Carbon Massflow from Pacific White Shrimp (*Penaeus vannamei*) Production Using Life Cycle Assessment in Songkhla Province, Thailand

Watcharaporn Tantipanatip, Suwit Jitpukdee, Prayong Keeratiurai, and Nathawut Thanee

***Abstract*—** Life cycle assessment was applied to evaluate the potential environmental impacts of Pacific white shrimp production in Songkhla province, southern Thailand. The aims of this study were to investigate the rate of carbon massflow from shrimp feed to Pacific white shrimp, and to study carbon emission from energy consumption for shrimp production during October, 2011 to September, 2012. In total, 17 hatcheries and 111 shrimp farm owners were surveyed and interviewed, and the sample properties were analyzed in laboratories. The results showed that carbon massflow from shrimp feed to shrimp by food consumption was 6.97×10^{-3}, carbon fixation was 5.20×10^{-3}, and carbon emission from shrimp was 1.77×10^{-3} kg.C/kg.shrimp/day. Furthermore, carbon emission from energy consumption of Pacific white shrimp production was 14.20 kg.C/kg.shrimp/day. This result indicated that Pacific white shrimp farming had significant environmental impacts per kilogram of shrimp meat production. These impacts were mainly caused by energy use, farm-level effluents and transportation. Therefore, the reduction of environmental impacts should focus on the problem of reducing energy consumption and modification guidelines for energy efficiency to optimize market-oriented shrimp supply chains and promote more sustainable shrimp production and consumption.

***Keywords*—** Carbon massflow, Pacific white shrimp, Life cycle assessment, Songkhla province, Thailand

I. Introduction

AQUACULTURE is a fast growing sector in the global seafood as it offers possibilities to accommodate increasing consumer's demand for seafood products. 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 the seafood products will be gradually more important as an additional food source, and aquaculture will play an important role in that consumption as natural aquatic animal stocks continue to decline [1, 2].

Asia plays the leading role in aquaculture farming, accounting for almost 80% of world shrimp culture, mainly comes from China and Thailand. Rapid growth of shrimp farming in Thailand has led to an economic boom in coastal provinces of the eastern and southern regions and stimulated the related industries and businesses. On the other hand, the expansion of shrimp aquaculture has drawn criticisms on environmental, economic and social sustainability such as the effluents from aquaculture ponds are enriched in suspended solids, nutrients and biochemical oxygen demand, which the effluents often contribute to eutrophication of receiving waters [3, 4], the deterioration of the benthos [5, 6], the discharge of pharmaceuticals and other chemicals into the environment, land modification and the depletion of wild stocks through broodstock [7].

Life cycle assessment (LCA) is a suitable methodology of the environmental assessment of the products by compiling an inventory of relevant inputs and outputs of the product systems [8, 9]. Therefore, LCA can be used to quantify potential environmental burdens throughout the life cycle of shrimp production. It can be used to calculate the energy and material usage in an overall process. Furthermore, the carbon footprint for food products is expected to increase due to the relevant contribution of food greenhouse gases (GHGs) emissions to global atmosphere [10].

The purposes of this study were to estimate carbon emission and energy consumption of a commercial-sized hatchery and farm for Pacific white shrimp production, that focused on carbon transferred by food chain and fixed in shrimp meat products. Furthermore, the evaluation of the rate of carbon massflow from shrimp feed to shrimp and carbon emissions from electricity and fuel used during shrimp production were also studied in Songkhla province, Thailand during 2011 – 2012.

II. Materials and Methods

A. Study Area

This study was conducted at the Pacific white shrimp farming in Songkhla province. Six amphoes; Mueang Songkhla, Khuan Niang, Sathing Phra, Singhanakhon, Krasae Sin, and Ranot, were chosen to represent the whole study area.

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Songkhla province is located on the Malay Peninsula, on the coast of the Gulf of Thailand. Based on the reports of Department of Fisheries, this province is rich with many shrimp farms and productions due to its location at the opening of the big Songkhla Lake to the Gulf of Thailand [11].

B. Sample Sizes

The determination of the random sample sizes was done following Krejcie and Morgan [12], and Yamane [13]. The permissible error in the sample size was defined to be 5% for 95% confidence and sample size was calculated as 17 hatcheries, 111 farms and 158 shrimps.

C. Analytical Methods

The data were collected directly from the owner's shrimp farms and hatcheries through a series of questionnaires and interview. Moreover, questionnaires comprised of a wide range of operational aspects and energy inputs for shrimp farms and hatcheries (consumption of electricity and fuel) as well as aspects related to transportation. The questionnaire was based on inventory data for life cycle analysis [14, 15].

The sample properties such as shrimp feed, faeces and shrimp meat products were analyzed in the laboratories at Suranaree University of Technology and Rajamangala University of Technology Srivijaya, Trang Campus. The analytical methods are shown in Table I.

TABLE I
ANALYZING METHODS OF SHRIMP FEED, PACIFIC WHITE SHRIMP MEAT PRODUCTS AND FAECES

Characteristic	Methods
Moisture content	Dry weight of known samples, dried at 105^{O}C for 24 h [16].
Volatile solid	Lost weight from known weight or volume of samples, incinerated at 550^{O}C for 30 min [17].
Fixed solid	Remaining weight from known weight or volume, incinerated at 550^{O}C for 30 min [17].
Carbon content	LECO CHN628 Series Elemental Analyzer and Gas Analyzer Respiration Trial System [16, 18].

III. RESULTS AND DISCUSSION

A. Operational Inputs to Farming

The survey yielded primary data on pond area, shrimp culture periods, pond preparation, shrimp stocking, and shrimp feed use per one production cycle. Additionally, the energy used as inputs into the Pacific white shrimp farming facilities comes in different forms: electricity and fuel, are presented in Table II.

On-farm material, shrimp feed and energy inputs showed substantial differences per kilogram live-weight of Pacific white shrimp produced by each farm. Overall, the Pacific white shrimp farming had used consistently higher on-farm energy and shrimp feed. Higher stocking density, water exchange rates and increased oxygen demand in the receiving water also required more electricity and fuel for aeration, lighting and water pumping in shrimp farms and hatcheries.

TABLE II
FARM-LEVEL INPUTS AND OUTPUTS FOR THE PRODUCTION OF 1 KILOGRAM LIVE-WEIGHT OF PACIFIC WHITE SHRIMP IN SONGKHLA PROVINCE (MEAN±SD)

Item	Unit	Farm
Pond area	rai	6.273±1.062
Shrimp production	kg/rai/year	4,296.923±1,004.330
Feed consumed	kg/rai/year	6,010.607±1,064.763
Feed conversion ratio	kg/kg	0.931±0.198
Electricity use	kWh/kg.Shrimp/rai	0.027±0.014
Fuel use	l/kg.Shrimp/rai	0.002±0.001

Note: *Rai is equivalent to 0.0016 square kilometer (km^2)

Moreover, feed 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 Pacific white shrimp production. Pelletier et al. [19] reported that FCR is influenced mostly by feed composition, feeding management and feed quality such as stability in water. If feed composition is the same and feed remained stable longer in water, appropriate feeding regimes would reduce feed loss and dramatically lowering the FCR.

B. Rates of Carbon Massflow in Pacific White Shrimp Farming System

The carbon contents in the Pacific white shrimp product per day (kg.C/kg.shrimp/day) were used to study the carbon massflow from shrimp feed for feeding to the biomass of shrimp (C-input), the carbon mass which was fixed in the shrimp body (C-fixation) and carbon emitted in the form of carbon dioxide (CO_2) and methane (CH_4) form faeces, digestion and respiration (C-emission).

The results showed that the rate of carbon transference from animal feed to shrimp was 6.97×10^{-3} and carbon fixation in shrimp bodies was 5.20×10^{-3} kg.C/kg.shrimp/day. At the same time, Pacific white shrimp emitted very low carbon per day at 1.77×10^{-3} kg.C/kg.shrimp/day (Table III).

TABLE III
RATES OF C-INPUT, C-FIXATION AND C-EMISSION OF PACIFIC WHITE SHRIMP IN SONGKHLA PROVINCE (MEAN±SD)

Carbon contents	Pacific white shrimp farm
Average of live-weight shrimp[1]	0.013±0.002
Weight of fresh faeces excreted[2]	0.006±0.002
Percentage of faeces excreted per weight shrimp (%)	62.56
C-input[3]	0.007±0.002
C-fixation[3]	0.005±0.002
C-emission[3]	0.002±0.000
C-emission/C-input (%)	28.57
C-emission/C-fixation (%)	40.00
Fixation efficiency, C = (C-input - C-emission)/C-input (%)	71.43

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

Additionally, Table IV shows the average of C-input from shrimp feed, C-fixation in shrimp bodies, C-output and C-emission in the form of CO_2 and CH_4 from shrimp faeces, digestion and respiration.

At the same time, the values of carbon released in the form of CO_2 and CH_4 from respiration and digestion of Pacific white shrimp were relatively low as shown in Fig. 1. These values were comparatively favorable than the carbon emissions values associated with beef, pork, poultry, chicken, and sheep productions [20 – 22].

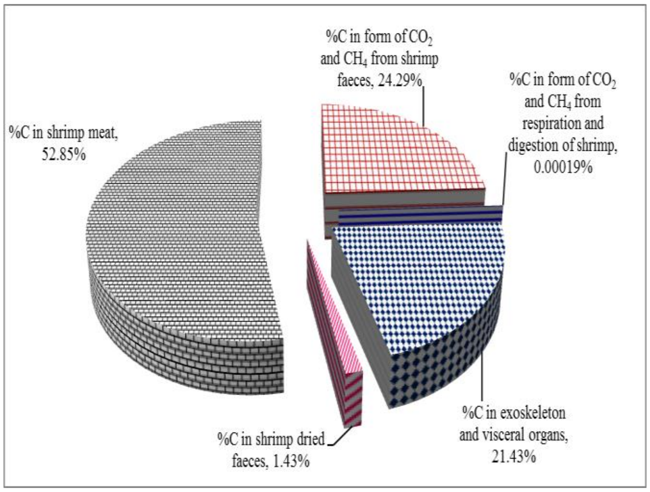

Fig. 1 Percentage of carbon from different parts of Pacific white shrimp transferred from shrimp feed per day in Songkhla province

C. *Rates of Carbon Emission in Pacific White Shrimp Production*

The survey of shrimp farms and hatcheries in Songkhla province found that hatcheries used energy for post larvae produced per day higher than the shrimp production in farms. Most of the energy used such as electricity for water pumps, lighting and aeration including fuel energy for water pumps and aeration.

TABLE IV

C-INPUT, C-FIXATION AND C-EMISSION IN THE FORM OF CO_2 AND CH_4 FOR PACIFIC WHITE SHRIMP (MEAN±SD) IN SONGKHLA PROVINCE

Carbon transferred from animal feed to shrimp (kg.C/kg.shrimp/day)			0.0070±0.0017
Carbon fixation (kg.C/kg.shrimp/day)	Shrimp meat		0.0037±0.0009
	Exoskeleton and visceral organs		0.0015±0.0007
	Total carbon accumulated in shrimp body		0.0052±0.0017
Carbon emission (kg.C/kg.shrimp/day)	Dry faeces		0.0001±0.0000
	C-emission of CO_2 and CH_4	Faeces	0.0017±0.0004
		Digestion and respiration	0.00000001±0.00000003
	Total carbon emission from shrimp		0.0018±0.0005

Aeration is the dissolution of oxygen from the atmosphere into water and oxygenation is the transfer of oxygen gas to water. Therefore, the aeration systems helps maintain adequate dissolved oxygen concentrations of at least 6 mg/L for best aquatic animal growth. The aeration systems in Pacific white shrimp farm with paddle wheels was common (75%) and some farmers used an air jet (25%) 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 80% of the owner's aquaculture farms; all of them measured pH and dissolved oxygen (DO) on a weekly to monthly basis. 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 was completely relied upon visual inspection to assess pond health.

Furthermore, the use of energy for transportation of Pacific white shrimp farms and hatcheries were used for transport of shrimp feed and post larvae to shrimp farms and hatcheries including transport of shrimp product to markets or processing plants. The calculated carbon emissions for the production of 1 kg Pacific white shrimp are shown in Table V.

This study, shrimp post larvae were purchased mostly from hatcheries in Songkhla, Krabi, Phang-Nga, Phuket, and Chumphon provinces, which are on averages about 168.99 km far away from shrimp farms. Transportation of shrimp feed and fuel to farms was estimated to be 48.18 km. Diesel-pickups were used to transport shrimp feed, post larvae and fuel from suppliers to farms. Other than this, the transportation of shrimp products from farms to the Mahachai Market in Samut Prakan province was also made, with an average transportation distance of 181.99 km. Refrigerator-trucks were used in this process with an estimated average load of 15,797.23 kg/trip. The proportion of energy used for transportation is shown in Fig. 2.

According to a report by Mungkung [23] concluded an environmental LCA of shrimp farming in Thailand, which environmental impacts arose mainly from the use of energy, shrimp feed, chemical and burnt lime. Transport of post larvae from non-local sources to aquaculture farms also resulted in significantly higher impacts. Another study conducted by Pelletier and Tyedmers [15], 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 including the distribution of aquatic animal products to consumers.

TABLE V
CARBON EMISSION FROM ENERGY CONSUMPTION OF PACIFIC WHITE SHRIMP FARM AND HATCHERY IN SONGKHLA PROVINCE (MEAN±SD)

Average carbon emission from energy use		Carbon emission (kg.C/kg.shrimp/day)
Farm	Electricity	0.0201±0.0083
	Fuel for transportation	4.9887±3.3524
	Fuel for machine	0.0089±0.0046
	Total carbon emission from energy use/1 kg shrimp/day	5.0177
Hatchery	Electricity	2.2309±1.2714
	Fuel for transportation	6.6954±9.1532
	Fuel for machine	0.2564±0.5591
	Total carbon emission from energy use/1 kg shrimp/day	9.1827
Total carbon emission from energy use of two source (kg.C/kg.shrimp/day)		14.2004

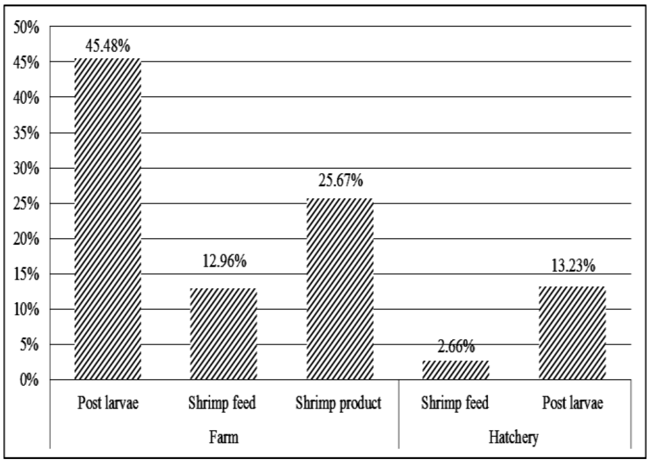

Fig. 2 Proportion of energy used for transportation of Pacific white shrimp production

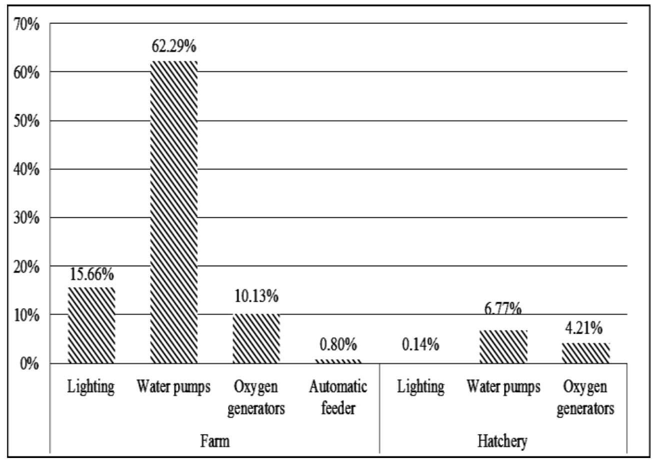

Fig. 3 Proportion of electricity consumption for Pacific white shrimp production

With regard to transportation, it was found that an important factors influencing the GHGs emissions of aquatic animal products transport include 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 [24, 25].

The proportion of electricity consumption in farms and hatcheries revealed that Pacific white shrimp production had used the highest electricity energy for water pumps in farm and hatchery (Fig. 3).

Results of energy consumption are consistent with a study by Hagos [26], who reported that at the Asian seabass and Cobia cage farms, 23% and 37% energy were used from electricity for water pumps, respectively. Tyedmers et al. [19] reported that the GHGs emissions from the Atlantic and coho salmon in net pen rearing were 6.47 and 8.02 kg.CO_2/kg.fish, respectively. However, the values estimated in this study were significantly higher than them. In contrast to this evaluation, Tyedmers [14] did not consider the contribution from the fish's respiration. In addition, it was likely that the GHGs emissions expressed in kg.CO_2/kg.fish were significantly higher for the freshwater rearing phase than that of the net pen rearing phase.

IV. CONCLUSIONS

The study of carbon massflow from Pacific white shrimp production using life cycle assessment in Songkhla province showed that shrimp farming system had contributed the most to the energy consumption and environmental impacts. Therefore, the reduction of carbon emissions should be focused on the issue of reducing energy consumption and modification guidelines for energy efficiency, which can reduce the amount of carbon emissions from Pacific white shrimp production. For instance, the range of shrimp farming, the farmers should use liquefied petroleum gas (LPG) as the energy source to aeration instead of the use of fuel (diesel oil), which LPG has a higher efficiency in the combustion process including create less ash and environmental impacts than diesel oil. Additionally, the farmers should reduce distance and the number of trips for transportation for example the farmer should buy shrimp feed and post larvae within the province or from the neighboring shrimp farms.

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References

[1] FAO, "The state of world fisheries and aquaculture 2008 (SOFIA)," *Rome: Electronic Publishing Policy and Support Branch*, 196p, 2009.

[2] J. S. Diana, "Aquaculture production and biodiversity conservation," *Bioscience*, vol. 59, pp. 27–38, January, 2009. http://dx.doi.org/10.1525/bio.2009.59.1.7

[3] C. Folke, N. Kautsky, and M. Troell, "The cost of eutrophication from salmon farming: Implications for policy," *J. Environ. Manag.*, vol. 40, pp. 173–182, April, 1992. http://dx.doi.org/10.1006/jema.1994.1013

[4] F. E. Dierberg, and W. Kiattisimkul, "Issues, impacts and implications of shrimp aquaculture in Thailand," *J. Environ. Manag.*, vol. 20, pp. 649–666, September, 1996. http://dx.doi.org/10.1007/BF01204137

[5] H. R. Findlay, L. Watling, and M. L. Mayer, (1995). "Environmental impact of salmon net-pen culture on marine benthic communities in Maine: A case study," *Estuaries*, vol. 18, no. 2, pp. 145–179, March, 1995. http://dx.doi.org/10.2307/1352289

[6] F. Paez-Osuna, "The environmental impact of shrimp aquaculture: A global perspective," *Environ. Pollut.*, vol. 112, no. 2, pp. 229–231, April, 2001. http://dx.doi.org/10.1016/S0269-7491(00)00111-1

[7] R. L. Naylor, R. J. Goldburg, J. H. Primavera, N. Kautsky, M. C. M. Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney, and M. Troell, "Effect of aquaculture on world fish supplies," *Nature*, vol. 405, pp. 1017–1024, June, 2000. http://dx.doi.org/10.1038/35016500

[8] N. L. Pelletier, and P. H. Tyedmers, "Feeding farmed salmon: Is organic better?," *Aquaculture*, vol. 272, pp. 399–416, November, 2007. http://dx.doi.org/10.1016/j.aquaculture.2007.06.024

[9] D. M. Bartley, C. Brugere, D. Soto, P. Gerber, and B. Harvey, "Comparative assessment of the environmental costs of aquaculture and other food production sectors: Methods for meaningful comparisons," *FAO Fisheries Proceedings*, 241p, 2007.

[10] T. Garnett, "*Food, greenhouse gas emissions and our changing climate*," Report of the food climate research network, University of Surrey, United Kingdom, 156p, 2008.

[11] Department of Fisheries, *Fishery data* [On-line], Available: http://www.kungthai.com/KungThai/con_detail.php?id=26, 2010, Accessed date: August, 12, 2011.

[12] R. V. Krejcie, and E. W. Morgan, "*Determining sample size for research activities*," Educational and psychological measurement, pp. 607–610, 1970.

[13] T. Yamane, "*Mathematics for economists: An elementary survey*," 2nd ed., New Delhi: Prentice-Hall, 1973.

[14] P. Tyedmers, "*Energy consumed by North Atlantic fisheries*," University of British Columbia, 23p, 2002.

[15] N. L. Pelletier, and P. H. Tyedmers, "Life cycle assessment of frozen tilapia fillets from Indonesian lake-based and pond-based intensive aquaculture systems," *J. Ind. Ecol.*, vol. 14, pp. 467–481, June, 2010. http://dx.doi.org/10.1111/j.1530-9290.2010.00244.x

[16] R. J. Manlay, A. Ickowicz, D. Masse, C. Floret, D. Richard, and C. Feller, "Spatial carbon, nitrogen and phosphorus budget of a village in the West African savanna-I, element pools and structure of a mixed-farming system," *Agricultural Systems*, vol. 79, pp. 55–81, March, 2004. http://dx.doi.org/10.1016/S0308-521X(03)00053-2

[17] APHA, AWWA, WEF, "*Standard methods for the examination of water and wastewater*," 18th ed., Washington. D.C., USA: American Public Health Association, 1992.

[18] T. Kawashima, F. Terada, and M. Shibata, "Respiration experimental system," in *Improvement of cattle production with locally available feed resources in Northeast Thailand*, Japan International Research Center for Agricultural Sciences, Japan and Department of Livestock Development, Thailand, pp. 1–21, 2000.

[19] N. L. Pelletier, P. H. Tyedmers, U. Sonesson, A. Scholz, F. Ziegler, A. Flysjo, S. Kruse, B. Cancino, and H. Silverman, "Not all salmon are created equal: Life cycle assessment (LCA) of global salmon farming systems," *Environ. Sci. Technol.*, vol. 43, pp. 8730–8736, September, 2009. http://dx.doi.org/10.1021/es9010114

[20] F. Nemry, J. Theunis, T. Brechet, and P. Lopez, "*Greenhouse gas emissions reduction and material flows*," Institute Wallan, Federal Office for Scientific, Technical and Cultural Affairs, Belgium, 2001.

[21] N. Thanee, W. Dankittikul, and P. Keeratiurai, "Comparison of carbon emitted from ox buffalo pig and chicken farms and slaughterhouses in meat production," *Suranaree J. Sci. Technol.*, vol. 16, no. 2, pp. 79–90, April, 2009a.

[22] N. Thanee, W. Dankittikul, and P. Keeratiurai, "Comparison of carbon emitted factors from ox and buffalo farms and slaughterhouses in meat production," *Thai Journal of Agricultural Science*, vol. 42, no. 2, pp. 97–107, August, 2009b.

[23] R. T. Mungkung, "*Shrimp aquaculture in Thailand: Application of life cycle assessment to support sustainable development*," Ph.D. thesis, Center for Environmental Strategy, School of Engineering, University of Surrey, United Kingdom, 2005.

[24] R. T. Mungkung, H. A. Udo de Haes, and R. Clift, "Potentials and limitations of life cycle assessment in setting ecolabelling criteria: A case study of Thai shrimp aquaculture product," *Int. J. LCA.*, vol. 11, no. 1, pp. 55–59, January, 2006. http://dx.doi.org/10.1065/lca2006.01.238

[25] F. Ziegler, U. Winther, E. S. Hognes, A. Emanuelsson, V. Sund, and H. Ellingsen, "The carbon footprint of Norwegian seafood products on the global seafood market," *J. Ind. Ecol.*, vol. 17, no. 1, pp. 103–116, July, 2012. http://dx.doi.org/10.1111/j.1530-9290.2012.00485.x

[26] W. K. Hagos, "*Survey of resource use efficiency and estimation of carbon and water footprints in fish farming systems using life cycle analysis*," Ph.D. Thesis. Environment and Science, University of Rhode Island, 2012.