology is now well established throughout the culture range of this species. Giant perch broodstock are held in floating cages or in concrete or fiberglass tanks. They may be maintained in either fresh or seawater but must be placed in seawater (28-35%) prior to the breeding season to enable final gonadal maturation to take place.

Moreover, giant perch are generally reared in circular or rectangular concrete tanks or in circular canvas tanks up to 26 m^3 capacity. A microalgal culture (usually *Tetraselmis* spp.) is added to the rearing tanks at densities ranging from $8\text{-}10\times10^3$ to $1\text{-}3\times10^5$ cells/ml. Intensively reared giant perch are fed on rotifers (*Brachionus plicatilis*) from day two until day 12, and on brine shrimp (*Artemia* sp.) from day eight onwards. Both rotifers and brine shrimp fed to giant perch are cultured on microalgae or commercial enrichment products to increase levels of highly unsaturated fatty acids.

Giant perch fingerlings are also produced using extensive (pond-based) rearing procedures. Pond areas used for the extensive larval rearing of giant perch range from 0.05 to 6 rais and may be earthen or giant perch cage culture. Giant perch larvae are stocked at densities of 3,000-5,000 individual/rai. Survival of extensively reared giant perch averages about 20%, but is highly variable, ranging from zero to 90%.

The data were obtained through a series of questionnaires filled out and with interviews of the owners of 220 giant perch farms in three studied provinces. Questionnaires comprised a wide range of operational aspects in giant perch farming such as pond preparation, culture periods, fish stocking, fish food use including the consumption of electricity, fuel and LPG. The results are shown in Tables 4.9 - 4.11.

Table 4.9 Type of energy consumption within giant perch farms in Trang, Phatthalung and Songkhla provinces.

Province	Type of energy use	Lighting	Water pumps	Aeration
Trang	Electricity	✓	✓	
	Diesel		✓	
	LPG			✓
Phatthalung	Electricity	✓		
	Diesel		✓	
	LPG			✓
Songkhla	Electricity	✓	✓	
	Diesel		✓	✓
	LPG			✓

The study for aquatic food used of giant perch farming in Trang, Phatthalung and Songkhla provinces found that several farmers have two food types such as pelleted diets and trash fish. Most of farmers often used fish trash for giant perch culture due to most giant perch farms located near the coasts and fish piers which was easy to find fish trash. Giant perch was fed twice daily at 3-10% body weight. Larger farms may use automatic feeder systems but smaller farms still use hand-feed. Therefore, the food conversion ratio (FCR) for giant perch farming had an average highest at 1.72±1.32 for Phatthalung, 1.10±0.63 for Trang, and 0.89±0.64 for Songkhla provinces, respectively.

Table 4.10 Farm-level inputs and outputs for the production of 1 kg live-weight of giant perch (*Lates calcarifer*) in Trang and Phatthalung provinces (mean±SD).

Item	Unit	Trang		Phatthalung
		The size of farm		The size of farm
		<1 rais	1-5 rais	<1 rais
Pond area	rai	0.18±0.01	1.30±0.04	0.18±0.01
Fish production	kg/rai/year	1,850.74±915.65	455.67±108.91	2,006.48±816.26
Feed consumed	kg/rai/year	3,858.40±3,370.51	5,526.33±1,085.69	3,217.94±3,174.16
FCR	kg/kg	1.64±1.11	0.55±0.15	1.72±1.32
Electricity use	kWh/kg.fish/rai	11.408±8.702	3.273±1.411	17.925±10.737
Diesel use	l/kg.fish/rai	8.927±3.160	0.360±0.919	9.066±3.673
LPG use	kg/kg.fish/rai	1.408±2.151	0.000±0.000	5.261±8.062

Table 4.11 Farm-level inputs and outputs for the production of 1 kg live-weight of giant perch (*Lates calcarifer*) in Songkhla province (mean±SD).

Item	Unit	The size of farm		
		<1 rais	1-5 rais	>5 rais
Pond area	rai	0.28±0.15	1.26±0.55	5.04±0.08
Fish production	kg/rai/year	2,859.02±1,417.09	1,399.17±1,474.91	392.52±119.81
Feed consumed	kg/rai/year	4,173.65±2,831.72	7,053.97±4,001.43	2,601.12±444.47
FCR	kg/kg	1.65±1.35	0.70±0.50	0.33±0.08
Electricity use	kWh/kg.fish/rai	9.706±9.867	1.792±1.726	0.147±0.029
Diesel use	l/kg.fish /rai	6.498±5.783	0.878±0.966	0.040±0.008
LPG use	kg/kg.fish/rai	4.818±8.680	0.938±1.347	0.000±0.000

In terms of overall environmental impact, the giant perch farming showed substantial differences per kg live-weight of giant perch produced in each farm size. Giant perch farming impact came from use of fish food, energy consumption, construction material production and fish metabolism. Water exchange rates and increased oxygen demand in the receiving water also required more electricity and fuel oil used for aeration, lighting and water pumping in farm. Moreover, the amount of fish food required to produce 1 kg of giant perch was 11.94 in Trang, 9.10 in Phatthalung, and 5.80 in Songkhla provinces, respectively.

Regardless of differing cultural management, most aquaculture farms were small and farmers used similar pond preparation techniques. Pacific white shrimp production took place on small farms, with 70% of farms at less than 5 rais and 25% of farms at 1-5 rais, while prawn and fish farms was 1-5 rais in total area for water and used ponds (85% of all farms) including an average pond depth of 1.4 meters. Semi-intensive culture was the most common production system for aquaculture farming in studied provinces.

Water used for aquatic animal culture was most commonly obtained directly from natural or manmade canals. Only 25% of farmers used water storage ponds prior to draining water into culture ponds. Prior to stocking, ponds were dried from 7 to 30 days, soil was tilled and plowed, and dykes were repaired. Ponds were filled and treated most commonly with lime or dolomite. Aquatic animals were stocked within 1-15 days after ponds had been filled.

4.2 Rate of carbon massflow in aquaculture farming system

4.2.1 Summarized data for carbon input, carbon fixation and carbon emission in each aquaculture kind

The carbon contents in the unit of kg carbon per kg of aquatic animal product per day (kg.C/kg.aquatic animal/day) were used to study the comparison of carbon massflow from aquatic food for feeding to the biomass of different aquatic animals (C-input), the carbon mass that was fixed in the aquatic body (C-fixation) and the carbon emitted in faeces, digestion and respiration (C-emission).

The results showed that Pacific white shrimp emitted the highest value at 1.30×10^{-3} kg.C/kg.shrimp/day, which Pacific white shrimp in Songkhla province has carbon emitted higher than Trang and Phatthalung provinces. This may be because Pacific white shrimp obtained higher carbon at 7.60×10^{-3} kg.C/kg.shrimp/day from aquatic food and carbon fixation of shrimp bodies was 6.30×10^{-3} kg.C/kg.shrimp/day. Whereas, a giant perch emitted the lowest carbon per day at 2.00×10^{-4} kg.C/kg.fish/day, but obtained the highest carbon at 7.70×10^{-3} kg.C/kg.fish/day. Giant perch fixed carbon in the body at 7.50×10^{-3} kg.C/kg.fish/day.

Additionally, the rate of carbon transferred from animal food to giant freshwater prawn was 3.80×10^{-3} and carbon emitted of prawn was 5.90×10^{-4} kg.C/kg.prawn/day. Giant freshwater prawns fixed the lowest carbon in the body at 3.20×10^{-3} kg.C/kg.prawn/day. Comparison of the efficiency of carbon fixation in aquatic animal found that giant perch could efficiently fix carbon in the body at 97.05%, which higher than Pacific white shrimp (81.76%) and giant freshwater prawn (81.72%). The rate of total carbon input from aquatic food to aquatic animal by consumption including carbon fixation in aquatic animal bodies and faeces during rearing duration are shown in Tables 4.12 - 4.19.

Additionally, Tables 4.20 - 4.28 show the average of C-input from aquatic food, C-fixation in aquatic animal bodies, C-output and C-emission in form of CO_2 and CH_4 from animal faeces, digestion and respiration.

Each kind of aquatic animal emitted different average total carbon per kg. The results showed that Pacific white shrimp had the highest carbon emission compared with giant freshwater prawn and giant perch which were 1.30×10^{-3}, 6.00×10^{-4} and 2.00×10^{-4} kg.C/kg.aquatic animal/day, respectively.

Total carbon emission per day from a Pacific white shrimp in Songkhla, Trang and Phatthalung provinces were 0.0018±0.0007, 0.0012±0.0002 and 0.0009±0.0004 kg.C/kg.shrimp/day, respectively. Most carbon content was in the form of shrimp faeces (C-output) at 24.29%, 12.69% and 11.46% of all carbon emissions from Songkhla, Phatthalung and Trang provinces, respectively (Table 4.29).

Giant freshwater prawn emitted carbon in Songkhla province was 0.0013±0.0012, Trang province was 0.0003±0.0003 and Phatthalung province was 0.0001±0.0001 kg.C/kg.prawn/day. Most carbon content was in the form of prawn faeces at 27.27%, 13.48% and 7.14% of total carbon emissions in Trang, Songkhla and Phatthalung provinces, respectively (Table 4.30).

Table 4.12 Rates of carbon input, carbon fixation and carbon emitted of Pacific white shrimp (*Penaeus vannamei*) in Trang province (mean±SD).

Carbon contents	The size of farm		
	<5 rais	5-10 rais	>10 rais
Average of live-weight shrimp[1]	0.0150±0.0061	0.0161±0.0061	0.0152±0.0078
Weight of fresh faeces excreted[2]	0.0071±0.0086	0.0047±0.0029	0.0030±0.0012
Percentage of faeces excreted per weight shrimp	76.34	49.48	35.89
C_{input}[3]	0.0152±0.0306	0.0084±0.0071	0.0053±0.0018
$C_{fixation}$[3]	0.0142±0.0306	0.0072±0.0070	0.0039±0.0015
$C_{emitted}$[3]	0.0010±0.0004	0.0012±0.0005	0.0014±0.0005
$C_{emitted}/C_{input}$ (%)	6.58	14.29	26.42
$C_{emitted}/C_{fixation}$ (%)	7.04	16.67	35.90
Fixation efficiency, $C = (C_{input} - C_{emitted})/C_{input}$ (%)	93.42	85.71	73.59

Note: [1] Unit = kg per individual, [2] Unit = kg per kg of shrimp per day, [3] Unit = kg carbon per kg of shrimp per day

Table 4.13 Rates of carbon input, carbon fixation and carbon emitted of Pacific white shrimp (*Penaeus vannamei*) in Phatthalung province (mean±SD).

Carbon contents	The size of farm	
	<5 rais	5-10 rais
Average of live-weight shrimp[1]	0.0158±0.0065	0.0183±0.0050
Weight of fresh faeces excreted[2]	0.0083±0.0023	0.0028±0.0017
Percentage of faeces excreted per weight shrimp	54.72	28.33
C_{input}[3]	0.0079±0.0043	0.0047±0.0009
$C_{fixation}$[3]	0.0068±0.0042	0.0041±0.0009
$C_{emitted}$[3]	0.0011±0.0003	0.0006±0.0002
$C_{emitted}/C_{input}$ (%)	13.92	12.77
$C_{emitted}/C_{fixation}$ (%)	16.18	15.00
Fixation efficiency, $C = (C_{input} - C_{emitted})/C_{input}$ (%)	86.08	87.23

Note: [1] Unit = kg per individual, [2] Unit = kg per kg of shrimp per day, [3] Unit = kg carbon per kg of shrimp per day

Table 4.14 Rates of carbon input, carbon fixation and carbon emitted of Pacific white shrimp (*Penaeus vannamei*) in Songkhla province (mean±SD).

Carbon contents	The size of farm		
	<5 rais	5-10 rais	>10 rais
Average of live-weight shrimp[1]	0.0121±0.0038	0.0139±0.0014	0.0137±0.0013
Weight of fresh faeces excreted[2]	0.0066±0.0023	0.0065±0.0026	0.0048±0.0006
Percentage of faeces excreted per weight shrimp	74.72	64.95	48.00
C_{input}[3]	0.0071±0.0017	0.0073±0.0023	0.0065±0.0010
$C_{fixation}$[3]	0.0061±0.0017	0.0053±0.0025	0.0042±0.0008
$C_{emitted}$[3]	0.0010±0.0004	0.0020±0.0007	0.0023±0.0003
$C_{emitted}/C_{input}$ (%)	14.09	27.40	35.39
$C_{emitted}/C_{fixation}$ (%)	16.39	37.74	54.76
Fixation efficiency, $C = (C_{input} - C_{emitted})/C_{input}$ (%)	85.92	72.60	64.62

Note: [1] Unit = kg per individual, [2] Unit = kg per kg of shrimp per day, [3] Unit = kg carbon per kg of shrimp per day

Table 4.15 Rates of carbon input, carbon fixation and carbon emitted of giant freshwater prawn (*Macrobrachium rosenbergii*) in Trang province (mean±SD).

Carbon contents	The size of farm	
	<1 rais	1-5 rais
Average of live-weight prawn[1]	0.0310±0.0027	0.0679±0.0024
Weight of fresh faeces excreted[2]	0.0042±0.0018	0.0029±0.0030
Percentage of faeces excreted per weight prawn	42.34	6.47
C_{input}[3]	0.0009±0.0002	0.0013±0.0004
$C_{fixation}$[3]	0.0008±0.0002	0.0008±0.0003
$C_{emitted}$[3]	0.0001±0.0000	0.0005±0.0002
$C_{emitted}/C_{input}$ (%)	11.11	38.46
$C_{emitted}/C_{fixation}$ (%)	12.50	62.50
Fixation efficiency, C = $(C_{input} - C_{emitted})/C_{input}$ (%)	88.89	61.54

Note: [1] Unit = kg per individual, [2] Unit = kg per kg of prawn per day, [3] Unit = kg carbon per kg of prawn per day

Table 4.16 Rates of carbon input, carbon fixation and carbon emitted of giant freshwater prawn (*Macrobrachium rosenbergii*) in Phatthalung province (mean±SD).

Carbon contents	The size of farm		
	<1 rais	1-5 rais	>5 rais
Average of live-weight prawn[1]	0.0410±0.0117	0.0561±0.0083	0.0561±0.0150
Weight of fresh faeces excreted[2]	0.0068±0.0042	0.0005±0.0001	0.0005±0.0001
Percentage of faeces excreted per weight prawn	63.79	49.52	18.19
C_{input}[3]	0.0011±0.0002	0.0012±0.0002	0.0019±0.0001
$C_{fixation}$[3]	0.0009±0.0002	0.0011±0.0002	0.0018±0.0001
$C_{emitted}$[3]	0.0002±0.0001	0.0001±0.0000	0.0001±0.0000
$C_{emitted}/C_{input}$ (%)	18.18	8.33	5.26
$C_{emitted}/C_{fixation}$ (%)	22.22	9.09	5.56
Fixation efficiency, $C = (C_{input} - C_{emitted})/C_{input}$ (%)	81.82	91.67	94.74

Note: [1] Unit = kg per individual, [2] Unit = kg per kg of prawn per day, [3] Unit = kg carbon per kg of prawn per day

Table 4.17 Rates of carbon input, carbon fixation and carbon emitted of giant freshwater prawn (*Macrobrachium rosenbergii*) in Songkhla province (mean±SD).

Carbon contents	The size of farm		
	<1 rais	1-5 rais	>5 rais
Average of live-weight prawn[1]	0.0562±0.0083	0.0566±0.0089	0.0944±0.0136
Weight of fresh faeces excreted[2]	0.0080±0.0079	0.0012±0.0002	0.0144±0.0061
Percentage of faeces excreted per weight prawn	17.57	3.26	25.00
C_{input}[3]	0.0033±0.0027	0.0060±0.0045	0.0175±0.0052
$C_{fixation}$[3]	0.0019±0.0012	0.0059±0.0045	0.0150±0.0040
$C_{emitted}$[3]	0.0014±0.0001	0.0001±0.0001	0.0025±0.0015
$C_{emitted}/C_{input}$ (%)	42.42	1.67	14.29
$C_{emitted}/C_{fixation}$ (%)	73.68	1.70	16.67
Fixation efficiency, $C = (C_{input} - C_{emitted})/C_{input}$ (%)	57.58	98.33	85.71

Note: [1] Unit = kg per individual, [2] Unit = kg per kg of prawn per day, [3] Unit = kg carbon per kg of prawn per day

Table 4.18 Rates of carbon input, carbon fixation and carbon emitted of giant perch (*Lates calcarifer*) in Trang and Phatthalung provinces (mean±SD).

Carbon contents	Trang		Phatthalung
	<1 rais	1-5 rais	<1 rais
Average of live-weight fish[1]	1.9533±0.5222	1.3250±0.1422	1.9500±0.5272
Weight of fresh faeces excreted[2]	0.0073±0.0029	0.0078±0.0025	0.0066±0.0039
Percentage of faeces excreted per weight fish	37.37	39.24	16.92
C_{input}[3]	0.0092±0.0065	0.0079±0.0029	0.0085±0.0126
$C_{fixation}$[3]	0.0090±0.0064	0.0077±0.0028	0.0083±0.0125
$C_{emitted}$[3]	0.0002±0.0001	0.0002±0.0001	0.0002±0.0001
$C_{emitted}/C_{input}$ (%)	2.17	2.53	2.35
$C_{emitted}/C_{fixation}$ (%)	2.22	2.60	2.41
Fixation efficiency, $C = (C_{input} - C_{emitted})/C_{input}$ (%)	97.83	97.47	97.65

Note: [1] Unit = kg per individual, [2] Unit = kg per kg of fish per day, [3] Unit = kg carbon per kg of fish per day

Table 4.19 Rates of carbon input, carbon fixation and carbon emitted of giant perch (*Lates calcarifer*) in Songkhla province (mean±SD).

Carbon contents	The size of farm		
	<1 rais	1-5 rais	>5 rais
Average of live-weight fish[1]	2.4120±1.2020	2.2817±1.4152	2.3700±0.1059
Weight of fresh faeces excreted[2]	0.0058±0.0048	0.0054±0.0048	0.0022±0.0004
Percentage of faeces excreted per weight fish	9.62	11.83	4.64
C_{input}[3]	0.0060±0.0075	0.0074±0.0049	0.0047±0.0004
$C_{fixation}$[3]	0.0058±0.0074	0.0072±0.0048	0.0044±0.0003
$C_{emitted}$[3]	0.0002±0.0001	0.0002±0.0001	0.0003±0.0001
$C_{emitted}/C_{input}$ (%)	3.33	2.70	6.38
$C_{emitted}/C_{fixation}$ (%)	3.45	2.78	6.82
Fixation efficiency, $C = (C_{input} - C_{emitted})/C_{input}$ (%)	96.67	97.30	93.62

Note: [1] Unit = kg per individual, [2] Unit = kg per kg of fish per day, [3] Unit = kg carbon per kg of fish per day

Table 4.20 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of Pacific white shrimp (mean±SD) in Trang province.

The size of farm	Amount C transferred from aquatic food to shrimp (kg.C/kg.shrimp/day)			0.0152±0.0306
<5 rais	Carbon fixation (kg.C/kg.shrimp/day)	Meat		0.0099±0.0193
		Exoskeleton and visceral organs		0.0043±0.0113
		Total C accumulated in body (mass equilibrium)		0.0142±0.0306
	Carbon emission (kg.C/kg.shrimp/day)	Dry faeces		0.0001±0.0001
		C-emission of CO_2 and CH_4	Faeces	0.0009±0.0003
			Digestion and respiration	0.000000002±0.000000009
		Total C-emission from shrimp		0.0010±0.0004
	Amount C transferred from aquatic food to shrimp (kg.C/kg.shrimp/day)			0.0084±0.0071
5-10 rais	Carbon fixation (kg.C/kg.shrimp/day)	Meat		0.0049±0.0041
		Exoskeleton and visceral organs		0.0023±0.0029
		Total C accumulated in body (mass equilibrium)		0.0072±0.0070
	Carbon emission (kg.C/kg.shrimp/day)	Dry faeces		0.0001±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0011±0.0005
			Digestion and respiration	0.000000004±0.000000014
		Total C-emission from shrimp		0.0012±0.0005

Table 4.20 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of Pacific white shrimp (mean±SD) in Trang province (Continued).

The size of farm				
	Amount C transferred from aquatic food to shrimp (kg.C/kg.shrimp/day)			0.0053±0.0018
>10 rais	Carbon fixation (kg.C/kg.shrimp/day)	Meat		0.0025±0.0011
		Exoskeleton and visceral organs		0.0014±0.0004
		Total C accumulated in body (mass equilibrium)		0.0039±0.0015
	Carbon emission (kg.C/kg.shrimp/day)	Dry faeces		0.00002±0.00001
		C-emission of CO_2 and CH_4	Faeces	0.0014±0.0004
			Digestion and respiration	0.000000020±0.000000041
		Total C-emission from shrimp		0.0014±0.0005

Table 4.21 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of Pacific white shrimp (mean±SD) in Phatthalung province.

The size of farm	Amount C transferred from aquatic food to shrimp (kg.C/kg.shrimp/day)			0.0079±0.0043
<5 rais	Carbon fixation (kg.C/kg.shrimp/day)	Meat		0.0041±0.0030
		Exoskeleton and visceral organs		0.0027±0.0012
		Total C accumulated in body (mass equilibrium)		0.0068±0.0042
	Carbon emission (kg.C/kg.shrimp/day)	Dry faeces		0.0002±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0009±0.0003
			Digestion and respiration	0.000000010±0.000000028
		Total C-emission from shrimp		0.0011±0.0003
	Amount C transferred from aquatic food to shrimp (kg.C/kg.shrimp/day)			0.0047±0.0009
5-10 rais	Carbon fixation (kg.C/kg.shrimp/day)	Meat		0.0029±0.0008
		Exoskeleton and visceral organs		0.0012±0.0001
		Total C accumulated in body (mass equilibrium)		0.0041±0.0009
	Carbon emission (kg.C/kg.shrimp/day)	Dry faeces		0.00003±0.00002
		C-emission of CO_2 and CH_4	Faeces	0.0006±0.0002
			Digestion and respiration	0.000000020±0.000000041
		Total C-emission from shrimp		0.0006±0.0002

Table 4.22 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of Pacific white shrimp (mean±SD) in Songkhla province.

The size of farm	Amount C transferred from aquatic food to shrimp (kg.C/kg.shrimp/day)			0.0071±0.0017
<5 rais	Carbon fixation (kg.C/kg.shrimp/day)	Meat		0.0049±0.0012
		Exoskeleton and visceral organs		0.0012±0.0005
		Total C accumulated in body (mass equilibrium)		0.0061±0.0017
	Carbon emission (kg.C/kg.shrimp/day)	Dry faeces		0.0001±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0009±0.0003
			Digestion and respiration	0.000000003±0.000000012
		Total C-emission from shrimp		0.0010±0.0004
	Amount C transferred from aquatic food to shrimp (kg.C/kg.shrimp/day)			0.0073±0.0023
5-10 rais	Carbon fixation (kg.C/kg.shrimp/day)	Meat		0.0032±0.0011
		Exoskeleton and visceral organs		0.0021±0.0014
		Total C accumulated in body (mass equilibrium)		0.0053±0.0025
	Carbon emission (kg.C/kg.shrimp/day)	Dry faeces		0.0001±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0019±0.0007
			Digestion and respiration	0.000000003±0.000000013
		Total C-emission from shrimp		0.0020±0.0007

Table 4.22 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 from of Pacific white shrimp (mean±SD) in Songkhla province (Continued).

The size of farm	Amount C transferred from aquatic food to shrimp (kg.C/kg.shrimp/day)			0.0065±0.0010
>10 rais	Carbon fixation (kg.C/kg.shrimp/day)	Meat		0.0029±0.0005
		Exoskeleton and visceral organs		0.0013±0.0003
		Total C accumulated in body (mass equilibrium)		0.0042±0.0008
	Carbon emission (kg.C/kg.shrimp/day)	Dry faeces		0.0001±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0022±0.0002
			Digestion and respiration	0.000000032±0.000000053
		Total C-emission from shrimp		0.0023±0.0003

Table 4.23 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of giant freshwater prawn (mean±SD) in Trang province.

The size of farm	Amount C transferred from aquatic food to prawn (kg.C/kg.prawn/day)			0.0009±0.0002
<1 rais	Carbon fixation (kg.C/kg.prawn/day)	Meat		0.0007±0.0002
		Exoskeleton and visceral organs		0.0001±0.0000
		Total C accumulated in body (mass equilibrium)		0.0008±0.0002
	Carbon emission (kg.C/kg.prawn/day)	Dry faeces		0.0000±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0000
			Digestion and respiration	0.0000000000±0.0000000000
		Total C-emission from prawn		0.0001±0.0000
	Amount C transferred from aquatic food to prawn (kg.C/kg.prawn/day)			0.0013±0.0004
1-5 rais	Carbon fixation (kg.C/kg.prawn/day)	Meat		0.0006±0.0003
		Exoskeleton and visceral organs		0.0002±0.0000
		Total C accumulated in body (mass equilibrium)		0.0008±0.0003
	Carbon emission (kg.C/kg.prawn/day)	Dry faeces		0.0000±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0005±0.0002
			Digestion and respiration	0.0000000000±0.0000000001
		Total C-emission from prawn		0.0005±0.0002

Table 4.24 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of giant freshwater prawn (mean±SD) in Phatthalung province.

The size of farm	Amount C transferred from aquatic food to prawn (kg.C/kg.prawn/day)			0.0011±0.0002
<1 rais	Carbon fixation (kg.C/kg.prawn/day)	Meat		0.0008±0.0002
		Exoskeleton and visceral organs		0.0001±0.0000
		Total C accumulated in body (mass equilibrium)		0.0009±0.0002
	Carbon emission (kg.C/kg.prawn/day)	Dry faeces		0.0001±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0001
			Digestion and respiration	0.0000000000±0.0000000001
		Total C-emission from prawn		0.0002±0.0001
	Amount C transferred from aquatic food to prawn (kg.C/kg.prawn/day)			0.0012±0.0002
1-5 rais	Carbon fixation (kg.C/kg.prawn/day)	Meat		0.0009±0.0002
		Exoskeleton and visceral organs		0.0002±0.0000
		Total C accumulated in body (mass equilibrium)		0.0011±0.0002
	Carbon emission (kg.C/kg.prawn/day)	Dry faeces		0.0000±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0000
			Digestion and respiration	0.0000000001±0.0000000002
		Total C-emission from prawn		0.0001±0.0000

Table 4.24 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of giant freshwater prawn (mean±SD) in Phatthalung province (Continued).

The size of farm	Amount C transferred from aquatic food to prawn (kg.C/kg.prawn/day)			0.0019±0.0001
>5 rais	Carbon fixation (kg.C/kg.prawn/day)	Meat		0.0010±0.0001
		Exoskeleton and visceral organs		0.0008±0.0000
		Total C accumulated in body (mass equilibrium)		0.0018±0.0001
	Carbon emission (kg.C/kg.prawn/day)	Dry faeces		0.0000±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0000
			Digestion and respiration	0.0000000003±0.0000000003
		Total C-emission from prawn		0.0001±0.0000

Table 4.25 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of giant freshwater prawn (mean±SD) in Songkhla province.

The size of farm				
<1 rais	Amount C transferred from aquatic food to prawn (kg.C/kg.prawn/day)			0.0033±0.0027
	Carbon fixation (kg.C/kg.prawn/day)	Meat		0.0010±0.0006
		Exoskeleton and visceral organs		0.0009±0.0006
		Total C accumulated in body (mass equilibrium)		0.0019±0.0012
	Carbon emission (kg.C/kg.prawn/day)	Dry faeces		0.0001±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0013±0.0001
			Digestion and respiration	0.0000000000±0.0000000001
		Total C-emission from prawn		0.0014±0.0001
1 -5 rais	Amount C transferred from aquatic food to prawn (kg.C/kg.prawn/day)			0.0060±0.0045
	Carbon fixation (kg.C/kg.prawn/day)	Meat		0.0038±0.0029
		Exoskeleton and visceral organs		0.0021±0.0016
		Total C accumulated in body (mass equilibrium)		0.0059±0.0045
	Carbon emission (kg.C/kg.prawn/day)	Dry faeces		0.0000±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0001
			Digestion and respiration	0.0000000001±0.0000000002
		Total C-emission from prawn		0.0001±0.0001

Table 4.25 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of giant freshwater prawn (mean±SD) in Songkhla province (Continued).

The size of farm	Amount C transferred from aquatic food to prawn (kg.C/kg.prawn/day)			0.0175±0.0052
>5 rais	Carbon fixation (kg.C/kg.prawn/day)	Meat		0.0096±0.0022
		Exoskeleton and visceral organs		0.0054±0.0018
		Total C accumulated in body (mass equilibrium)		0.0150±0.0040
	Carbon emission (kg.C/kg.prawn/day)	Dry faeces		0.0002±0.0001
		C-emission of CO_2 and CH_4	Faeces	0.0023±0.0014
			Digestion and respiration	0.0000000002±0.0000000004
		Total C-emission from prawn		0.0025±0.0015

Table 4.26 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of giant perch (mean±SD) in Trang province.

The size of farm	Amount C transferred from aquatic food to fish (kg.C/kg.fish/day)			0.0092±0.0065
<1 rais	Carbon fixation (kg.C/kg.fish/day)	Meat		0.0073±0.0050
		Bone and visceral organs		0.0017±0.0014
		Total C accumulated in body (mass equilibrium)		0.0090±0.0064
	Carbon emission (kg.C/kg.fish/day)	Dry faeces		0.0001±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0000
			Digestion and respiration	0.000001595±0.000004401
		Total C-emission from fish		0.0002±0.0001
	Amount C transferred from aquatic food to fish (kg.C/kg.fish/day)			0.0079±0.0029
1-5 rais	Carbon fixation (kg.C/kg.fish/day)	Meat		0.0056±0.0018
		Bone and visceral organs		0.0021±0.0010
		Total C accumulated in body (mass equilibrium)		0.0077±0.0028
	Carbon emission (kg.C/kg.fish/day)	Dry faeces		0.0001±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0001
			Digestion and respiration	0.000001293±0.000003808
		Total C-emission from fish		0.0002±0.0001

Table 4.27 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of giant perch (mean±SD) in Phatthalung province.

The size of farm	Amount C transferred from aquatic food to fish (kg.C/kg.fish/day)			0.0085±0.0126
<1 rais	Carbon fixation (kg.C/kg.fish/day)	Meat		0.0064±0.0101
		Bone and visceral organs		0.0019±0.0024
		Total C accumulated in body (mass equilibrium)		0.0083±0.0125
	Carbon emission (kg.C/kg.fish/day)	Dry faeces		0.0001±0.0000
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0000
			Digestion and respiration	0.000001179±0.000003054
		Total C-emission from fish		0.0002±0.0001

Table 4.28 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of giant perch (mean±SD) in Songkhla province.

The size of farm			Amount C transferred from aquatic food to fish (kg.C/kg.fish/day)	0.0060±0.0075
<1 rais	Carbon fixation (kg.C/kg.fish/day)		Meat	0.0038±0.0038
			Bone and visceral organs	0.0020±0.0036
			Total C accumulated in body (mass equilibrium)	0.0058±0.0074
	Carbon emission (kg.C/kg.fish/day)		Dry faeces	0.0001±0.0001
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0000
			Digestion and respiration	0.000002663±0.000017202
			Total C-emission from fish	0.0002±0.0001
			Amount C transferred from aquatic food to fish (kg.C/kg.fish/day)	0.0074±0.0049
1-5 rais	Carbon fixation (kg.C/kg.fish/day)		Meat	0.0066±0.0047
			Bone and visceral organs	0.0006±0.0001
			Total C accumulated in body (mass equilibrium)	0.0072±0.0048
	Carbon emission (kg.C/kg.fish/day)		Dry faeces	0.0001±0.0001
		C-emission of CO_2 and CH_4	Faeces	0.0001±0.0000
			Digestion and respiration	0.000002451±0.000015214
			Total C-emission from fish	0.0002±0.0001

Table 4.28 Average of C-input, C-fixation, C-output and C-emission in form of CO_2 and CH_4 of giant perch (mean±SD) in Songkhla province (Continued).

The size of farm	Amount C transferred from aquatic food to fish (kg.C/kg.fish/day)			0.0047±0.0004
>5 rais	Carbon fixation (kg.C/kg.fish/day)	Meat		0.0031±0.0002
		Bone and visceral organs		0.0014±0.0001
		Total C accumulated in body (mass equilibrium)		0.0044±0.0003
	Carbon emission (kg.C/kg.fish/day)	Dry faeces		0.00002±0.00000
		C-emission of CO_2 and CH_4	Faeces	0.0003±0.0001
			Digestion and respiration	0.000004490±0.000012244
		Total C-emission from fish		0.0003±0.0001

At the same time, the results of carbon emissions of giant perch from three provinces had a similar value at 0.0002±0.0000 kg.C/kg.fish/day. Most carbon content in the form of fish faeces in Songkhla, Phatthalung and Trang provinces were 3.33%, 1.18% and 1.16% of total carbon emission, respectively (Table 4.31).

For the quantity of carbon that was released in the form of carbon dioxide (CO_2) and methane (CH_4) from respiration and digestion of these three aquatic animal species had a relatively low value as shown in the Figures 4.1 - 4.3. These values compared favorably with the reports to carbon emissions associated with beef, pork, poultry and sheep productions (Nemry, Theunis, Brechet, and Lopez, 2001; Thanee, Dankittikul, and Keeratiurai, 2009a, 2009b).

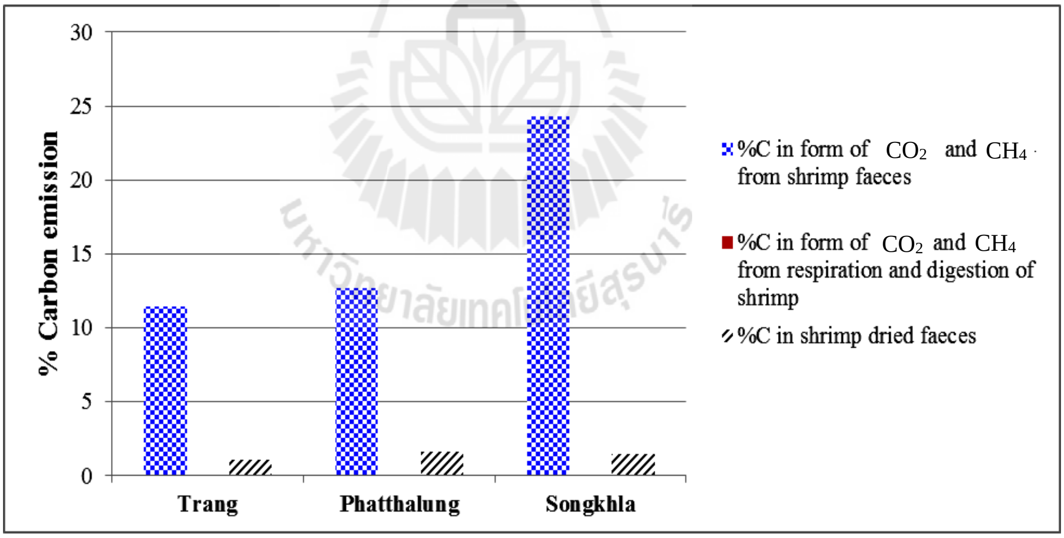


Figure 4.1 Proportion of carbon emission per 1 kg per day from different sources of Pacific white shrimp.

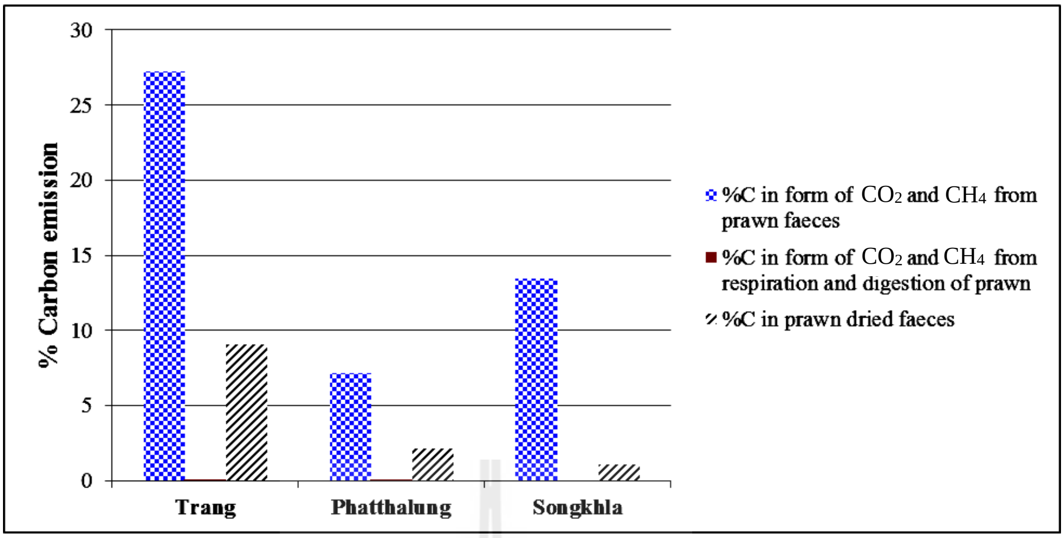


Figure 4.2 Proportion of carbon emission per 1 kg per day from different sources of giant freshwater prawn.

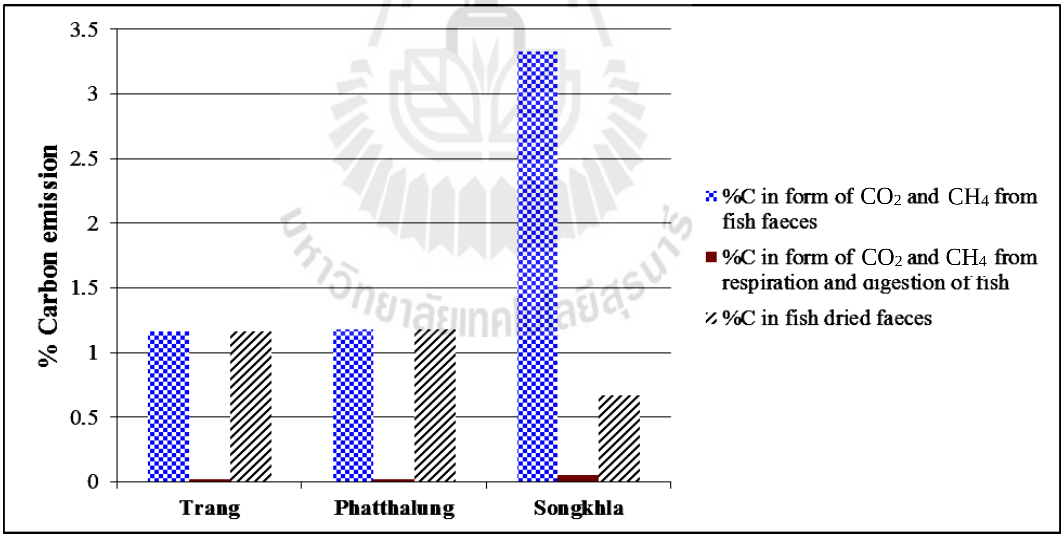


Figure 4.3 Proportion of carbon emission per 1 kg per day from different sources of giant perch.

Table 4.29 Average of carbon emission in the form of carbon dioxide (CO_2) and methane (CH_4) from Pacific white shrimp (mean±SD).

Province	**Mean of gas from**	**The size of farm (Rai)**	**CH_4**		**CO_2**		**Ratio CH_4 : CO_2**	
Trang	Feaces	<5	0.00068±0.00025	0.00085±0.00030	0.00150±0.00055	0.00186±0.00067	0.46	**0.04**
		5-10	0.00082±0.00034		0.00181±0.00074			
		>10	0.00103±0.00033		0.00226±0.00072			
	Digestion and respiration	<5	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.12	
		5-10	0.000000±0.000000		0.000000±0.000000			
		>10	0.000000±0.000000		0.000000±0.000000			
Phatthalung	Feaces	<5	0.00068±0.00020	0.00056±0.00018	0.00149±0.00044	0.00122±0.00039	0.46	**0.05**
		5-10	0.00043±0.00015		0.00095±0.00034			
	Digestion and respiration	<5	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.10	
		5-10	0.000000±0.000000		0.000000±0.000000			
Songkhla	Feaces	<5	0.00067±0.00025	0.00124±0.00032	0.00148±0.00054	0.00271±0.00071	0.46	**0.05**
		5-10	0.00142±0.00054		0.00311±0.00118			
		>10	0.00162±0.00018		0.00355±0.00040			
	Digestion and respiration	<5	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.10	
		5-10	0.000000±0.000000		0.000000±0.000000			
		>10	0.000000±0.000000		0.000000±0.000000			

Note: Unit = kg carbon per kg of shrimp per day

Table 4.30 Average of carbon emission in the form of carbon dioxide (CO_2) and methane (CH_4) from giant freshwater prawn (mean±SD).

Province	Mean of gas from	The size of farm (Rai)	CH_4		CO_2		Ratio CH_4 : CO_2	
Trang	Feaces	<1	0.00004±0.00003	0.00019±0.00026	0.00009±0.00005	0.00042±0.00058	0.45	**0.09**
		1-5	0.00034±0.00050		0.00074±0.00110			
	Digestion and respiration	<1	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.05	
		1-5	0.000000±0.000000		0.000000±0.000000			
Phatthalung	Feaces	<1	0.00007±0.00004	0.00005±0.00002	0.00015±0.00009	0.00011±0.00004	0.46	**0.05**
		1-5	0.00003±0.00001		0.00005±0.00001			
		>5	0.00007±0.00001		0.00014±0.00001			
	Digestion and respiration	<1	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.10	
		1-5	0.000000±0.000000		0.000000±0.000000			
		>5	0.000000±0.000000		0.000000±0.000000			
Songkhla	Feaces	<1	0.00097±0.00112	0.00092±0.00074	0.00206±0.00237	0.00195±0.00157	0.47	**0.05**
		1-5	0.00007±0.00004		0.00014±0.00008			
		>5	0.00173±0.00107		0.00366±0.00227			
	Digestion and respiration	<1	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.000000±0.000000	0.10	
		1-5	0.000000±0.000000		0.000000±0.000000			
		>5	0.000000±0.000000		0.000000±0.000000			

Note: Unit = kg carbon per kg of prawn per day

Table 4.31 Average of carbon emission in the form of carbon dioxide (CO_2) and methane (CH_4) from giant perch (mean±SD).

Province	Mean of gas from	The size of farm (Rai)	CH_4		CO_2		Ratio CH_4 : CO_2	
Trang	Feaces	<1	0.00007±0.00003	0.00007±0.00002	0.00016±0.00007	0.00016±0.00005	0.44	**0.04**
		1-5	0.00008±0.00001		0.00017±0.00003			
	Digestion and respiration	<1	0.000000±0.000000	0.000000±0.000000	0.000002±0.000004	0.000001±0.000004	0.10	
		1-5	0.000000±0.000000		0.000001±0.000004			
Phatthalung	Feaces	<1	0.00007±0.00004	0.00007±0.00004	0.00016±0.00008	0.00016±0.00008	0.44	**0.09**
	Digestion and respiration	<1	0.000000±0.000000	0.000000±0.000000	0.000001±0.000003	0.000001±0.000003	0.05	
Songkhla	Feaces	<1	0.00007±0.00003	0.00012±0.00005	0.00016±0.00007	0.00026±0.00010	0.46	**0.15**
		1-5	0.00009±0.00006		0.00019±0.00012			
		>5	0.00020±0.00005		0.00044±0.00011			
	Digestion and respiration	<1	0.000000±0.000000	0.000000±0.000000	0.000003±0.000017	0.000003±0.000015	0.03	
		1-5	0.000000±0.000000		0.000002±0.000015			
		>5	0.000000±0.000000		0.000004±0.000012			

Note: Unit = kg carbon per kg of fish per day

The Food and Agriculture Organization of the United Nations (FAO) reported that aquaculture production, compared to other animal husbandry practices, has a small overall CO_2 emission. The largest part of aquaculture production is based on freshwater species such as carp, requiring small amounts of fertilizer, often organic and in some cases, low-energy supplementary feeds. Although some species and systems, such as shrimp, salmon and marine carnivores, are a minor part of total production, they have high feed energy or system energy demands and consequently higher footprints (FAO, 2009).

The average amount of carbon was released in the form of CO_2 and CH_4 from digestion, respiration and faeces (see Tables 4.29 - 4.31). According to the proportion of CO_2 and CH_4 emissions, a giant perch emitted higher value at 0.09 time than giant freshwater prawn (0.06 time) and Pacific white shrimp (0.05 time) compared with the same weight of aquatic animals. The global warming potential (GWP) of CH_4 is estimated to be 21 times that of CO_2 and nitrous oxide (N_2O) almost 310 times that of CO_2 (IPCC, 2001). Therefore, it can be concluded that a giant perch had more contribution to the cause of global warming than Pacific white shrimp and giant freshwater prawn due to the CO_2 and CH_4 emissions.

Burg van den, Taal, Boer de, Bakker, and Viets (2012) reported GHGs emission of aquaculture systems that the methane formation occurred in an anaerobic environment, mainly in mud layers in aquaculture ponds. In many cases, the fish toss the soil, so an anaerobic environment does not exist, but in *Pangasius* sp. cultivation is different. Nitrous oxide (N_2O) is released during microbial transformation of nitrogen in the soil or in manure (i.e. nitrification of NH_3 into NO_3^- and incomplete denitrification of NO_3^- into N_2) as well as during nitrate fertilizer production for feed ingredients.

4.2.2 Comparison of carbon transfer analysis results in each aquaculture kind

A study of carbon emissions by the principle of conservation of mass, the UNECE (2004) explained that the emission of carbon by mass conservation principle which could tell total carbon emission from the production of 1 kg live-weight for Pacific white shrimp, giant freshwater prawn and giant perch as shown as follow:

$$\text{C-emitted}_{(\text{aquatic animal})} = (0.0005)\text{Pacific white shrimp} + (0.0002)\text{Giant freshwater prawn} + (0.0001)\text{Giant perch} \quad (4.1)$$

Where:

$\text{C-emitted}_{(\text{aquatic animal})}$ = Total carbon emission from Pacific white shrimp, giant freshwater prawn and giant perch bodies (ton carbon per year).

Pacific white shrimp = Weight of Pacific white shrimp (kg).

Giant freshwater prawn = Weight of giant freshwater prawn (kg).

Giant perch = Weight of giant perch (kg).

The results of the rate of carbon transfer from aquatic food to each aquatic animal by food consumption (C_{input}) and then fixed in aquatic animal bodies and organs ($C_{fixation}$), as well as the carbon content from animal faeces excreted and carbon in the form of CO_2 and CH_4 from digestion and respiration of aquatic animal ($C_{emitted}$) during rearing duration for aquatic animal are shown in Tables 4.20 - 4.28.

Additionally, a giant perch transferred carbon massflow from aquatic food to fish or carbon consumption per 1 kg of body weights per day, which higher than Pacific white shrimp and giant freshwater prawn. At same body weight of aquatic animals, the ranking of the carbon transfer (C_{input}) from the highest to lowest is giant perch > Pacific white shrimp > giant freshwater prawn ($p \leq 0.05$).

Thence, the results of regression analysis can be summarized the relationship between C-emitted and C-input for Pacific white shrimp of Trang, Phatthalung and Songkhla provinces are shown in the regression equations 4.2, 4.3 and 4.4.

$$\text{C-emitted}_{shrimp(Trang)} = 0.001(\text{C-input}_{shrimp\ food}) + 0.001 \quad (4.2)$$

Where:

$\text{C-emitted}_{shrimp(Trang)}$ = Carbon emitted from Pacific white shrimp in Trang province (kg.C/kg.shrimp/day).

$\text{C-input}_{shrimp\ food}$ = Carbon content in shrimp food which transferred to Pacific white shrimp by consumption with average value at 0.0096±0.0051 (kg.C/kg.shrimp/day).

$$\text{C-emitted}_{shrimp(Phatthalung)} = 0.047(\text{C-input}_{shrimp\ food}) + 0.001 \quad (4.3)$$

Where:

$C\text{-emitted}_{shrimp(Phatthalung)}$ = Carbon emitted from Pacific white shrimp in Phatthalung province (kg.C/kg.shrimp/day).

$C\text{-input}_{shrimp\ food}$ = Carbon content in shrimp food which transferred to Pacific white shrimp by consumption with average value at 0.0063±0.0023 (kg.C/kg.shrimp/day).

$$C\text{-emitted}_{shrimp(Songkhla)} = 0.004(C\text{-input}_{shrimp\ food}) + 0.002 \quad (4.4)$$

Where:

$C\text{-emitted}_{shrimp(Songkhla)}$ = Carbon emitted from Pacific white shrimp in Songkhla province (kg.C/kg.shrimp/day).

$C\text{-input}_{shrimp\ food}$ = Carbon content in shrimp food which transferred to Pacific white shrimp by consumption with average value at 0.0070±0.0004 (kg.C/kg.shrimp/day).

The analysis of relationship between C-emitted and C-input of giant freshwater prawn in Trang, Phatthalung and Songkhla provinces are shown in the regression equations 4.5, 4.6 and 4.7.

$$C\text{-emitted}_{prawn(Trang)} = 1.083(C\text{-input}_{prawn\ food}) + 0.001 \quad (4.5)$$

Where:

$C\text{-emitted}_{prawn(Trang)}$ = Carbon emitted from giant freshwater prawn in Trang province (kg.C/kg.prawn/day).

$C\text{-input}_{prawn\ food}$ = Carbon content in prawn food which transferred to giant freshwater prawn by consumption with average value at 0.0011±0.0003 (kg.C/kg. prawn/day).

$$C\text{-emitted}_{prawn(Phatthalung)} = 0.033(C\text{-input}_{prawn\ food}) \quad (4.6)$$

Where:

$C\text{-emitted}_{prawn(Phatthalung)}$ = Carbon emitted from giant freshwater prawn in Phatthalung province (kg.C/kg.prawn/day).

$C\text{-input}_{prawn\ food}$ = Carbon content in prawn food which transferred to giant freshwater prawn by consumption with average value at 0.0014±0.0004 (kg.C/kg. prawn/day).

$$C\text{-emitted}_{prawn(Songkhla)} = 0.106(C\text{-input}_{prawn\ food}) \quad (4.7)$$

Where:

$C\text{-emitted}_{prawn(Songkhla)}$ = Carbon emitted from giant freshwater prawn in Songkhla province (kg.C/kg.prawn/day).

$C\text{-input}_{prawn\ food}$ = Carbon content in prawn food which transferred to giant freshwater prawn by consumption with average value at 0.0089±0.0075 (kg.C/kg. prawn/day).

The analysis of relationship between C-emitted and C-input of giant perch in Trang, Phatthalung and Songkhla provinces are shown in the regression equations as follows:

$$C\text{-emitted}_{fish(Trang)} = 0.006(C\text{-input}_{fish\ food}) \quad (4.8)$$

Where:

$C\text{-emitted}_{fish(Trang)}$ = Carbon emitted from giant perch in Trang province (kg.C/kg.fish/day).

$C\text{-input}_{fish\ food}$ = Carbon content in fish food which transferred to giant perch by consumption with average value at 0.0086±0.0009 (kg.C/kg.fish/day).

$$C\text{-emitted}_{fish(Phatthalung)} = 0.005(C\text{-input}_{fish\ food}) \quad (4.9)$$

Where:

$C\text{-emitted}_{fish(Phatthalung)}$ = Carbon emitted from giant perch in Phatthalung province (kg.C/kg.fish/day).

$C\text{-input}_{fish\ food}$ = Carbon content in fish food which transferred to giant perch by consumption with average value at 0.0085±0.0000 (kg.C/kg.fish/day).

$$C\text{-emitted}_{fish(Songkhla)} = 0.005(C\text{-input}_{fish\ food}) \quad (4.10)$$

Where:

$C\text{-emitted}_{fish(Songkhla)}$ = Carbon emitted from giant perch in Songkhla province (kg.C/kg.fish/day).

$C\text{-input}_{fish\ food}$ = Carbon content in fish food which transferred to giant perch by consumption with average value at 0.0060±0.0014 (kg.C/kg.fish/day).

According to the Principle of Conservation of Mass, it is found that carbon fixation in aquatic animal body (C-fixation) at 1 kg live-weight per day from carbon in the form of feed consumption (C-input) minus the carbon emitted from faeces, digestion and respiration (C-emission). All carbons which accumulated in the aquatic animals bodies each day are used for a normal life and metabolism of the body to create new tissues. The balance of minerals and water within the aquatic animal body. Including the movement of food in the digestive system, respiratory, circulation, nerve function, reproductive, temperature regulation, and the movement of aquatic animals, which all require energy. Aquatic animals use several physiological and behavioral mechanisms to maintain their body temperature and minimize the loss of energy.

De Silva and Anderson (1995) have described how animals get energy by food consumption, which the energy appears in the form of chemical bond in molecules, protein, carbohydrates and fats. Thus, each animal has the ability to obtain energy from different kinds of food. A protein is the main organic component of aquatic animal tissues including to being used for growth and repair of tissues. Protein is also used extensively for providing energy in routine metabolism by aquatic animal (Guillaume, Kaushik, Bergot, and Metailler, 2004). It is therefore, an essential nutrient for both maintenance and growth.

Comparison of the percentage of average carbons fixed in aquatic animals per average carbon content in aquatic food for each aquatic animal per day ($C_{fixation}/C_{input}$) showed that giant perch fixed the highest (97.08%) carbon value from aquatic food (Table 4.32).

The results of the fixation rates from animal food to aquatic animals by consumption in raising duration and the Principle of Mass Conservation (UNECE, 2004) can be shown in different formula in each aquatic animal as follow:

$$C_{input} = (0.0028)\text{Pacific white shrimp} + (0.0014)\text{Giant freshwater prawn} + (0.0028)\text{Giant perch} \quad (4.11)$$

$$C_{fixation} = (0.0023)\text{Pacific white shrimp} + (0.0012)\text{Giant freshwater prawn} + (0.0027)\text{Giant perch} \quad (4.12)$$

Where:

C_{input} = Carbon massflow from food to aquatic animals by consumption of each aquatic animal in utilized age (ton carbon per year).

$C_{fixation}$ = Carbon fixation in each aquatic animal body (ton carbon per year).

Pacific white shrimp = Weight of Pacific white shrimp (kg).

Giant freshwater prawn = Weight of giant freshwater prawn (kg).

Giant perch = Weight of giant perch (kg).

Table 4.32 Ratio of total meat, shell, bone and entrails in each aquatic animal (mean±SD).

Animal	Province	Total meat (%)	Exoskeleton, bone, and visceral organs (%)	$C_{fixation}/C_{input}$ (%)	
Pacific white shrimp	Trang	64.504±7.431	35.424±9.397	87.49	82.50
	Phatthalung	63.216±6.331	34.069±2.638	85.73	
	Songkhla	67.544±8.386	34.188±9.397	74.28	
Giant freshwater prawn	Trang	74.800±3.271	35.200±12.739	63.64	79.92
	Phatthalung	76.020±4.391	38.388±12.930	90.72	
	Songkhla	78.109±3.584	37.298±12.473	85.40	
Giant perch	Trang	84.400±2.608	15.600±2.608	97.66	97.08
	Phatthalung	85.450±2.583	13.480±2.587	97.62	
	Songkhla	86.359±2.481	15.287±2.471	95.95	

The relationships between carbon input to aquatic animals by food consumption and carbon fixation in each aquatic animal can be shown in the formula 4.13 - 4.21 at 95% confidence ($p \leq 0.05$).

Thence, the results of regression analysis can be summarized the relationship between C-fixation and C-input for Pacific white shrimp in Trang, Phatthalung and Songkhla provinces as shown in the regression equations as follow:

$$C\text{-fixation}_{shrimp(Trang)} = 0.990(C\text{-input}_{shrimp\ food}) - 0.001 \quad (4.13)$$

Where:

$C\text{-fixation}_{shrimp(Trang)}$ = Carbon fixation in Pacific white shrimp in Trang province (kg.C/kg.shrimp/day).

$C\text{-input}_{shrimp\ food}$ = Carbon content in shrimp food which transferred to Pacific white shrimp by consumption with average value at 0.0096±0.0051 (kg.C/kg.shrimp/day).

$$C\text{-fixation}_{shrimp(Phatthalung)} = 0.093(C\text{-input}_{shrimp\ food}) - 0.001 \quad (4.14)$$

Where:

$C\text{-fixation}_{shrimp(Phatthalung)}$ = Carbon fixation in Pacific white shrimp of Phatthalung province (kg.C/kg.shrimp/day).

$C\text{-input}_{shrimp\ food}$ = Carbon content in shrimp food which transferred to Pacific white shrimp by consumption with average value at 0.0063±0.0023 (kg.C/kg.shrimp/day).

$$C\text{-fixation}_{shrimp(Songkhla)} = 1.004(C\text{-input}_{shrimp\ food}) - 0.002 \quad (4.15)$$

Where:

$C\text{-fixation}_{shrimp(Songkhla)}$ = Carbon fixation from Pacific white shrimp in Songkhla province (kg.C/kg.shrimp/day).

$C\text{-input}_{shrimp\ food}$ = Carbon content in shrimp food which transferred to Pacific white shrimp by consumption with average value at 0.0070±0.0004 (kg.C/kg.shrimp/day).

The analysis of relationship between C-fixation and C-input of giant freshwater prawn in Trang, Phatthalung and Songkhla provinces are shown in the regression equations 4.16 - 4.18.

$$C\text{-fixation}_{prawn(Trang)} = 0.085(C\text{-input}_{prawn\ food}) + 0.001 \quad (4.16)$$

Where:

$C\text{-fixation}_{prawn(Trang)}$ = Carbon fixation from giant freshwater prawn in Trang province (kg.C/kg.prawn/day).

$C\text{-input}_{prawn\ food}$ = Carbon content in prawn food which transferred to giant freshwater prawn by consumption with average value at 0.0011±0.0003 (kg.C/kg. prawn/day).

$$C\text{-fixation}_{prawn(Phatthalung)} = 1.035(C\text{-input}_{prawn\ food}) + 0.001 \quad (4.17)$$

Where:

$C\text{-}fixation_{prawn(Phatthalung)}$ = Carbon fixation from giant freshwater prawn in Phatthalung province (kg.C/kg.prawn/day).

$C\text{-}input_{prawn\ food}$ = Carbon content in prawn food which transferred to giant freshwater prawn by consumption with average value at 0.0014±0.0004 (kg.C/kg. prawn/day).

$$C\text{-}fixation_{prawn(Songkhla)} = 0.894(C\text{-}input_{prawn\ food}) + 0.001 \quad (4.18)$$

Where:

$C\text{-}fixation_{prawn(Songkhla)}$ = Carbon fixation from giant freshwater prawn in Songkhla province (kg.C/kg.prawn/day).

$C\text{-}input_{prawn\ food}$ = Carbon content in prawn food which transferred to giant freshwater prawn by consumption with average value at 0.0089±0.0075 (kg.C/kg.prawn/day).

Additionally, the analysis of relationship between C-fixation and C-input of a giant perch from Trang, Phatthalung and Songkhla provinces are shown in the regression equations as follows:

$$C\text{-}fixation_{fish(Trang)} = 0.994(C\text{-}input_{fish\ food}) \quad (4.19)$$

Where:

$C\text{-}fixation_{fish(Trang)}$ = Carbon fixation from giant perch in Trang province (kg.C/kg.fish/day).

$C\text{-}input_{fish\ food}$ = Carbon content in fish food which transferred to giant perch by consumption with average value at 0.0086±0.0009 (kg.C/kg.fish/day).

$$C\text{-}fixation_{fish(Phatthalung)} = 0.995(C\text{-}input_{fish\ food}) \quad (4.20)$$

Where:

$C\text{-}fixation_{fish(Phatthalung)}$ = Carbon fixation from giant perch in Phatthalung province (kg.C/kg.fish/day).

$C\text{-}input_{fish\ food}$ = Carbon content in fish food which transferred to giant perch by consumption with average value at 0.0085±0.0000 (kg.C/kg.fish/day).

$$C\text{-}fixation_{fish(Songkhla)} = 0.995(C\text{-}input_{fish\ food}) \quad (4.21)$$

Where:

$C\text{-}fixation_{fish(Songkhla)}$ = Carbon fixation from giant perch in Songkhla province (kg.C/kg.fish/day).

$C\text{-}input_{fish\ food}$ = Carbon content in fish food which transferred to giant perch by consumption with average value at 0.0060±0.0014 (kg.C/kg.fish/day).

Nevertheless, Figures 4.4 - 4.6 show the proportion of carbon contents from aquatic food which are transferred to each aquatic animal and fixed into parts of animal body and faeces including carbon in the form of CO_2 and CH_4 from the digestion and respiration per kg of aquatic animal per day. Carbon content at 100 parts in aquatic food was fixed in the body of giant perch, Pacific white shrimp and giant freshwater prawn at 97.08%, 82.50% and 79.92%, respectively. The rest of carbon content was released from each kind of aquatic animals through the excretion of waste, respiration and digestion at 2.92%, 17.50% and 20.08%, respectively. These carbons are an important part in causing the harmful environmental impacts. Therefore, it can be concluded that giant perch fixed the highest amount of carbon in their bodies and released the lowest amount of carbons compared to other studied aquatic animals. Whereas, giant freshwater prawn released carbon into the environment at 20.08% of all consumed aquatic food. Hence, the giant freshwater prawn production created more environmental impacts than other aquatic animal productions.

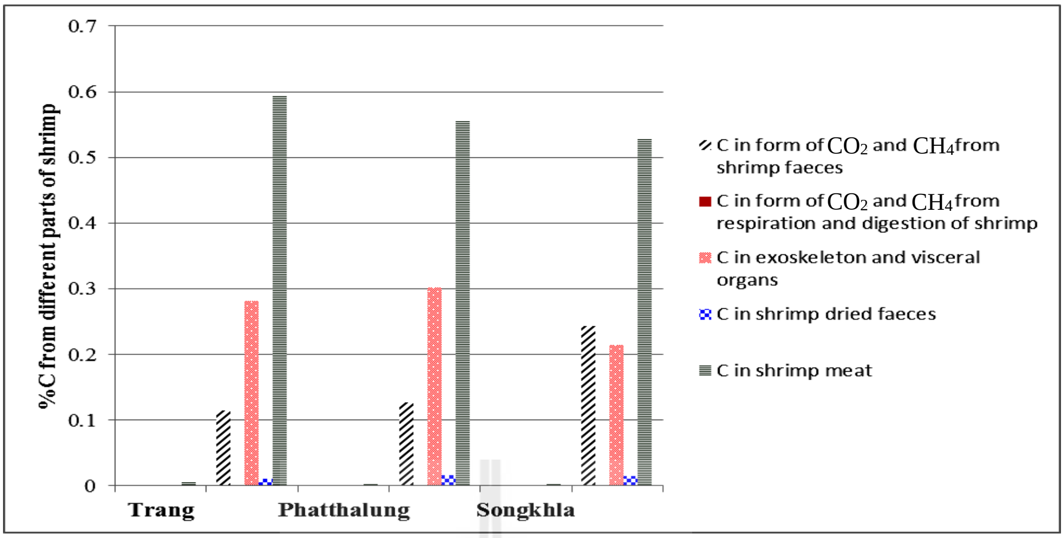


Figure 4.4 Percentage of carbon from different parts of Pacific white shrimp transferred from aquatic food per day in Trang, Phatthalung and Songkhla provinces.

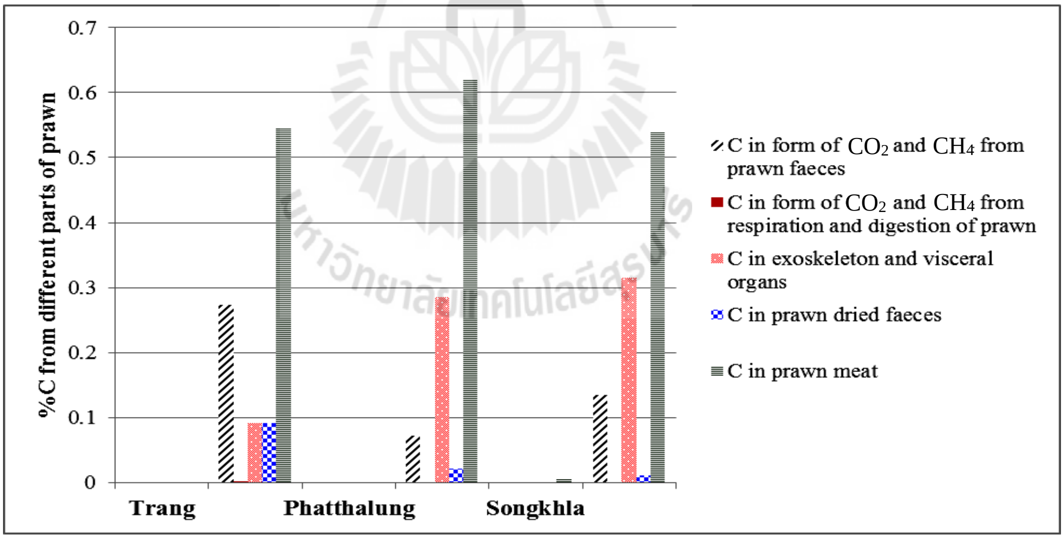


Figure 4.5 Percentage of carbon from different parts of giant freshwater prawntransferred from aquatic food per day in Trang, Phatthalung and Songkhla provinces.

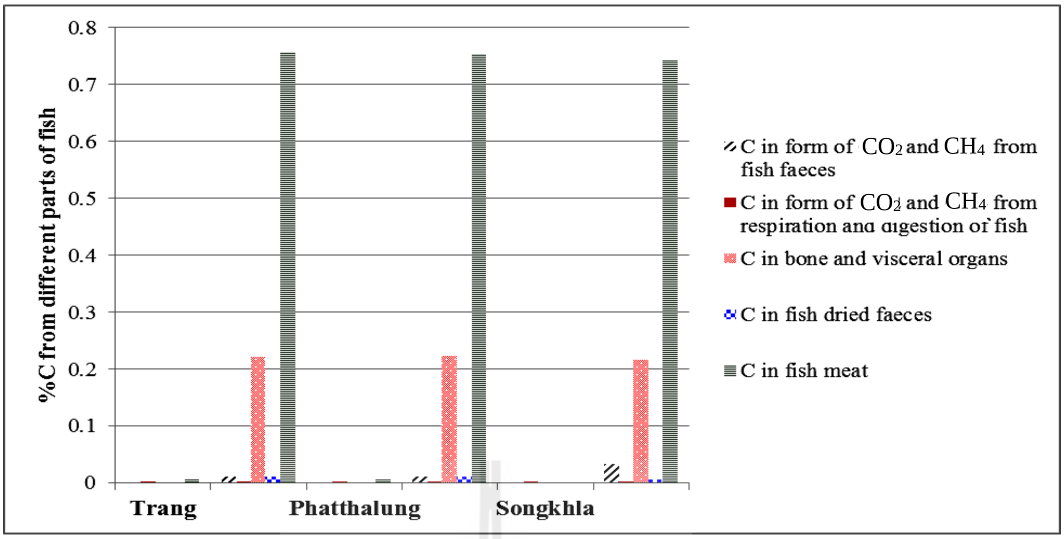


Figure 4.6 Percentage of carbon from different parts of giant perch transferred fromaquatic food per day in Trang, Phatthalung and Songkhla provinces.

4.3 Amount of carbon emission from energy use in aquaculture farm, hatchery and market

The survey of farms, hatcheries and markets in Trang, Phatthalung and Songkhla provinces found that aquaculture farms have used much energy for raising aquatic animal per day. Most of energy are used for aquatic meat production such as electricity for water pumps, lighting and aeration, fuel energy for water pumps and aeration including liquefied petroleum gas (LPG) for aeration.

Aeration systems helps maintain adequate dissolved oxygen (DO) concentrations of at least 6 mg/L. Carbon dioxide (CO_2) concentrations should be kept at less than 25 mg/L for best aquatic animal growth. Aeration is the uptake of oxygen from the atmosphere into water and oxygenation is the transfer of oxygen gas to water.

Throughout the cycle farmers either regularly managed water or used treatment only at times of poor water quality. For Pacific white shrimp farm, aeration with paddle wheels was common (85%) and some farmers used an air jet (15%). Only 10% of giant freshwater prawn and giant perch farms used paddle wheels for increased aeration in culture ponds. Water was exchanged every 14 days on average to maintain water quality or topped up to compensate for losses due to evaporation. Water quality in culture ponds was measured by 78% of the owner's aquaculture farms; all of them were measured pH on a weekly to monthly basis. A few also measured dissolved oxygen, alkalinity, ammonia and nitrogen. Periods of poor water quality were experienced by 45%; most common treatments included lime, dolomite or water exchange to control pH. Farmers who did not monitor water quality relied on visual inspection to assess pond health.

Furthermore, energy were used for transport of aquatic food, post larvae or giant perch fingerlings and LPG to farms and hatcheries including transport of aquatic product to markets or processing plants. The calculated carbon emissions for the production of 1 kg aquatic animal are shown in Tables 4.33 - 4.35 and Figures 4.7 - 4.9.

The result of carbon emission from giant perch farms had higher value than Pacific white shrimp and giant freshwater prawn farms which were 19.29, 11.94 and 5.63 kg.C/kg.aquatic animal/day, respectively. Most of energy used for transportation of fingerlings or post larvae, aquatic food and LPG to farms as well as transports of aquatic product to markets or processing plants.

Table 4.33 Average of C-emission from energy consumption in farm and hatchery of Pacific white shrimp (mean±SD).

Average carbon from energy use		C-emission (kg.C/kg.shrimp/day)			
		Trang	Phatthalung	Songkhla	Average
Farm	Electricity	0.0073±0.0068	0.0065±0.0027	0.0201±0.0083	0.0113±0.0059
	Fuel for transportation	14.9749±11.6976	15.4898±4.8648	4.9887±3.3524	11.8178±6.6383
	Fuel for machine	0.0003±0.0005	0.0011±0.0014	0.0089±0.0046	0.0034±0.0022
	LPG	0.0002±0.0004	0.0000±0.0001	0.0000±0.0000	0.0001±0.0002
	Total C from energy/1 kg shrimp/day	14.9826	15.4975	5.0177	11.8326
Hatchery	Electricity	3.6804±3.7517	N.D.	2.2309±1.2714	2.9557±2.5116
	Fuel for transportation	9.3973±6.9268	N.D.	6.6954±9.1532	8.0464±8.0400
	Fuel for machine	1.6201±1.3004	N.D.	0.2564±0.5591	0.9383±0.9298
	LPG	0.0000±0.0000	N.D.	0.0000±0.0000	0.0000±0.000
	Total C from energy/1 kg shrimp/day	14.6978	N.D.	9.1827	7.9602
Total $C_{emission}$ from energy of two source (kg.C/kg.shrimp/day)		29.6804	15.4975	14.2004	19.7928

Note: Reports and charts of electricity of Thailand in 2012 (2013) and TC Common data (2013) analyzed CO_2 emission from electricity = 0.5610 Kg.CO_2/kWh or 0.153 kg.C/kWh; Intergovernmental Panel on Climate Change (2007) has identified the CO_2 emission from fuel energy used (diesel) for transportation = 0.0494 kg.CO_2/1 ton-km or 0.014 kg.C/1 ton-km; CO_2 emission from diesel (stationary combustion) = 2.7080 kg.CO_2/L or 0.739 kg.C/L; CO_2 emission from LPG used = 3.11 Kg.CO_2/1 kg.LPG or 0.848 kg.C/1 kg.LPG.

Table 4.34 Average of C-emission from energy consumption in farm, hatchery and market of giant freshwater prawn (mean±SD).

Average carbon from energy use		C-emission (kg.C/kg.prawn/day)			
		Trang	Phatthalung	Songkhla	Average
Farm	Electricity	0.0002±0.0002	0.0012±0.0018	0.0006±0.0009	0.0007±0.0010
	Fuel for transportation	13.7270±4.6363	7.6800±3.1606	8.8420±6.6488	10.0830±4.8152
	Fuel for machine	0.0037±0.0046	0.0021±0.0024	0.0003±0.0003	0.0020±0.0024
	LPG	0.0003±0.0005	0.0001±0.0002	0.0000±0.0001	0.0001±0.0003
	Total C from energy/1 kg prawn/day	13.7312	7.6834	8.8429	10.0858
Hatchery	Electricity	2.5936±1.4403	1.1947±0.2292	1.6724±0.2931	1.8202±0.6542
	Fuel for transportation	4.1915±0.5141	3.2709±1.6247	3.5542±2.5011	3.6722±1.5466
	Fuel for machine	0.0000±0.0000	0.0000±0.0000	0.4075±0.2798	0.1358±0.0933
	Total C from energy/1 kg prawn/day	6.7851	4.4656	5.6341	5.6283
Market	Electricity	0.0014±0.0008	0.0018±0.0009	0.0018±0.0012	0.0017±0.0010
	Fuel for transportation	5.4491±5.0284	12.7582±5.8113	10.2543±4.5974	9.4872±5.1457
	LPG	0.0068±0.0071	0.0144±0.0046	0.0059±0.0101	0.0090±0.0073
	Total C from energy/1 kg prawn/day	5.4573	12.7744	10.2620	9.4979
Total $C_{emission}$ from energy of three source (kg.C/kg.prawn/day)		25.9736	24.9234	24.7390	25.2120

Note: Reports and charts of electricity of Thailand in 2012 (2013) and TC Common data (2013) analyzed CO_2 emission from electricity = 0.5610 Kg.CO_2/kWh or 0.153 kg.C/kWh; Intergovernmental Panel on Climate Change (2007) has identified the CO_2 emission from fuel energy used (diesel) for transportation = 0.0494 kg.CO_2/1 ton-km or 0.014 kg.C/1 ton-km; CO_2 emission from diesel (stationary combustion) = 2.7080 kg.CO_2/L or 0.739 kg.C/L; CO_2 emission from LPG used = 3.11 Kg.CO_2/1 kg.LPG or 0.848 kg.C/1 kg.LPG.

Table 4.35 Average of C-emission from energy consumption in farm, hatchery and market of giant perch (mean±SD).

Average carbon from energy use		C-emission (kg.C/kg.fish/day)			
		Trang	Phatthalung	Songkhla	Average
Farm	Electricity	0.4075±0.2278	0.4937±0.2957	0.2228±0.18286	0.3747±0.2355
	Fuel for transportation	20.4854±4.3733	23.3216±7.1334	12.9160±8.70417	18.9077±6.7370
	Fuel for machine	0.0033±0.0030	0.0054±0.0031	0.0028±0.0027	0.0038±0.0029
	LPG	0.0011±0.0030	0.0016±0.0047	0.0017±0.0037	0.0015±0.0038
	Total C from energy/1 kg fish/day	20.8973	23.8223	13.1433	19.2876
Hatchery	Electricity	2.0031±2.1087	0.3681±0.1423	0.3982±0.1402	0.9231±0.7971
	Fuel for transportation	2.8067±2.3584	3.1443±0.9825	3.6768±2.9462	3.2093±2.0957
	Fuel for machine	0.0000±0.0000	0.2483±0.2298	0.0000±0.0000	0.0828±0.0766
	Total C from energy/1 kg fish/day	4.8098	3.7607	4.0750	4.2152
Market	Electricity	0.0063±0.0069	0.0024±0.0020	0.0051±0.0031	0.0046±0.0040
	Fuel for transportation	13.4478±10.2560	7.3778±5.6451	4.7569±4.2035	8.5275±6.7015
	LPG	0.0145±0.0084	0.0039±0.0020	0.0071±0.0066	0.0085±0.0057
	Total C from energy/1 kg fish/day	13.4686	7.3841	4.7691	8.5406
Total $C_{emission}$ from energy of three source (kg.C/kg.fish/day)		39.1757	34.9671	21.9874	32.0434

Note: Reports and charts of electricity of Thailand in 2012 (2013) and TC Common data (2013) analyzed CO_2 emission from electricity = 0.5610 Kg.CO_2/kWh or 0.153 kg.C/kWh; Intergovernmental Panel on Climate Change (2007) has identified the CO_2 emission from fuel energy used (diesel) for transportation = 0.0494 kg.CO_2/1 ton-km or 0.014 kg.C/1 ton-km; CO_2 emission from diesel (stationary combustion) = 2.7080 kg.CO_2/L or 0.739 kg.C/L; CO_2 emission from LPG used = 3.11 Kg.CO_2/1 kg.LPG or 0.848 kg.C/1 kg.LPG.

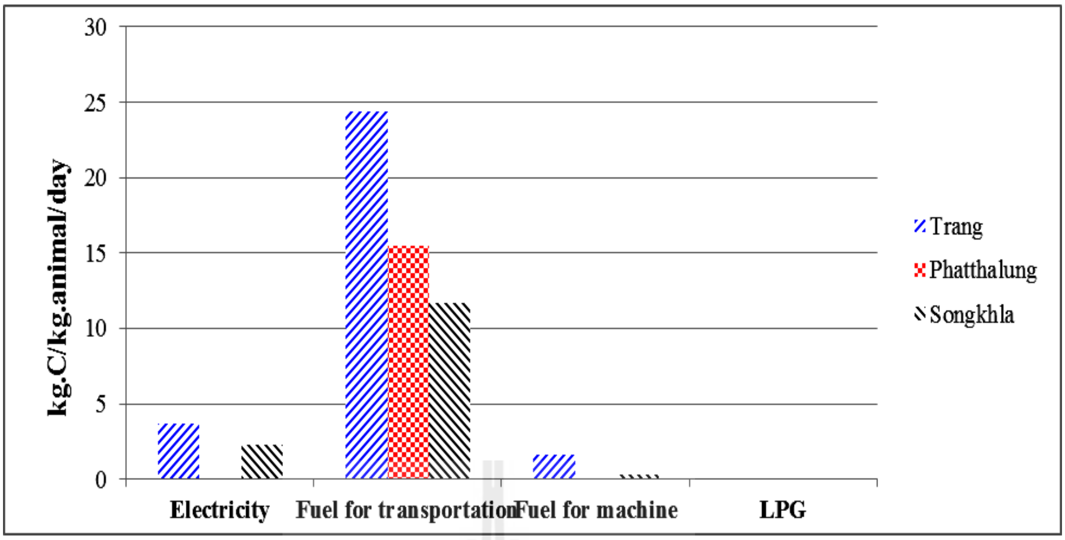


Figure 4.7 Total carbon emission from the use of electricity, fuel and LPG for production of Pacific white shrimp meat at 1 kg (kg.C/kg.shrimp/day).

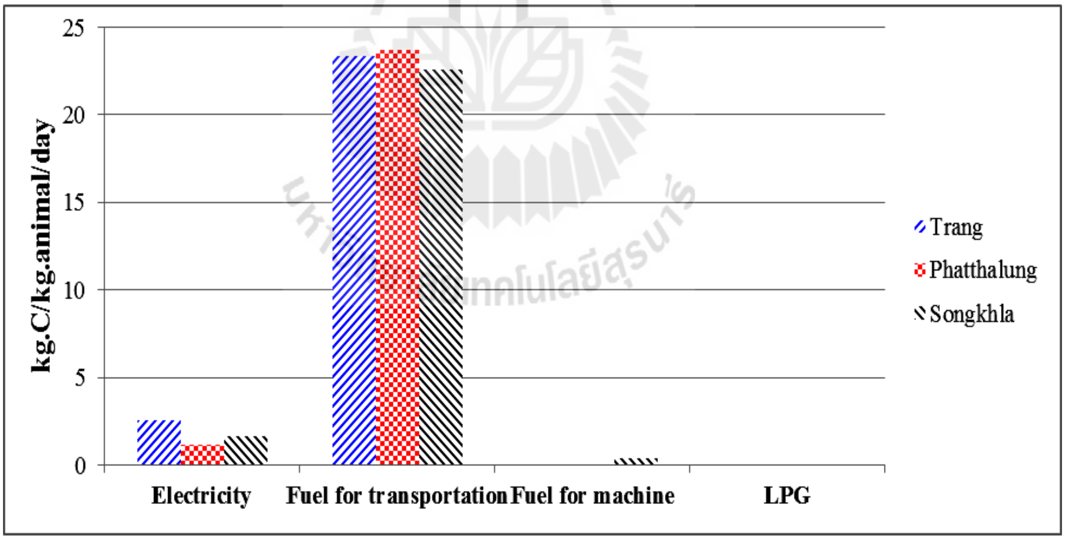


Figure 4.8 Total carbon emission from the use of electricity, fuel and LPG for production of giant freshwater prawn meat at 1 kg (kg.C/kg.prawn/day).

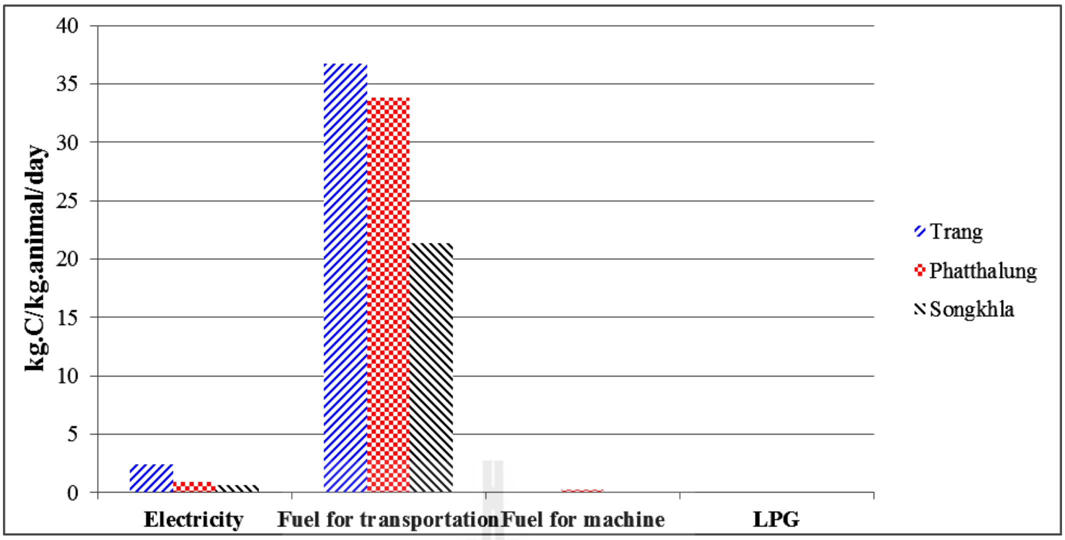


Figure 4.9 Total carbon emission from the use of electricity, fuel and LPG for production of giant perch meat at 1 kg (kg.C/kg.fish/day).

The hatchery used few of energy for transport of aquatic food, post larvae or giant perch fingerlings including water pumps, light and aeration. Carbon emission from these parts were at 11.94, 5.63 and 4.21 kg.C/kg.aquatic animal/day for production of post larvae of Pacific white shrimp, giant freshwater prawn and giant perch fingerlings, respectively (Figure 4.10).

Considering the energy used in markets or processing plant, there are middlemen who collect Pacific white shrimp products from shrimp farms before being distributed to the Mahachai Market, Samut Sakhon province; one of Thailand's largest traditional fresh seafood markets. There are about 80% of total shrimp products are sent to this market because the farmers can sell their shrimp at reasonable prices. Another 20% of total shrimp products are sent to the Charoen Pokphand Foods Public Company Limited (CPF) in Songkhla province, which most of shrimp yield that have been submitted at this processing plant is shrimp products from CPF's farm.

Therefore, this study does not show the information of market or processing plant for Pacific white shrimp.

At the same time, the survey of markets for giant perch and giant freshwater prawn in Trang, Phatthalung and Songkhla provinces found that the farmers sell their fish and prawn products directly to local consumers at farms about 80% of total aquatic products. Another 20% of total aquatic products would be sold to the local markets and restaurants within these provinces. Most of energy used such as electricity for lighting and LPG for cooking including fuel for transportation of LPG, fish and prawn products. The carbon emission from energy consumption in the markets and restaurants for giant perch and giant freshwater prawn were 8.54 and 9.50 kg.C/kg.aquatic animal/day, respectively (Figure 4.10).

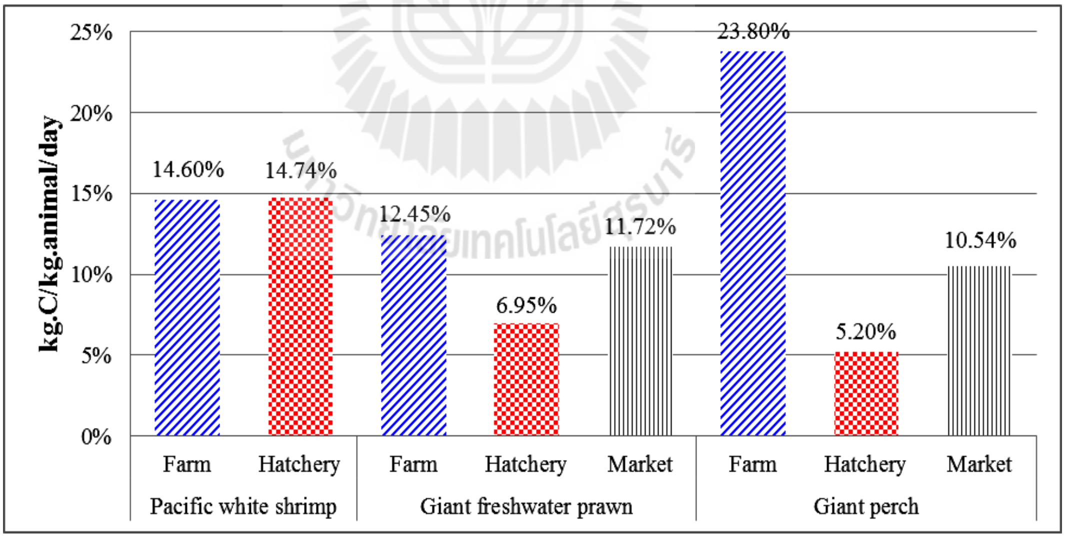


Figure 4.10 Proportion of carbon emissions from energy consumption for Pacificwhite shrimp, giant freshwater prawn and giant perch productions in aquaculture farms, hatcheries and markets.

The aquaculture farms have significant differences in the distance that the post larvae and fingerlings are transported from their sources. This study, post larvae shrimps were purchased mostly from hatcheries in Phuket, Chumphon and Songkhla provinces with a distance about 206.91 km. Whereas, giant perch fingerlings and prawn post larvae have been transported in round trip distance between fish and prawn farms in studied provinces and hatcheries in Trang, Satun, Phatthalung and Songkhla provinces averages about 87.26 and 64.87 km, respectively. A post larvae and fingerlings survival rate of 70% from stocking in grow-out ponds to harvest size was surveyed. Transportation of aquatic food and LPG to farm was estimated at 73.89, 44.60 and 19.90 km of Pacific white shrimp, giant freshwater prawn and giant perch productions, respectively. Diesel-pickups were used to transport aquatic food, LPG, post larvae and fingerlings from suppliers to farms. Moreover, the transportation of shrimp product from farms to the Mahachai Market in Samut Prakan province, with an average transportation distance of 181.99 km was included. Refrigerator-trucks were used in this process with an estimated average load of 15,797.23 kg/trip. While the transportation of fish and prawn products from farms to the local markets and restaurants within province by diesel-pickups, with an average transportation distance at 32.53 and 34.40 km, respectively. The proportion of energy used for transportation as shown in Figures 4.11 - 4.13.

Post larvae and fingerlings are the most important input in aquaculture farming and they are consumed in large quantities. Most of the time they are produced at locations far away from aquaculture farms. Therefore, they have transported to aquaculture farms using different means of transportation. This has an impact on energy used and emissions of carbon dioxide.

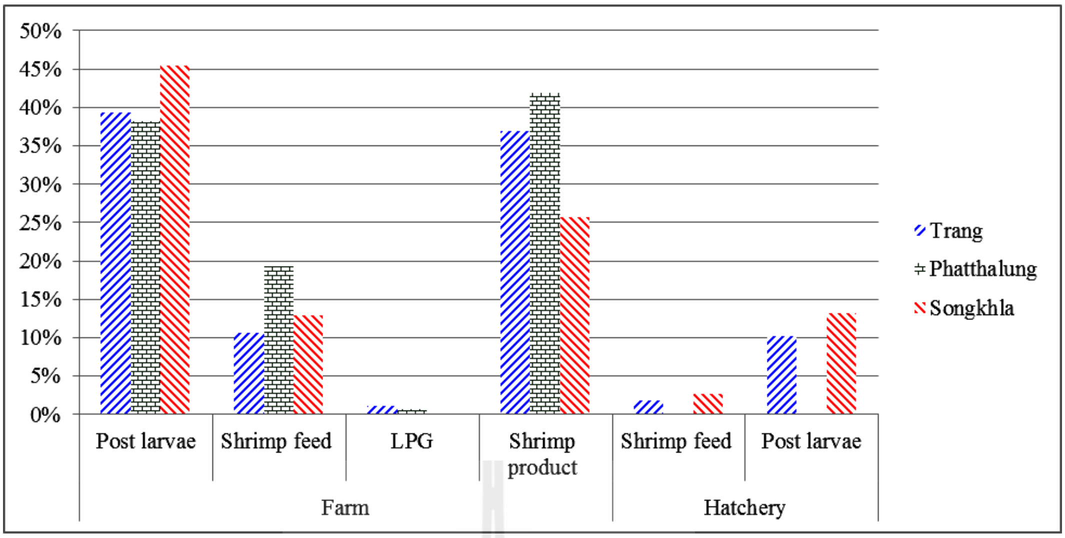


Figure 4.11 Proportion of energy used for transportation in Pacific white shrimp (*Penaeus vannamei*) production.

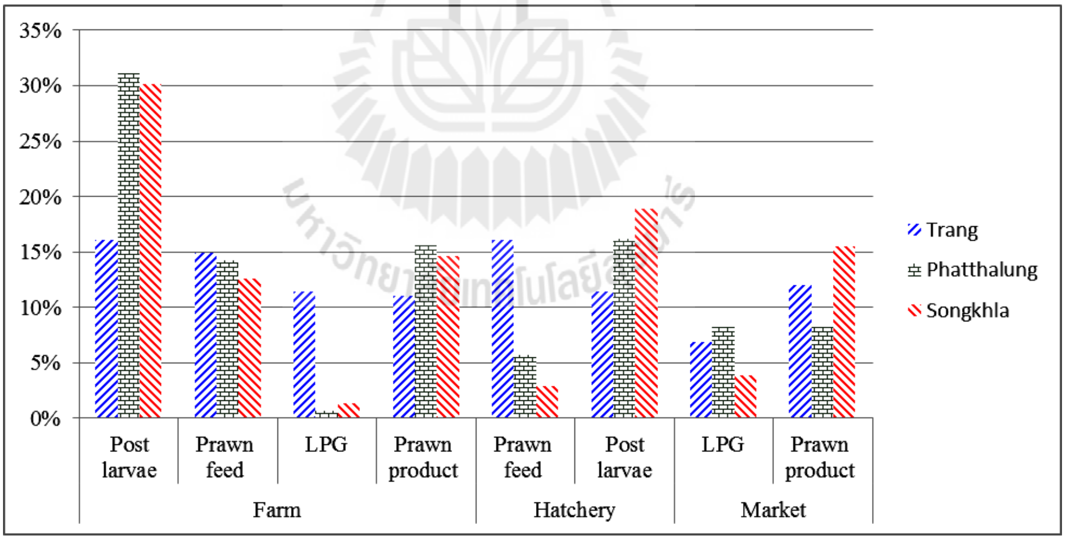


Figure 4.12 Proportion of energy used for transportation in giant freshwater prawn (*Macrobrachium rosenbergii*) production.

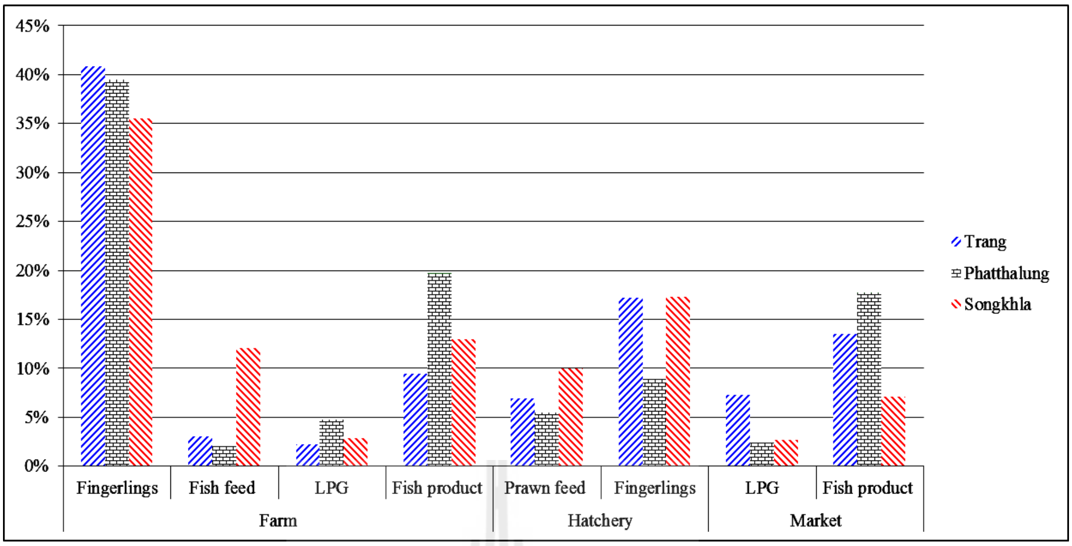


Figure 4.13 Proportion of energy used for transportation in giant perch (*Lates calcarifer*) production.

However, motorcycles fueled by gasoline were used on aquaculture farms to provide transportation for many tasks, e.g., nightly dissolved oxygen monitoring, aerator maintenance, worker transport and supervision, aquatic animal health evaluation, and off-farm errands related to aquatic animal production, etc. Some farms also have small trucks for transporting supplies on farms. Data were not available for quantities of gasoline used in motorcycles and small trucks.

According to Mungkung (2005) concluded an environmental LCA of shrimp farming in Thailand, which included hatchery, farming, processing, distribution, consumption, and waste management phases. The functional unit was a standard consumer-package size containing 3 kg of block-frozen shrimp. Farming was the key life cycle stage contributing to the environmental impacts. These impacts arose mainly from the use of energy, shrimp food, chemical and burnt lime. Transport of post larvae from non-local sources to farms also resulted in significantly higher impacts. Another study by Pelletier and Tyedmers (2010), who concluded that important factors influencing the GHGs emission of seafood production were come from the use of energy during production, processing, storage and transportation of raw materials in hatcheries, farms and processing plants includes the distribution of aquatic products to consumers.

With regard to transport, it was found that an important factors influencing the GHGs emissions of aquatic products transport included the transport mode (i.e., truck, pickup, ship, train or aircraft), the size of the vehicle, speed, load capacity, transportation time, need for refrigeration, and distance (Mungkung, Udo de Haes, and Clift, 2006; Ziegler et al., 2012).

Moreover, the electricity requirements of equipment at the aquaculture farms, hatcheries and markets for giant perch, giant freshwater prawn and Pacific white shrimp production were 930.87, 917.17 and 873.86 kWh/kg.aquatic animal, respectively. Hatcheries used most of electricity energy for water pumps, light and aeration.

The proportion of electricity consumption in aquaculture farms, hatcheries and markets are evident that Pacific white shrimp and giant freshwater prawn productions have the highest electricity energy used for water pumps in farm and hatchery (Figures 4.14 and 4.15). Whereas, a giant perch production has most energy used for light in farm (Figure 4.16).

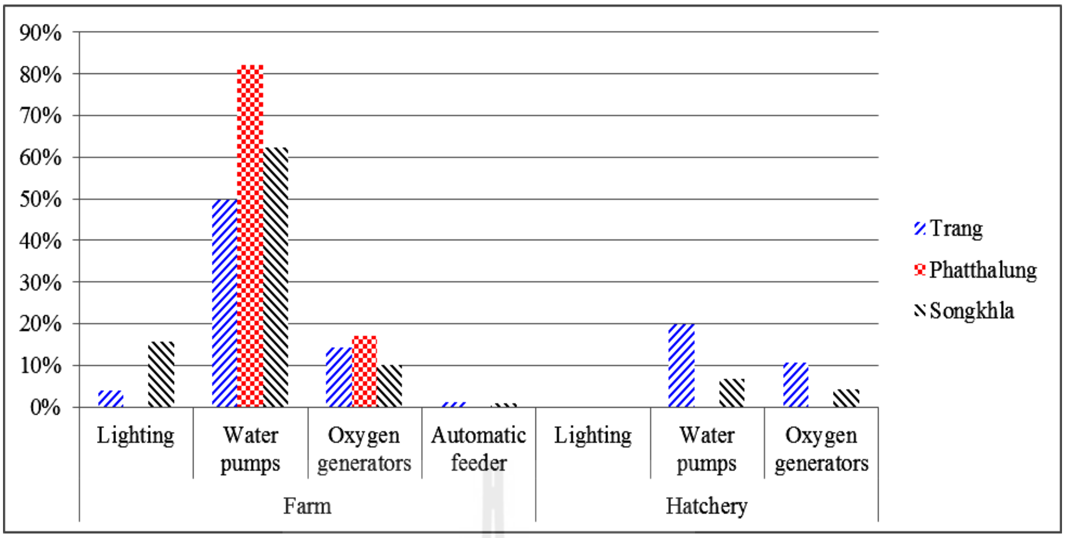


Figure 4.14 Proportion of electricity consumption for Pacific white shrimp (*Penaeus vannamei*) production.

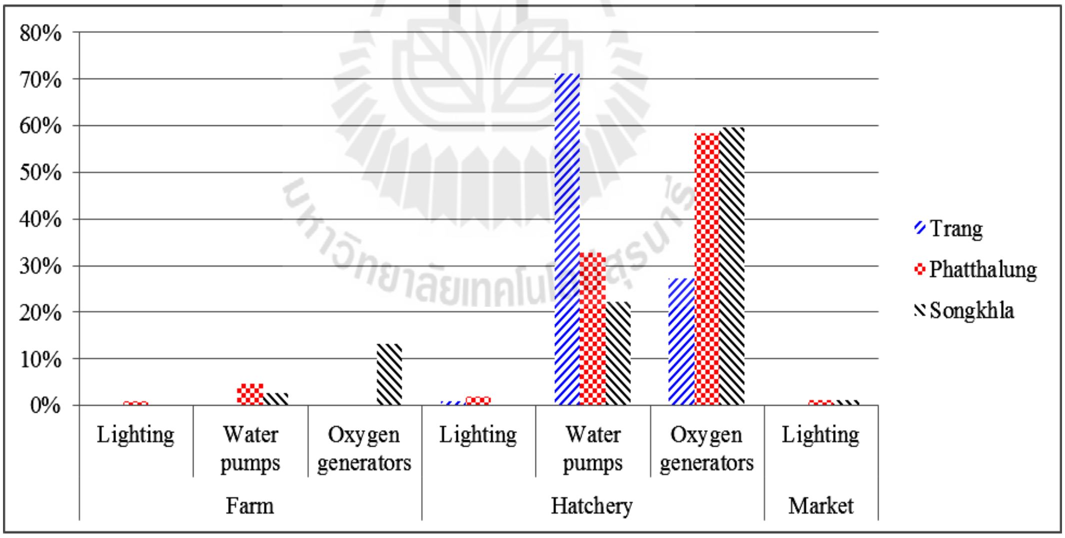


Figure 4.15 Proportion of electricity consumption for giant freshwater prawn (*Macrobrachium rosenbergii*) production.

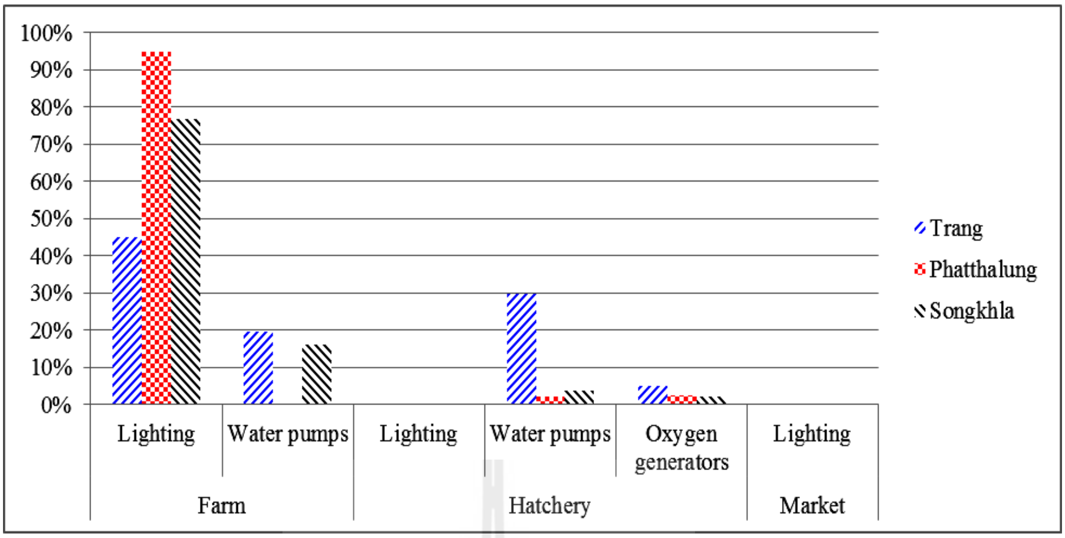


Figure 4.16 Proportion of electricity consumption for giant perch (*Lates calcarifer*) production.

Results of energy consumption are consistent with a study by Hagos (2012) that, at the Asian seabass farm 75% of the embedded energy comes from aquatic food and 23% from the use of electricity energy for water pumps. In the case of Cobia cage farm, 49% of the total embedded energy produced comes from aquatic food, 37% from electricity energy used for water pumps and 13% from diesel, which is mostly used for transport. Furthermore, Ayers and Tyedmers (2009) concluded that recirculation aquaculture systems consumed higher energy than cage farms due to high use of pumping for treatment and recirculation of wastewater.

As well as a study by Ruiz-Velazco, Hernandez-Llamas, Gomez-Munoz, and Magallon (2010) reported that oxygen concentration and aeration were the important factors determining survival rates and final production for shrimp ponds in intensive commercial farms. High aeration rates or early start of aeration resulted in higher survival rates. Raising aeration from 9,000 to 14,000 horsepower per hour per hectare increased production by 32%. Starting aeration after 5 weeks resulted in an 18% decrease in shrimp yield compared to starting at the beginning of the culture cycle.

Stocking density, feeding and aeration rate were the key management techniques which could significantly influence farm profitability in aquaculture farming systems. Though stocking density was positively correlated to profitability, it should not exceed a pond's carrying capacity. Furthermore, Schwantes, Diana, and Yi (2009) reported that feeding rate and water exchange had the greatest impacts of giant freshwater prawn production in Thailand. There were also included indirect predictors that descriptive of the management strategy such as stocking PLs directly or nursing them in separate ponds, and found farmers' year of experience and harvest methods also had significant impacts on net profits.

The absence of aeration also had a negative effect on production; farmers who did not aerate may have lower production due to low dissolved oxygen events in early morning. Also, New (2000) reported that aquaculture farms utilizing intensive marine farming technology that included paddlewheel aeration could attain high production. In addition to aeration, water exchange was necessary to maintain water quality when utilizing protein rich diets and in this survey production was negatively linked to the number of days between water exchanges or additions. While most farmers exchanged or added water of culture pond within 1 to 15 days, some waited as many as 30 to 45 days. This, combined with high feeding rates and lack of water quality monitoring, could be detrimental to aquatic animal. This study found that farm size and water exchange rate had insignificant effect on farm profits. Pond size was shown to be important in explaining the profitability of shrimp farms by Gordon and his colleague (Gordon and Bjerndal, 2009).

At the same weight for each aquatic animal (1 kg of live-weight), it was found that a giant perch emitted carbon from the use of energy for fish meat production at 41.59% of all carbon emission while giant freshwater prawn and Pacific white shrimp meat productions were 32.72% and 25.69%, respectively. Total carbon emission from a giant perch production was the highest average at 32.0434 kg.C/kg.fish/day, which they emitted carbon from Trang province was higher than Phatthalung and Songkhla provinces (Table 4.35). Besides, giant perch farms showed higher carbon emission than markets and hatcheries at 19.2876, 8.5406 and 4.2152 kg.C/kg.fish/day, respectively (Figure 4.17). Therefore, it can be concluded that giant perch meat production from aquaculture farms create higher environmental impacts than giant freshwater prawn and Pacific white shrimp meat productions when compare at 1 kg live-weight of aquatic animal (Formula 4.22).

$$\text{C-emission}_{(energy)} = (7.224)\text{Pacific white shrimp} + (9.202)\text{ Giant freshwater prawn} + (11.696)\text{Giant perch} \quad (4.22)$$

Where:

$\text{C-emission}_{(energy)}$	=	Total carbon emission from energy used for aquatic animal productions (ton carbon per year).
Pacific white shrimp	=	Weight of Pacific white shrimp (kg).
Giant freshwater prawn	=	Weight of giant freshwater prawn (kg).
Giant perch	=	Weight of giant perch (kg).

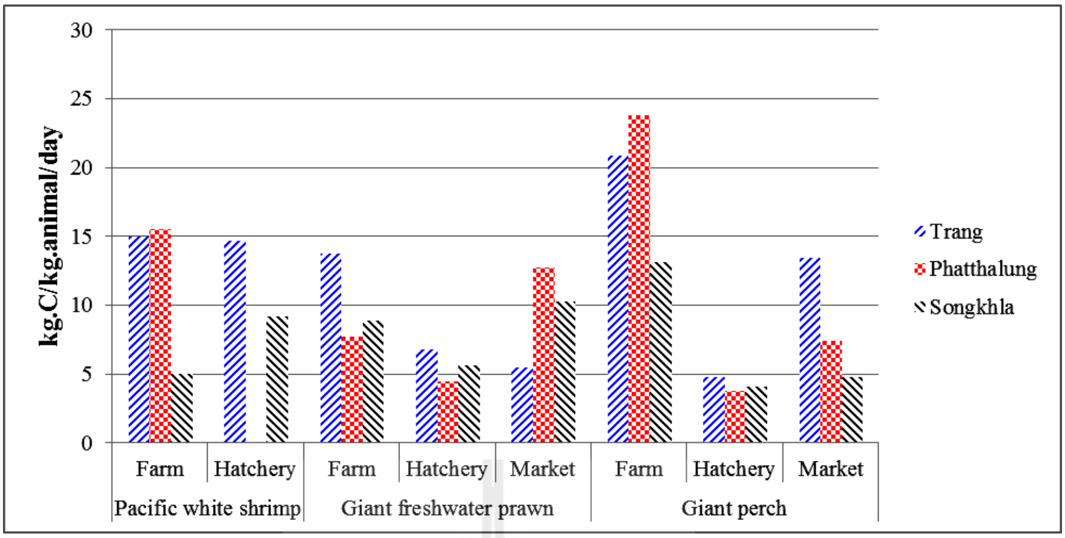


Figure 4.17 Carbon emissions from energy consumption for Pacific white shrimp, giant freshwater prawn and giant perch productions in aquaculture farms, hatcheries and markets at 1 kg live-weight of aquatic animals.

Tyedmers (2002) reported that GHGs emissions from net pen rearing of Atlantic and coho salmon were 6.47 and 8.02 kg.CO_2/kg.fish, respectively. The values estimated in this study were significantly higher (see Tables 4.33 - 4.35). In contrast to this evaluation, Tyedmers (2002) did not consider the contribution from the fish's respiration. In addition, it is likely that the GHGs emissions expressed in kg.CO_2/kg.fish are significantly larger for the freshwater rearing phase compared to net pen rearing.

4.4 Relationship between percentage of carbon content in aquatic food, meat and faeces including analysis of environmental impacts from Pacific white shrimp, giant freshwater prawn and giant perch productions

The results of average dry weight of aquatic food, meat and dry faeces which were explored by the amount of aquatic food consumption and faeces excreted in one day per individual including average living aquatic animal weight from all aquaculture farms could get the ratio of relationship between dry faeces weight per average dry weight of aquatic food per day.

A giant perch released the highest faeces at 34.24% of fish food followed by giant freshwater prawn and Pacific white shrimp which released of faeces at 33.45% and 29.98% of each aquatic food, respectively (Tables 4.36 - 4.38). Pacific white shrimp consumed 0.019% of shrimp food and released 0.005% of shrimp faeces which higher than giant perch and giant freshwater prawn consumed were 0.018% and 0.010% of each aquatic food including released 0.006% and 0.002% of each aquatic faeces, respectively. This is positively correlated with the relationship between carbon consumption (C_{input}) and carbon emission from aquatic animals ($C_{emitted}$) at a confidence level of 95%.

Figure 4.18 shows the carbon content in aquatic food, meat and faeces in each aquatic animal. The giant perch has higher carbon accumulated in their bodies than giant freshwater prawn and Pacific white shrimp were 49.52%, 45.48% and 42.80%, respectively. This is another reason to support that giant perch farms create lower environmental impacts than giant freshwater prawn and Pacific white shrimp farms because a giant perch is capable to accumulate carbon ($C_{fixation}$) in the bodies better than other aquatic animals.

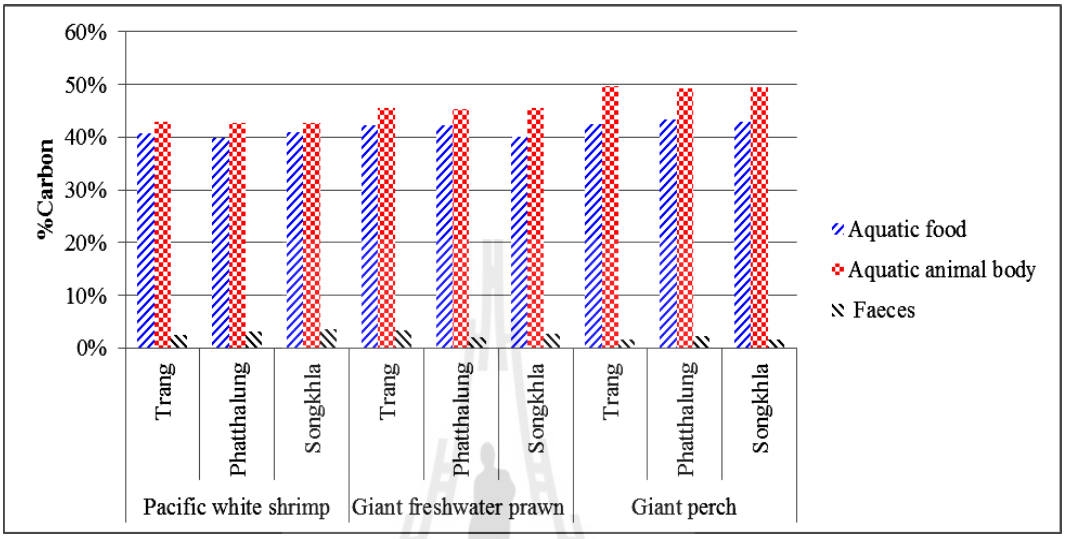


Figure 4.18 Percentage of carbon content in aquatic food, meat and faeces of Pacific white shrimp, giant freshwater prawn and giant perch.

The percentage of moisture, ash, volatile solids (TVS) and carbon content in aquatic food, meat, entrails and faeces of aquatic animals are illustrated in Tables 4.39 - 4.41. Furthermore, it also shows the relationship between percentage of total volatile solids (%TVS) and percentage of carbon content (%C) which help in analysis of percentage of carbon in the laboratory. At the same time, the results of this study can also be analyzed environmental impacts from each aquatic animal production. The analysis is based on the Payoff Matrix Principle by using all alternatives such as aquatic animal production and carbon emission scenarios (Table 4.42) then make the decision follow this theories (Yaemphuan, 1999; Sullivan, Wicks, and James, 2003).

Table 4.36 Average and relationship between carbon, dry weight of shrimp food and faeces excreted from Pacific white shrimp per day was compared at 1 kg live-weight of Pacific white shrimp (mean±SD).

Province	Trang	Phatthalung	Songkhla	Average
Average rearing duration (day)	98.2841±18.4749	100.8182±15.9825	77.9887±9.3859	92.3637±14.6144
Live shrimp weight (kg/ind)	0.0154±0.0067	0.0170±0.0057	0.0132±0.0022	0.0152±0.0049
Dry shrimp food for shrimp consumption (kg/ind/day)	0.0002±0.0001	0.0004±0.0003	0.0002±0.0000	0.0002±0.0002
Dry shrimp food for shrimp consumption (kg/kg.shrimp/day)	0.0237±0.0326	0.0158±0.0065	0.0171±0.0041	0.0189±0.0144
Dry faeces (kg/ind/day)	0.0001±0.0000	0.0001±0.0001	0.0001±0.0000	0.0001±0.0000
Dry faeces (kg/kg.shrimp/day)	0.0049±0.0042	0.0054±0.0020	0.0060±0.0018	0.0054±0.0027
Dry weight of shrimp food consumption per live shrimp weight	0.041%	0.021%	0.024%	0.029%
Dry weight of faeces per live shrimp weight	0.008%	0.007%	0.008%	0.008%
Dry weight of faeces per dry weight of shrimp food consumption	20.675%	34.177%	35.088%	29.980%
C in the form of CO_2 and CH_4 per C in shrimp food	0.089%	0.076%	0.041%	0.069%
C in shrimp faeces per C in shrimp food	0.624%	1.752%	1.717%	1.364%

Table 4.37 Average and relationship between carbon, dry weight of prawn food and faeces excreted from giant freshwater prawn per day was compared at 1 kg live-weight of giant freshwater prawn (mean±SD).

Province	Trang	Phatthalung	Songkhla	Average
Average rearing duration (day)	180.0000±0.0000	209.1071±10.4086	224.1575±12.8015	204.4216±7.7367
Live prawn weight (kg/ind)	0.0494±0.0026	0.0510±0.0117	0.0691±0.0103	0.0565±0.0082
Dry prawn food for prawn consumption (kg/ind/day)	0.0045±0.0002	0.0047±0.0007	0.0038±0.0015	0.0043±0.0008
Dry prawn food for prawn consumption (kg/kg.prawn/day)	0.0026±0.0008	0.0032±0.0004	0.0231±0.0104	0.0096±0.0039
Dry faeces (kg/ind/day)	0.00002±0.00001	0.00001±0.00001	0.00001±0.00000	0.00001±0.00001
Dry faeces (kg/kg.prawn/day)	0.0012±0.0006	0.0010±0.0004	0.0053±0.0021	0.0025±0.0010
Dry weight of prawn food consumption per live prawn weight	0.005%	0.010%	0.033%	0.016%
Dry weight of faeces per live prawn weight	0.002%	0.003%	0.008%	0.004%
Dry weight of faeces per dry weight of prawn food consumption	46.154%	31.250%	22.944%	33.449%
C in the form of CO_2 and CH_4 per C in prawn food	0.182%	0.071%	0.011%	0.088%
C in prawn faeces per C in prawn food	5.091%	1.857%	1.169%	2.706%

Table 4.38 Average and relationship between carbon, dry weight of fish food and faeces excreted from giant perch per day was compared at 1 kg live-weight of giant perch (mean±SD).

Province	Trang	Phatthalung	Songkhla	Average
Average rearing duration (day)	210.0000±29.4594	245.0000±57.5224	298.6676±151.6899	251.2225±79.5572
Live fish weight (kg/ind)	1.6392±0.3322	1.9500±0.5272	2.3546±0.9077	1.9813±0.5890
Dry fish food for fish consumption (kg/ind/day)	0.0086±0.0050	0.0134±0.0101	0.0041±0.0052	0.0087±0.0067
Dry fish food for fish consumption (kg/kg.fish/day)	0.0202±0.0110	0.0196±0.0289	0.0141±0.0118	0.0180±0.0173
Dry faeces (kg/ind/day)	0.0033±0.0010	0.0062±0.0035	0.0024±0.0013	0.0040±0.0019
Dry faeces (kg/kg.fish/day)	0.0075±0.0027	0.0066±0.0039	0.0045±0.0034	0.0062±0.0033
Dry weight of fish food consumption per live fish weight	3.311%	3.822%	3.320%	3.484%
Dry weight of faeces per live fish weight	1.229%	1.287%	1.060%	1.192%
Dry weight of faeces per dry weight of fish food consumption	37.129%	33.673%	31.915%	34.239%
C in the form of CO_2 and CH_4 per C in fish food	16.279%	14.118%	52.459%	27.619%
C in fish faeces per C in fish food	0.767%	0.882%	0.639%	0.763%

Table 4.39 Relationship between moisture, volatile solid and carbon content of shrimp food, faeces, meat and entrails of Pacific white shrimp (mean±SD).

Province	Data type	Moisture (%)	Ash (%)	Total volatile solid (%)	Carbon content (%C)	Relationship between %TVS and %C	R^2
Trang	Food	8.2739±1.3835	73.1675±3.4968	80.9899±3.4525	40.7176±0.9021	%TVS = 0.032(%C) + 79.921	0.01
	Faeces	51.4378±13.2746	16.4948±4.7912	49.5703±21.6049	2.4169±1.3700	%TVS = 0.505(%C) + 52.839	0.03
	Meat	77.9048±1.8155	82.1653±1.7390	75.6555±5.1975	42.7675±0.5693	%TVS = 0.268(%C) + 66.410	0.02
	Exoskeleton and visceral organs	69.0260±8.5718	64.6533±4.7521	19.5943±15.9589	38.2550±1.4373	%TVS = 0.699(%C) + 45.872	0.04
Phatthalung	Food	9.0826±0.8263	72.4376±4.6385	82.8503±3.9132	39.8796±1.2787	%TVS = 0.908(%C) + 46.891	0.19
	Faeces	46.1726±7.4447	14.9082±5.1337	59.6606±8.6498	3.1630±2.0554	%TVS = 0.729(%C) + 60.169	0.37
	Meat	79.8609±1.8103	82.7812±1.1201	77.8096±3.6349	42.6875±0.4476	%TVS = 1.998(%C) - 7.641	0.65
	Exoskeleton and visceral organs	66.0233±5.1494	61.8782±3.4756	14.6929±8.7311	38.4647±1.0182	%TVS = 0.158(%C) + 7.160	0.01
Songkhla	Food	8.5348±0.5633	73.1581±4.3208	83.5641±2.9196	40.8921±0.5383	%TVS = 0.351(%C) + 97.596	0.07
	Faeces	44.6089±5.6845	18.9839±4.3482	63.8119±4.5240	3.6416±2.7803	%TVS = 0.155(%C) + 62.322	0.03
	Meat	79.6421±1.5604	82.4475±1.4047	79.4539±2.9199	42.8030±0.5499	%TVS = 0.562(%C) + 54.660	0.12
	Exoskeleton and visceral organs	69.1451±3.8535	64.7974±2.9285	16.8992±10.5693	38.0126±0.9530	%TVS = 3.500(%C) + 56.084	0.50

Table 4.40 Relationship between moisture, volatile solid and carbon content of prawn food, faeces, meat and entrails of giant freshwater prawn (mean±SD).

Province	Data type	Moisture (%)	Ash (%)	Total volatile solid (%)	Carbon content (%C)	Relationship between %TVS and %C	R^2
Trang	Food	6.4267±0.4655	73.3458±3.6253	99.9789±0.0028	44.4444±0.1704	%TVS = 0.002(%C) + 90.049	0.09
	Faeces	51.6366±7.7991	18.5333±4.8216	48.2743±11.8320	3.3683±2.2558	%TVS = 5.607(%C) + 67.160	0.35
	Meat	80.6052±0.3346	81.9708±1.6694	74.1134±1.0841	45.5019±0.0890	%TVS = 8.402(%C) + 56.434	0.34
	Exoskeleton and visceral organs	68.6236±0.6736	66.5792±5.7914	14.6130±14.5757	37.5396±2.3493	%TVS = 3.406(%C) + 42.481	0.31
Phatthalung	Food	6.9705±2.1923	71.1150±3.0545	90.7678±6.1443	42.4035±1.3094	%TVS = 2.735(%C) + 29.592	0.23
	Faeces	49.8132±8.1738	19.0463±5.9063	51.4331±15.4436	2.1008±1.3294	%TVS = 6.824(%C) + 27.377	0.21
	Meat	80.2180±0.9496	82.2460±1.3176	78.2981±1.9575	45.4595±0.0709	%TVS = 13.323(%C) + 64.325	0.15
	Exoskeleton and visceral organs	67.9855±4.2809	64.2826±4.0774	12.5880±9.3996	36.8487±1.2793	%TVS = 0.422(%C) - 1.409	0.50
Songkhla	Food	5.0785±1.9384	72.5031±1.1774	97.7108±4.9041	40.6191±7.7556	%TVS = 0.125(%C) + 91.693	0.14
	Faeces	55.1670±12.2380	18.5275±4.6185	45.6888±21.3061	2.7267±1.7903	%TVS = 0.008(%C) + 45.776	0.10
	Meat	79.8182±1.3610	82.4601±1.4003	77.5181±3.6494	45.4805±0.1014	%TVS = 5.269(%C) - 61.251	0.16
	Exoskeleton and visceral organs	71.7828±2.4265	62.8454±2.9136	18.9098±10.8051	36.2437±1.8882	%TVS = 0.817(%C) + 48.772	0.20

Table 4.41 Relationship between moisture, volatile solid and carbon content of fish food, faeces, meat and entrails of giant perch (mean±SD).

Province	Data type	Moisture (%)	Ash (%)	Total volatile solid (%)	Carbon content (%C)	Relationship between %TVS and %C	R^2
Trang	Food	63.7325±17.5734	75.1025±3.1280	69.9104±4.3395	42.4834±3.0853	%TVS = 0.327(%C) + 83.931	0.48
	Faeces	49.2304±4.4369	56.2342±5.7855	33.9826±10.5824	1.7261±0.2822	%TVS = 3.427(%C) + 39.601	0.08
	Meat	75.1719±2.6781	80.8931±0.8572	77.8179±3.1117	49.6923±0.7525	%TVS = 0.769(%C) + 61.017	0.35
	Bone and visceral organs	64.5997±1.1529	92.7375±2.4169	91.9086±2.7858	37.4520±1.0705	%TVS = 0.467(%C) + 19.289	0.27
Phatthalung	Food	52.1774±32.1144	73.4444±3.5004	71.2467±3.4555	43.4522±3.3325	%TVS = 0.141(%C) + 77.380	0.19
	Faeces	48.9921±3.9771	59.7778±7.1966	40.3847±8.6085	2.2128±0.9868	%TVS = 3.642(%C) + 32.326	0.74
	Meat	73.2573±3.4648	81.0185±0.7377	80.3752±4.0264	49.3901±0.8152	%TVS = 2.138(%C) - 25.216	0.87
	Bone and visceral organs	61.7747±4.2030	92.6667±3.5700	92.0546±4.8515	37.2308±0.8086	%TVS = 0.345(%C) + 14.905	0.03
Songkhla	Food	47.0763±30.6060	73.4946±3.8224	71.9759±4.7614	42.8941±2.1187	%TVS = 0.224(%C) + 80.808	0.15
	Faeces	50.4817±2.9039	61.1433±4.3540	40.3613±7.2577	1.7381±0.4446	%TVS = 2.459(%C) + 35.322	0.25
	Meat	75.2092±4.3230	80.8889±0.8743	79.4690±3.8089	49.4884±1.1425	%TVS = 0.350(%C) + 96.679	0.16
	Bone and visceral organs	60.5983±9.1628	90.7342±10.1561	90.0064±11.3117	37.2453±1.1949	%TVS = 1.078(%C) + 51.107	0.25

Table 4.42 Carbon emission scenarios from aquaculture production follow the payoff matrix principle.

Alternative of aquaculture	Scenarios of carbon emission (kg.C/kg.aquatic animal/day)	
	C-emitted from aquatic animal	C-emission from energy used
Pacific white shrimp	0.0013	19.7928
Giant freshwater prawn	0.0006	25.2120
Giant perch	0.0002	32.0434

Analysis of the scenarios were applied the Laplace's Rule to choose the kind of aquaculture that caused the highest environmental impacts by setting the probability of the equal scenarios (n=2) as shown in Table 4.43. According to the Laplace's Rule, results of this analysis can be concluded that Pacific white shrimp is the best alternative in aquaculture production (9.8970), while a giant perch creates the highest environmental impacts (16.0218) followed by a giant freshwater prawn (12.6063).

Table 4.43 Carbon emission scenarios for aquaculture production from the application of Laplace's Rule.

Alternative of aquaculture	(C-emitted + C-emission) ÷ n
Pacific white shrimp	(0.0013 + 19.7928) ÷ 2
Giant freshwater prawn	(0.0006 + 25.2120) ÷ 2
Giant perch*	(0.0002 + 32.0434) ÷ 2

Remark: *Selected aquaculture type creates maximum environmental impact.

Moreover, the Maximax Rules was applied to indicate the environmental impacts of aquaculture production by selection of scenarios in Table 4.42 which get the maximum result and then select the maximum result from every alternative again.

It can be stated by this following mathematical model (Sullivan, Wicks, and James, 2003):

$$\frac{\max}{i}\left[\frac{\max Pij}{j}\right] \tag{4.23}$$

Where:

P_{ij} is the result of i from scenarios j in Table 4.42

The results are shown in Table 4.44 which found that the Pacific white shrimp production was the best alternative of aquaculture farm because Pacific white shrimp farming caused less environmental impacts than giant freshwater prawn and giant perch, respectively.

Table 4.44 Carbon emission scenarios for aquaculture production from the application of the Maximax Rules.

Alternative of aquaculture	$\frac{\max Pij}{i(x)}$
Pacific white shrimp	19.7928
Giant freshwater prawn	25.2120
Giant perch*	32.0434

Remark: *Selected aquaculture type creates maximum environmental impact.

When the Minimax Regret Rule was applied to avoid the regret that the decision is already made in taking the poor alternative of aquaculture production. This can be done by selecting the maximum result in each carbon emission scenarios from

Table 4.42 and then this result was minus with all results of carbon emission scenarios. Consideration of the maximum result in each carbon emission scenarios, then the matrix was set (Table 4.45) and the maximum regret in each alternative of aquaculture production was selected. Each alternative was selected to find minimum value again and can be shown as:

$$\frac{\min}{i}\left[\frac{\max Rij}{j}\right] \quad (4.24)$$

Where:

R_{ij} is the sorrow value for alternative *i* and *j* of the various scenarios.

Table 4.45 The sorrow value in each alternative of aquaculture production.

Alternative of aquaculture	Scenarios of carbon emission (kg.C/kg.aquatic animal/day)	
	C-emitted from aquatic animal	C-emission from energy used
Pacific white shrimp	0	12.2506
Giant freshwater prawn	0.0007	6.8312
Giant perch	0.0011	0

Meanwhile, Table 4.46 shows the results of Pacific white shrimp farming and shrimp that meat production are better alternative than the farming of giant freshwater prawn and giant perch including them meat productions, respectively.

Table 4.46 The maximum sorrow value of each alternative of aquaculture.

Alternative of aquaculture	$\max_{j} Rij$
Pacific white shrimp	12.2506
Giant freshwater prawn	6.8312
Giant perch*	0.0011

Remark: *Selected aquaculture type creates maximum environmental impact.

According to the theories and rules, it can be concluded that a Pacific white shrimp farming and shrimp meat production are the best alternative of aquaculture. While the giant perch farming and fish meat production causes the highest environmental impacts followed by a giant freshwater prawn farming and prawn production.

4.5 Guidelines for the decrease of carbon emissions from aquatic meat production and tendency of this aquaculture in the future

4.5.1 Carbon emissions from Pacific white shrimp, giant freshwater prawn and giant perch productions

Total carbon emission from aquatic animal bodies in the form of CO_2 and CH_4 from the respiration and digestion in each aquatic animal (Tables 4.20 - 4.28) and carbon emissions from energy used of aquaculture farms, hatcheries and markets in Trang, Phatthalung and Songkhla provinces (Tables 4.33 - 4.35). This studies found that the total carbon emission per kg per year for the production of giant perch, giant freshwater prawn and Pacific white shrimp were 11.6959, 9.2026 and 7.2248 ton.C/kg.aquatic animal/year, respectively. Based on the Principle of the Conservation of Mass (UNECE, 2004) and the results of this study can be used to indicate the total carbon emission for aquatic animal products as shown in Formula 4.25 as follows:

$$\text{C-emission}_{(\text{aquatic animal + energy use})} = (7.2248)\ \text{Pacific white shrimp} + (9.2026)\ \text{Giant freshwater prawn} + (11.6959)\ \text{Giant perch} \quad (4.25)$$

Where:

$\text{C-emission}_{(\text{aquatic animal + energy use})}$	=	Total carbon emission from aquatic animals and energy used for meat production (ton carbon per year
Pacific white shrimp	=	Weight of Pacific white shrimp (kg).
Giant freshwater prawn	=	Weight of giant freshwater prawn (kg).
Giant perch	=	Weight of giant perch (kg).

4.5.2 Environmental impacts, perception and adoption of alternative systems

The results of carbon emissions into the atmosphere from aquaculture production found throughout the process of producing aquatic animal to consumers. Carbon emitted into the atmosphere due to the use of energy such as electricity, fuel and LPG especially for transportation. Therefore, the consideration to reduce carbon emissions should focus on the issue of reducing energy consumption or modification guidelines for energy efficiency, which can reduce the amount of carbon emissions from the production of Pacific white shrimp, giant freshwater prawn and giant perch. For instance, the range of aquaculture farming, the farmers should use LPG as the energy source to aeration instead of the use of fuel (diesel). LPG has a higher efficiency in the combustion process including create less ash and environmental impacts than diesel oil. Additionally, LPG releases heat energy about 11,832-12,034 Kcal/kg equivalent to electricity at 13.70 kWh/kg (Vichit-Vadakan et al., 2001).

At the same time, a guidelines to reduce carbon emissions from energy used for transport of aquatic food, post larvae or fingerlings, and LPG to farm and hatchery including transport of aquatic products to market should be considered. The result showed that this sector had the most of energy consumption and carbon emission. So, it can be recommended that the farmers should reduce distance and reduce the number of trips for transportation, for example the farmer should buy aquatic food and LPG within the province or neighborhood with aquaculture farm.

Additionally, another way for the reduction of carbon emissions from the production of Pacific white shrimp, giant freshwater prawn and giant perch by ranking and selection of aquatic animal kind that should guide and encourage the farmers for aquatic meat production should be proceeded. The results of this study should encourage the Pacific white shrimp culture because of the proportion of all carbon emissions including individual and energy consumption to produce shrimp are lower than the production of giant freshwater prawn and giant perch.

A vast majority of farmers have not utilized any type of water treatment prior to discharging water into public canals and waterways. This combined with intensive production that utilizes protein rich diets has the potential to significantly degrade water quality in the natural canals and waterways used by multiple users. While water treatment systems could mitigate current and future environmental problems, it is necessary that these systems optimally balance adequate environment. From an environmental standpoint, impacts of intensive farming systems will only become exacerbated if the discharge of untreated effluent continues. New (2002) states that recognition of responsible aquaculture should include attention to the discharge of polluted effluents into natural waterways. So, the water treatment holds a guarantee in completely avoiding the release of waste water from aquaculture, where the environmental impact towards eutrophication is relatively non-existent (Ayer and Tyedmers, 2009).

It is also important to notice that aquaculture production is not restricted to the mentioned impacts; rather there are several aquaculture specific impacts that need to be considered. These aquaculture specific impacts (e.g. disease transfer, water use, etc.) have been the main problem considered in classical environmental impact assessments of aquaculture. However, until now these impacts have proven difficult in characterization and are generally ignored studies. Therefore, further research is urgently required in understanding and characterization of these impacts in aquaculture.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Amount of carbon massflow in aquatic animal production

The study of carbon emission per day from Pacific white shrimp, giant freshwater prawn and giant perch by comparing the same weight in the unit of kg carbon per kg of aquatic animal weight per day (kg.C/kg.aquatic animal/day) found that Pacific white shrimp emitted the highest value at 1.30×10^{-3} kg.C/kg.shrimp/day in Songkhla province. Pacific white shrimp received carbon from shrimp food at 7.60×10^{-3} kg.C/kg.shrimp/day and carbon fixation of shrimp bodies was 6.30×10^{-3} kg.C/kg.shrimp/day. Whereas, the giant perch emitted the lowest carbon per day at 2.00×10^{-4} kg.C/kg.fish/day and obtained the highest carbon from consumed fish food at 7.70×10^{-3} kg.C/kg.fish/day. Additionally, giant perch fixed the highest carbon into the body at 7.50×10^{-3} kg.C/kg.fish/day in Trang province.

In contrast, giant freshwater prawn fixed the lowest carbon in the body at 3.20×10^{-3} kg.C/kg.prawn/day and prawn received the lowest carbon from prawn food was 3.80×10^{-3} kg.C/kg.prawn/day. Also, a giant freshwater prawn emitted carbon was 5.90×10^{-4} kg.C/kg.prawn/day. Moreover, the efficiency of carbon fixation in aquatic animal found that a giant perch can efficiently fixed carbon in the body at

97.05%, which higher than Pacific white shrimp and giant freshwater prawn were 81.76% and 81.72%, respectively.

Most of carbon emissions per day of aquatic animals were found in faeces. Pacific white shrimp emitted the highest carbon in the form of CO_2 and CH_4 at 16.15%, which shrimp farming in Songkhla province had higher carbon emission than the other two provinces, followed by giant freshwater prawn emitted carbon at 15.96% and a maximum value of carbon emission from Trang province. Furthermore, giant perch emitted the lowest carbon in the form of CO_2 and CH_4 at 1.89%.

Comparison of the percentage of average carbon fixation into body and organs of aquatic animals per average carbon input from aquatic food to these aquatic animals through the food consumption per day ($C_{fixation}/C_{input}$) found that a giant perch fixed the highest carbon (97.08%) followed by Pacific white shrimp (82.50%) and giant freshwater prawn (79.92%) from aquatic food.

5.1.2 Carbon emissions from energy consumption for aquatic meat production

According to the survey of aquaculture farms, hatcheries and markets in studied areas found that giant perch emitted the highest carbon from energy consumption for fish meat production at 32.0434 kg.C/kg.fish/day, which Trang province was higher than Phatthalung and Songkhla provinces. In contrast, Pacific white shrimp emitted the lowest carbon at 19.7928 kg.C/kg.shrimp/day. Most of energy used for transportation of fingerlings or post larvae, aquatic food and LPG to farms as well as transport of aquatic products to markets.

Aquaculture farms used much energy for raising aquatic animals per day. In addition, the giant perch farms emitted higher carbon value than Pacific white shrimp and giant freshwater prawn farms at 19.29, 11.94 and 5.63 kg.C/kg.aquatic animal/day, respectively.

Therefore, it can be concluded that giant perch meat production from aquaculture farming system create higher environmental impacts than giant freshwater prawn and Pacific white shrimp meat productions when compared at 1 kg of live-weight of aquatic animals. At the same time, this result also indicates the amount of total carbon emissions from the use of energy in farms, hatcheries and markets as follows:

$$\text{C-emission}_{(energy)} = (7.224)\text{Pacific white shrimp} + (9.202)\text{ Giant freshwater prawn} + (11.696)\text{Giant perch} \quad (5.4)$$

Where:

$\text{C-emission}_{(energy)}$	=	Total carbon emission from energy used for aquatic animals productions (ton carbon per year).
Pacific white shrimp	=	Weight of Pacific white shrimp (kg).
Giant freshwater prawn	=	Weight of giant freshwater prawn (kg).
Giant perch	=	Weight of giant perch (kg).

5.1.3 Guidelines for the decrease of carbon emission from aquatic meat production and tendency of aquaculture farming system in the future

Total carbon emission from each aquatic animal body in the form of CO_2 and CH_4 from the respiration and digestion including the use of energy in aquaculture farms, hatcheries and markets found that the total of carbon emission per kg per year for the production of giant perch, giant freshwater prawn and Pacific white shrimp were 11.6959, 9.2026 and 7.2248 ton.C/kg.aquatic animal/year, respectively. According to the Principle of Conservation of Mass, the results can be used to indicate the total carbon emission for aquatic animal products as shown in the Formula 5.5 as follow:

$$C\text{-emission}_{(aquatic\ animal\ +\ energy\ use)} = (7.2248)\ \text{Pacific white shrimp} + (9.2026)\ \text{Giant freshwater prawn} + (11.6959)\ \text{Giant perch} \quad (5.5)$$

Where:

$C\text{-emission}_{(aquatic\ animal\ +\ energy\ use)}$ = Total carbon emission in each aquatic animal kind and from energy used for aquatic meat production (ton carbon per year).

Pacific white shrimp = Weight of Pacific white shrimp (kg).

Giant freshwater prawn = Weight of giant freshwater prawn (kg).

Giant perch = Weight of giant perch (kg).

The results of this study showed that most carbon emission from Pacific white shrimp, giant freshwater prawn and giant perch production was from energy used such as electricity, fuel and LPG particularly energy fuel used for transportation. Therefore, the reduction of carbon emissions should focus on the issue of reducing energy consumption and modification guidelines for energy efficiency, which can reduce the amount of carbon emissions from the production of Pacific white shrimp, giant freshwater prawn and giant perch as follows:

(1) Ranking and selection of aquatic animal kind that should guide and encourage the farmers for aquatic meat production. The results of this study should encourage the Pacific white shrimp culture because the proportion of all carbon emissions including individual and energy consumption to shrimp meat proportion were lower than the production of giant freshwater prawn and giant perch.

(2) Farmers should use LPG as the energy source to aeration instead of the use of diesel oil due to LPG had a higher efficiency in the combustion process including created less ash and environmental impacts than diesel oil.

(3) Farmers should reduce distance and reduce the number of trips for transportation such as the farmer should buy aquatic food and LPG within the province or neighbourhood with aquaculture farm. Moreover, they should plan the use of aquatic food, LPG and other raw materials to reduce the number of trips for transportation in aquaculture processes.

5.2 Recommendations

Aquaculture farming is an increasing trend in Thailand especially in provinces that locate on the coastal areas in the southern and the eastern parts of Thailand. Besides, Pacific white shrimp, giant freshwater prawn and giant perch farming, there are also other aquaculture farming such as giant tiger prawn, Asian green mussel, oyster, walking catfish and Nile tilapia, etc. Further investigation should be focused on the study of carbon massflow from these aquaculture farming to be used as a data for carbon transfer and carbon emission from aquatic meat production including the development of the carbon footprint in Thailand.

This study focused on aquaculture farm, hatchery and market only, which it does not cover the entire process of aquatic meat production. Therefore, the aquatic food production processes should be investigated in future studies.

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APPENDICES

APPENDIX A

THE MULTIPLIER OF CARBON EMISSIONS FROM THE USE OF ELECTRICITY, FULE, LIQUEFIED PETROLEUM GAS AND THE AMOUNT OF CARBON IN VARIOUS ENERGY SOURCES

Table A1 The multiplier of carbon emissions from fuel energy (stationary combustion).

Fuel type	Unit	Emission factor ($kg.CO_2$-eq/Unit)	Reference sources
Liquefied petroleum gas (LPG)	L	1.6812	IPCC, 2007
Liquefied petroleum gas (LPG)	kg	3.1100	IPCC, 2007
Natural gas	MJ	0.0099	IPCC, 2007
Diesel	L	2.7080	IPCC, 2007
Benzene	L	2.1896	IPCC, 2007
Coking coal	kg	2.6268	IPCC, 2007
Lignite	kg	1.0624	IPCC, 2007
Fuel oil	L	3.0883	IPCC, 2007
Fuel oil	MJ	0.0926	IPCC, 2007
Kerosene	L	2.4777	IPCC, 2007
Biomass	kg	0.6930	IPCC, 2007
Biodiesels	L	2.6265	IPCC, 2007

Table A2 The multiplier of carbon emissions from fuel energy (combustion for transportation)

Fuel type	Unit	Emission factor ($kg.CO_2$-eq/Unit)	Reference sources
Liquefied petroleum gas (LPG)	L	1.5362	IPCC, 2007
Liquefied petroleum gas (LPG)	kg	2.8400	IPCC, 2007
Natural gas (CNG)	kg	2.2472	IPCC, 2007
Diesel	L	2.7446	IPCC, 2007
Benzene	L	2.1896	IPCC, 2007
Gasohol	L	2.1896	IPCC, 2007
Biomass	L	2.6265	U.S. Energy Information Administration

Table A3 Emissions from electricity generation (g/kWh).

Power plant type		CO_2	NO_2	SO_2
Commercial fuel	Coking coal	322.80	1.80	3.40
	Fuel	258.50	0.88	1.70
	Natural gas	178.00	0.90	0.001
	Nuclear	7.80	0.003	0.03
Renewable energy	Biomass	0.00	0.60	0.14
	Wind power	6.70	Very few	Very few
	Water power	5.90	Very few	Very few
	Geothermal energy	51.50	Very few	Very few

Table A4 Analysis of carbon input for electricity production at 1 kWh from the proportion of fuel energy used of Thailand in 2012.

Proportion of the Thailand's electricity production*	Electricity production		Relationship between the reaction and products	C-input from electricity energy use	Amount of CO_2 (t)
	Ability of fuel	Fuel density			
Fuel oil 0.84%	11.05 kWh/L	Light oil at 15^{O}C = 930 g/l	Fuel oil, C_nH_{2n+2} (C = 14-20) = (168/198)×(930/11.05)	0.0716 Kg.C_{C20H42}/kWh 0.0714 Kg.C_{C14H30}/kWh	968,767
Diesel oil 0.24%	10.12 kWh/L	Diesel oil at 20^{O}C = 850 g/l	Diesel oil ($C_{12}H_{26}$) = (144/170)×(850/10.12)	0.0711 Kg.C_{C12H26}/kWh	50,904
Coking coal/ Lignite 19.28%	2.91 kWh/kg	Coking coal/Lignite** = %C = 73% by weight	1g C_{CH4}= (2.9/667)×(16/12)	0.251 Kg.$C_{Lignite}$/kWh	17,717,652
Natural gas 66.90%	0.29 kWh/m^3	1 m^3 of CH_4 = 0.667 kg at standard condition (20^{O}C 1atm)	1 kg C_{CH4} = 5.783 kWh	0.173 Kg.C_{CH4}/kWh	24,597,771
Biomass 1.90%	3.52 kWh/kg	biomass*** (bagasse + chaff) = %C = 45% by weight		0.128 Kg.$C_{biomass}$/kWh	-
Water-power 10.76%				-	-
Wind power + Sun light (very few)				-	-
The use of electricity energy at 1 kWh is equal to				0.158 Kg.C/kWh	0.5610 Kg.CO_2-eq/kWh

Note: * Reports and charts of electricity of Thailand in 2012 (2013) and TC Common data (2013)

** Hanzade et al. (2001)

*** Brody (1945); Maynard and Loosli (1969)

Table A5 Average of carbon input (C-input) in aquaculture farm, hatchery and market for Pacific white shrimp production (mean±SD).

Average of carbon		C-input (kg.C/kg.shrimp/day)		
		Trang	Phatthalung	Songkhla
Aquaculture farm	Electricity	0.0079±0.0075	0.0072±0.0030	0.0220±0.0090
	Fuel for transportation	17.6737±13.8058	18.2813±5.7415	5.8878±3.9565
	Fuel for machine	0.0003±0.0005	0.0011±0.0014	0.0087±0.0045
	LPG	0.0017±0.0035	0.0004±0.0011	0.0000±0.0000
	Total C-input/1 shrimp/day	17.6836	18.2900	5.9184
Hatchery	Electricity	4.0251±4.1031	N.D.	2.4399±1.3905
	Fuel for transportation	179.2211±63.4738	N.D.	124.7463±123.6501
	Fuel for machine	1.5794±1.2678	N.D.	0.2500±0.5451
	LPG	0.0000±0.0000	N.D.	0.0000±0.0000
	Total C-input/1 shrimp/day	184.8256	N.D.	127.4362
Total C-input from energy of two source	kg.C/kg.shrimp/day	202.5092	18.2900	133.3546

Note: * Reports and charts of electricity of Thailand in 2012 (2013) and TC Common data (2013)

Table A6 Average of carbon input (C-input) in aquaculture farm, hatchery and market for giant freshwater prawn production (mean±SD).

Average of carbon		C-input (kg.C/kg.prawn/day)		
		Trang	Phatthalung	Songkhla
Aquaculture farm	Electricity	0.0003±0.0002	0.0013±0.0019	0.0007±0.0010
	Fuel for transportation	16.2009±5.4718	9.0640±3.7302	10.4355±7.8471
	Fuel for machine	0.0036±0.0044	0.0021±0.0023	0.0003±0.0003
	LPG	0.0033±0.0051	0.0009±0.0024	0.0002±0.0008
	Total C-input/1 prawn/day	16.2081	9.0684	10.4368
Hatchery	Electricity	2.8365±1.5752	1.3066±0.2507	1.8291±0.3205
	Fuel for transportation	139.0716±6.6338	97.4371±63.8169	107.5473±64.4709
	Fuel for machine	0.0000±0.0000	0.0000±0.0000	0.2874±0.1825
	LPG	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000
	Total C-input/1 prawn/day	141.9081	98.7437	109.6638
Market	Electricity	0.0015±0.0009	0.0020±0.0009	0.0019±0.0014
	Fuel for transportation	7.8607±5.8915	27.9443±11.3737	29.8912±8.1303
	LPG	0.0657±0.0683	0.1396±0.0445	0.0576±0.0980
	Total C-input/1 prawn/day	7.9279	28.0859	29.9507
Total C-input from energy of three source	kg.C/kg.prawn/day	166.0441	135.8980	150.0513

Note: * Reports and charts of electricity of Thailand in 2012 (2013) and TC Common data (2013)

Table A7 Average of carbon input (C-input) in aquaculture farm, hatchery and market for giant perch production (mean±SD).

Average of carbon		C-input (kg.C/kg.fish/day)		
		Trang	Phatthalung	Songkhla
Aquaculture farm	Electricity	0.4457±0.2491	0.5399±0.3234	0.2437±0.2000
	Fuel for transportation	24.1773±5.1614	27.5246±8.4190	15.2437±10.2728
	Fuel for machine	0.0032±0.0029	0.0053±0.0031	0.0028±0.0027
	LPG	0.0107±0.0293	0.0157±0.0456	0.0162±0.0357
	Total C-input/1 fish/day	24.6369	28.0855	15.5064
Hatchery	Electricity	2.1907±2.3062	0.4026±0.1556	0.4355±0.1534
	Fuel for transportation	99.3744±83.5024	92.7743±28.9902	99.0142±46.4508
	Fuel for machine	0.0000±0.0000	0.2420±0.2240	0.0000±0.0000
	LPG	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000
	Total C-input/1 fish/day	101.5651	93.4189	99.4497
Market	Electricity	0.0069±0.0075	0.0026±0.0022	0.0056±0.0034
	Fuel for transportation	16.0417±12.1713	4.8234±3.7964	2.8115±3.6816
	LPG	0.1401±0.0812	0.0381±0.0190	0.0688±0.0642
	Total C-input/1 fish/day	16.1887	4.8641	2.8859
Total C-input from energy of three source	kg.C/kg.fish/day	142.3907	126.3685	117.8420

Note: * Reports and charts of electricity of Thailand in 2012 (2013) and TC Common data (2013)

APPENDIX B

RELATIONSHIP BETWEEN CARBON EMISSION AND CARBON CONSUMPTION FROM AQUATIC ANIMAL AT A CONFIDENCE LEVEL OF 95%

Table B1 Relationship between carbon emitted ($C_{emitted}$) and carbon transfer into Pacific white shrimp by food consumption (C_{input}) at a confidence level of 95% in Trang province.

Regression Statistics			C-input and C-emitted of Pacific white shrimp	
			Observation	153
R Square	Adjusted R Square	Standard Error		
0.001	0.005	0.00042479		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	0.174	0.677
Residual	151	0.000		
Total	152			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.001	0.000	27.978	0.000
Variable	0.001	0.001	0.417	0.677

Table B2 Relationship between carbon emitted ($C_{emitted}$) and carbon transfer into Pacific white shrimp by food consumption (C_{input}) at a confidence level of 95% in Phatthalung province.

Regression Statistics			C-input and C-emitted of Pacific white shrimp	
			Observation	16
R Square	Adjusted R Square	Standard Error		
0.292	0.241	0.00029365		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	5.767	0.031
Residual	14	0.000		
Total	15			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.001	0.000	4.151	0.001
Variable	0.047	0.020	2.401	0.031

Table B3 Relationship between carbon emitted ($C_{emitted}$) and carbon transfer into Pacific white shrimp by food consumption (C_{input}) at a confidence level of 95% in Songkhla province.

Regression Statistics			C-input and C-emitted of Pacific white shrimp	
			Observation	111
R Square	Adjusted R Square	Standard Error		
0.000	0.009	0.00076086		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	0.011	0.918
Residual	109	0.000		
Total	110			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.002	0.000	5.582	0.000
Variable	0.004	0.037	0.103	0.918

Table B4 Relationship between carbon emitted ($C_{emitted}$) and carbon transfer into giant freshwater prawn by food consumption (C_{input}) at a confidence level of 95% in Trang province.

Regression Statistics			C-input and C-emitted of Giant freshwater prawn	
			Observation	8
R Square	Adjusted R Square	Standard Error		
0.722	0.675	0.00029514		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	15.558	0.008
Residual	6	0.000		
Total	7			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.001	0.000	2.756	0.033
Variable	1.083	0.275	3.944	0.008

Table B5 Relationship between carbon emitted ($C_{emitted}$) and carbon transfer into giant freshwater prawn by food consumption (C_{input}) at a confidence level of 95% in Phatthalung province.

Regression Statistics			C-input and C-emitted of Giant freshwater prawn	
			Observation	32
R Square	Adjusted R Square	Standard Error		
0.015	-0.018	0.00007835		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	0.465	0.501
Residual	30	0.000		
Total	31			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.000	0.000	2.279	0.030
Variable	0.033	0.048	0.682	0.501

Table B6 Relationship between carbon emitted ($C_{emitted}$) and carbon transfer into giant freshwater prawn by food consumption (C_{input}) at a confidence level of 95% in Songkhla province.

Regression Statistics			C-input and C-emitted of Giant freshwater prawn	
			Observation	60
R Square	Adjusted R Square	Standard Error		
0.170	0.156	0.00131206		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	11.868	0.001
Residual	58	0.000		
Total	59			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.000	0.000	1.337	0.187
Variable	0.106	0.031	3.445	0.001

Table B7 Relationship between carbon emitted ($C_{emitted}$) and carbon transfer into giant perch by food consumption (C_{input}) at a confidence level of 95% in Trang province.

Regression Statistics			C-input and C-emitted of Giant perch	
			Observation	27
R Square	Adjusted R Square	Standard Error		
0.420	0.397	0.00003920		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	18.102	0.000
Residual	25	0.000		
Total	26			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.000	0.000	7.507	0.000
Variable	0.006	0.001	4.255	0.000

Table B8 Relationship between carbon emitted ($C_{emitted}$) and carbon transfer into giant perch by food consumption (C_{input}) at a confidence level of 95% in Phatthalung province.

Regression Statistics			C-input and C-emitted of Giant perch	
			Observation	18
R Square	Adjusted R Square	Standard Error		
0.512	0.481	0.00006338		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	16.773	0.001
Residual	16	0.000		
Total	17			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.000	0.000	7.113	0.000
Variable	0.005	0.001	4.095	0.001

Table B9 Relationship between carbon emitted ($C_{emitted}$) and carbon transfer into giant perch by food consumption (C_{input}) at a confidence level of 95% in Songkhla province.

Regression Statistics			C-input and C-emitted of Giant perch	
			Observation	175
R Square	Adjusted R Square	Standard Error		
0.128	0.122	0.00008932		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	25.290	0.000
Residual	173	0.000		
Total	174			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.000	0.000	14.769	0.000
Variable	0.005	0.001	5.029	0.000

APPENDIX C

RELATIONSHIP BETWEEN CARBON FIXATION AND CARBON CONSUMPTION FROM AQUATIC ANIMAL AT A CONFIDENCE LEVEL OF 95%

Table C1 Relationship between carbon fixation ($C_{fixation}$) and carbon transfer into Pacific white shrimp by food consumption (C_{input}) at a confidence level of 95% in Trang province.

Regression Statistics			C-input and C-emitted of Pacific white shrimp	
			Observation	153
R Square	Adjusted R Square	Standard Error		
0.990	0.990	0.00042513		
ANOVA	df	MS	F	Sig.
Regression	1	0.102	564585.106	0.000
Residual	151	0.000		
Total	152			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	-0.001	0.000	-27.970	0.000
Variable	0.990	0.001	751.389	0.000

Table C2 Relationship between carbon fixation ($C_{fixation}$) and carbon transfer into Pacific white shrimp by food consumption (C_{input}) at a confidence level of 95% in Phatthalung province.

Regression Statistics			C-input and C-emitted of Pacific white shrimp	
			Observation	16
R Square	Adjusted R Square	Standard Error		
0.994	0.994	0.00029189		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	24111.062	0.000
Residual	14	0.000		
Total	15			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	-0.001	0.000	-4.155	0.001
Variable	0.953	0.019	49.103	0.000

Table C3 Relationship between carbon fixation ($C_{fixation}$) and carbon transfer into Pacific white shrimp by food consumption (C_{input}) at a confidence level of 95% in Songkhla province.

Regression Statistics			C-input and C-emitted of Pacific white shrimp	
			Observation	111
R Square	Adjusted R Square	Standard Error		
0.873	0.872	0.00076109		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	748.345	0.000
Residual	109	0.000		
Total	110			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	-0.002	0.000	-5.575	0.000
Variable	1.004	0.037	27.356	0.000

Table C4 Relationship between carbon fixation ($C_{fixation}$) and carbon transfer into giant freshwater prawn by food consumption (C_{input}) at a confidence level of 95% in Trang province.

Regression Statistics			C-input and C-emitted of Giant freshwater prawn	
			Observation	8
R Square	Adjusted R Square	Standard Error		
0.016	-0.148	0.00029474		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	0.095	0.768
Residual	6	0.000		
Total	7			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.001	0.000	2.771	0.032
Variable	0.085	0.274	0.308	0.768

Table C5 Relationship between carbon fixation ($C_{fixation}$) and carbon transfer into giant freshwater prawn by food consumption (C_{input}) at a confidence level of 95% in Phatthalung province.

Regression Statistics			C-input and C-emitted of Giant freshwater prawn	
			Observation	32
R Square	Adjusted R Square	Standard Error		
0.938	0.936	0.00007877		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	451.842	0.000
Residual	30	0.000		
Total	31			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.001	0.000	-2.319	0.027
Variable	1.035	0.049	21.257	0.000

Table C6 Relationship between carbon fixation ($C_{fixation}$) and carbon transfer into giant freshwater prawn by food consumption (C_{input}) at a confidence level of 95% in Songkhla province.

Regression Statistics			C-input and C-emitted of Giant freshwater prawn	
			Observation	60
R Square	Adjusted R Square	Standard Error		
0.936	0.935	0.00131222		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	847.379	0.000
Residual	58	0.000		
Total	59			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.001	0.000	-1.337	0.186
Variable	0.894	0.031	29.110	0.000

Table C7 Relationship between carbon fixation ($C_{fixation}$) and carbon transfer into giant perch by food consumption (C_{input}) at a confidence level of 95% in Trang province.

Regression Statistics			C-input and C-emitted of Giant perch	
			Observation	27
R Square	Adjusted R Square	Standard Error		
0.998	0.998	0.00003875		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	450350.475	0.000
Residual	25	0.000		
Total	26			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.000	0.000	-7.619	0.000
Variable	0.994	0.001	671.082	0.000

Table C8 Relationship between carbon fixation ($C_{fixation}$) and carbon transfer into giant perch by food consumption (C_{input}) at a confidence level of 95% in Phatthalung province.

Regression Statistics			C-input and C-emitted of Giant perch	
			Observation	18
R Square	Adjusted R Square	Standard Error		
0.997	0.997	0.00006441		
ANOVA	df	MS	F	Sig.
Regression	1	0.000	641005.183	0.000
Residual	16	0.000		
Total	17			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.000	0.000	-6.985	0.000
Variable	0.995	0.001	800.628	0.000

Table C9 Relationship between carbon fixation ($C_{fixation}$) and carbon transfer into giant perch by food consumption (C_{input}) at a confidence level of 95% in Songkhla province.

Regression Statistics			C-input and C-emitted of Giant perch	
			Observation	175
R Square	Adjusted R Square	Standard Error		
0.996	0.996	0.00008970		
ANOVA	df	MS	F	Sig.
Regression	1	0.009	1119171.812	0.000
Residual	173	0.000		
Total	174			
	Coefficients	Standard Error	t Stat.	Sig.
Intercept	0.000	0.000	-14.721	0.000
Variable	0.995	0.001	1057.909	0.000

APPENDIX D

CARBON CONTENT ANALYSIS BY LECO CHN628 SERIES ELEMENTAL ANALYZER AND GAS ANALYZER

The LECO CHN628 Series Elemental Analyzer is used to determine nitrogen, carbon/nitrogen and carbon/hydrogen/nitrogen in samples such as aquatic foods, aquatic meat products and faeces (Figure D1). Prior to carbon analysis, samples are oven dried at 103-105°C for 24 h and grind. For carbon analysis, the samples weigh about 0.2 g was wrapped by tin foil capsule and then put it in the loading chamber about 30 samples per round. The samples were tested by incinerating at temperatures range of at least 950-1,050°C with pure oxygen to ensure the complete combustion of all organic samples. Rapid analysis times (4-5 minutes) for all the elements being determined in each sample. Additionally, the instrument features custom Windows-based software operated through an external PC to control the system operation and data management.

Figure D1 LECO CHN628 Series Elemental Analyzer.

Initial Setup

Open the air compressor, helium gas and oxygen gas tanks follow by LECO CHN628 Series Elemental Analyzer and PC. Click on the Software CHN628 series program icon to start the program. The Software CHN628 series Main Window appears. Select “Diagnose” from the File menu. The Main window appears; click "Furnace" from the File menu and select an automated analysis at "Control Loop Status" by setting the temperature of 950°C; and then wait for the machine to set up a system of temperature and atmospheric pressure. Each value will begin to appear in the window. Main window displays the percentage of carbon, hydrogen and nitrogen as well as the status of various CHN628 Series parameters (Figure D2).

The CHN analyzers are calibrated with EDTA substance that indicates the percentage of carbon, hydrogen and nitrogen of 41.06±0.09, 5.55±0.03 and 9.56±0.03, respectively. EDTA substance, weighed about 0.2 g in tin foil capsule, are introduced into the loading chamber heated at a temperatures of 950-1,050°C with a constant flow of pure oxygen. Click "Configuration" from the File menu and select "Drift"; EDTA capsule is released into the furnace 1 capsule per time.

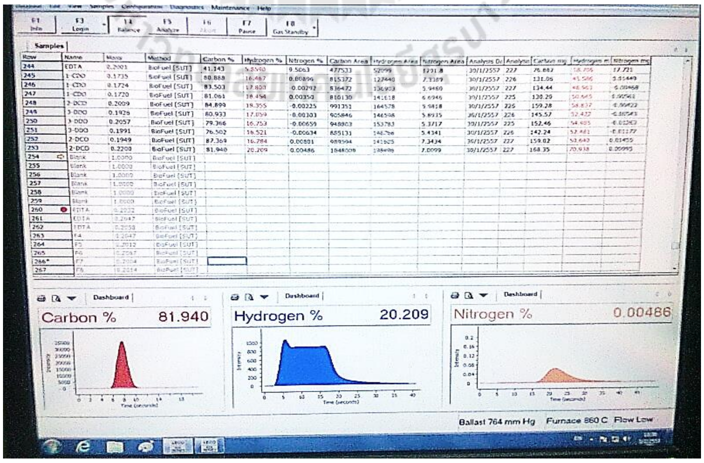

Figure D2 The main window displays of the LECO CHN628 Series Elemental Analyzer and CHN628 series parameters.

Analysis of carbon emission in the form of CO_2 and CH_4 from the digestion and respiration of aquatic animals and faeces were measured by Gas Analyzer.

Figure D3 The measuring gases of aquatic animal faeces by Gas Analyzer.

Figure D4 The measuring CO_2 from the respiration of aquatic animals.

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