CESEM

Center for Earth Systems Engineering and Management

# Where to Go From Here? Exploring Shrimp Farming LCA in Thailand

Michael Sieng

SSEBE-CESEM-2012-CPR-006
Course Project Report Series

May 2012

# Where to Go From Here?
# Exploring Shrimp Farming LCA in Thailand

Michael Sieng

SOS 598: Life Cycle Assessment for Civil Systems

Spring 2012

# Table of Contents

## Executive Summary

Thailand's huge shrimp export driven industry represents one of the largest in the world accounting for over twenty-five percent of food exports out of the country. The construction of shrimp ponds is considered the world's largest cause of coastal mangrove destruction. Prized for their ability to absorb the force of storms, provide habitat for countless plant and animal species, prevent erosion and filter pollutants, mangrove forests are among the most important ecosystems on earth. Shrimp facilities are also built in ecologically important salt flats and marshes, but intensive production almost always requires large-scale removal of coastal mangrove forests.

The goal of this study is to develop a solution option for the identified topic by means of an intervention strategy. To guide the research towards solution-options the over-arching question is: How can policy implementation transition from the currently problematic state to a sustainable shrimp production system?

Specific research questions include:

1. What are the current unsustainable practices in shrimp farm production?
2. In what part of the life cycle should intervention take place?
3. What does a sustainable shrimp farming practice look like in the future?

The major takeaway from the results conducted by Mungkung (2006) and Sun (2009) show that energy use and environmental impacts take place at the farming stage of the shrimp farming life cycle. The farming stage of this life cycle dominates all the impact categories with exception to marine toxicity potential (MTP). There has been extensive research in Thailand in regards to shrimp farms destroying local mangroves and the link to Mungkung's results can supplement these claims using LCA tools creating saliency and legitimacy for intervention.

Though the major impacts of shrimp farming takes place at the farm itself, the implementation of eco-labeling and standards will have to involve all aspects of the supply chain, especially the ones responsible for driving demand (shrimp exporters and consumers). Eco-labels would not be the end all solution for sustainable shrimp farming, but an intermediate step towards that goal. In order to establish the vision of a sustainable shrimp farming practice, all stakeholders need to be in agreement bearing the responsibility and accountability of their actions.

## Background

The research topic for this assignment is shrimp farming in Thailand located throughout the coastal areas of the southern, eastern, and central regions of the country. Thailand's huge shrimp export driven industry represents one of the largest in the world accounting for over twenty-five percent of food exports out of the country (Sriboonchitta & Wiboonpongse, n.d.).

The construction of shrimp ponds is considered the world's largest cause of coastal mangrove destruction. Prized for their ability to absorb the force of storms, provide habitat for countless plant and animal species, prevent erosion and filter pollutants, mangrove forests are among the most important ecosystems on earth. Shrimp facilities are also built in ecologically important salt flats and marshes, but intensive production almost always requires large-scale removal of coastal mangrove forests. Over the last 50 years or more, anywhere from five to 80 percent of mangrove areas in various countries have been lost (Huitric, Folke, & Kautsky, 2002). A report released by the United Nations Environment Program uses pictures of coastal areas taken from outer space to reveal the rapid increase of shrimp farms in Honduras, Ecuador, Thailand, and India/Bangladesh and the corresponding destruction of mangroves (Wells, 2006). According to a 2006 study in Science, all commercial fish and seafood populations will be depleted by 2048 (Worm et al., 2006).

## Research Statement

The goal of this study is to develop a solution option for the identified topic by means of an intervention strategy. To guide the research towards solution-options the over-arching question is: How can policy implementation transition from the currently problematic state to a sustainable shrimp production system?

Specific research questions include:

1. What are the current unsustainable practices in shrimp farm production? (using life cycle assessment)
2. In what part of the life cycle should intervention take place? (including impacts)
3. What does a sustainable shrimp farming practice look like in the future? (scenario)

## Methodology

Life cycle assessment (LCA) is a rigorous framework for conducting cradle-to-grave assessments of the environmental impacts associated with the production and distribution of consumer goods. Specifically within this study, the focus will be from cradle-to-gate, with emphasis on producer and supplier dynamics versus use/consumption and end of life. LCA methodology lends itself to a unified, integrated accounting system that makes transparent the environmental and socioeconomic costs of various seafood production processes.

The main data sources for the focus of this study will be from Mungkung (2005) and Sun (2009). Sun derived her numbers from the primary source of Mungkung, where she interpreted his results from his dissertation that was not made publically available. In his study he conducted 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 black-frozen shrimp. The system used wild-capture broodstock in the hatchery. The impacts assessed in this study 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. Farming was the key life cycle stage contributing to the impacts. These impacts arose mainly from the use of energy, shrimp feed, and burnt lime. Transport of post-larvae from a non-local source to farms also resulted in significantly higher impacts. This study only analyzed conventional farming systems, and did not cover other farming technologies, such as recirculating shrimp aquaculture systems (Mungkung, 2005).

In keeping things consistent with the referenced studies, the following diagrams will describe the schematic flow of shrimp farming in this paper and the system boundary:

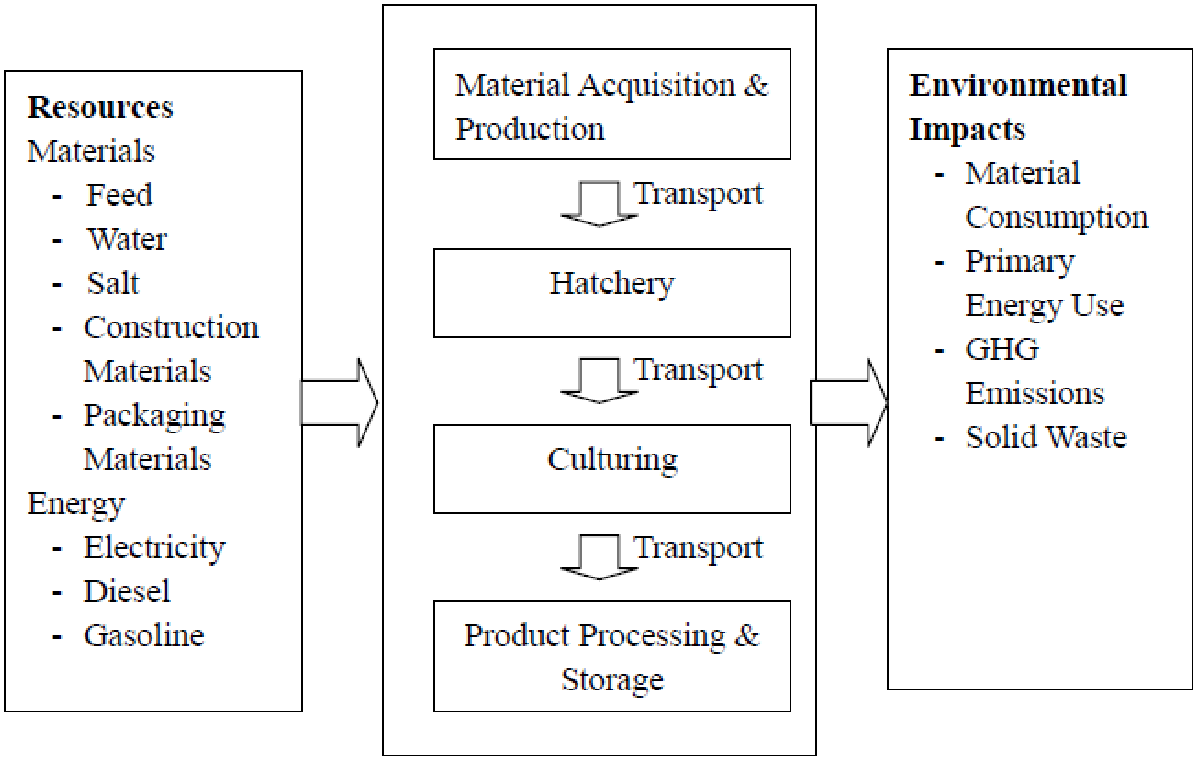



**Figure 1:** A life cycle schematic of a shrimp aquaculture system in Thailand (Sun, 2009)

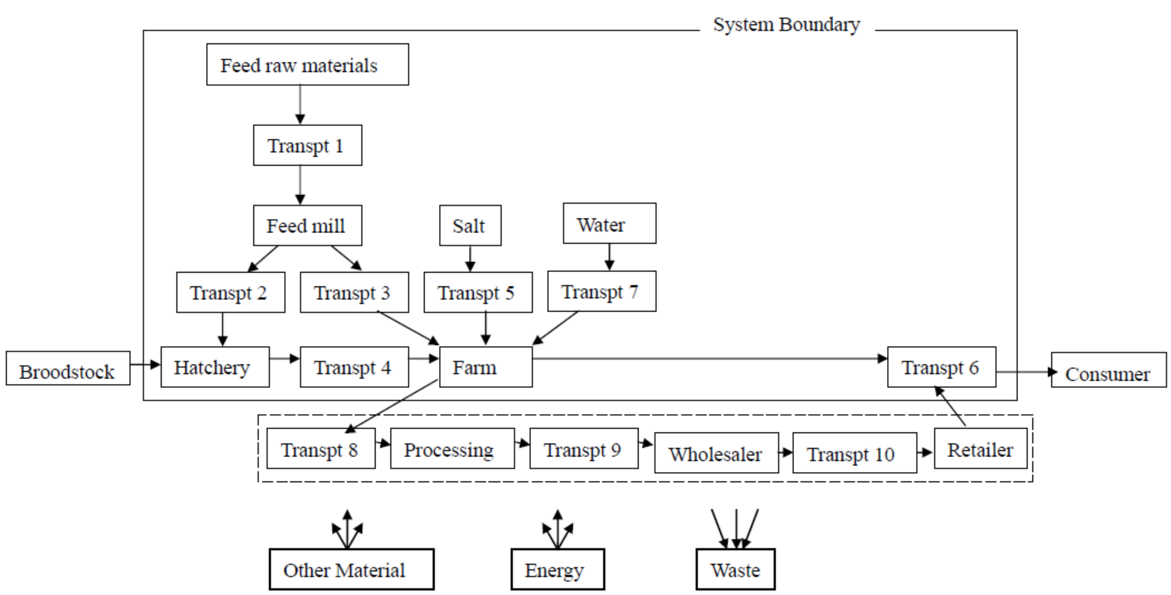



**Figure 2:** Life cycle of shrimp highlighting exclusion of broodstock and consumer stages (Sun, 2009)

With focus on the particular impacts of the life cycle of shrimp, the greatest impacts environmentally and socially were focused at the actual farming stage (Arquitt & Cornwell, 2007; Ayer, Tyedmers, Pelletier, Sonesson, & Scholz, 2007; Boyd & Clay, 1998; Flaherty, Szuster, & Miller, 2000; Hatanaka, 2010; Lebel et al., 2002; Lebel, Mungkung, Gheewala, & Lebel, 2010; Leepaisomboon, Chuchird, Limsuwan, Steenbruggen, & Mungkung, 2009; Mungkung, 2005; Mungkung & Clift, 2003; Mungkung, Udo de Haes, & Clift, 2006; Pelletier et al., 2007; Ronnback, 2002; Sandifer, 1996; Sun, 2009; Tunsutapanich, Mungkung, & Gheewala, 2006). This paper will summarize the findings of the energy and environmental impacts of the current shrimp farming practice in Thailand within the system boundary noted above excluding the consumption and brooding stages.

# Results

## Life Cycle Inventory

The summary of the impact categories for the research done by Mungkung (2005) are summarized in the table below which drive the impact assessment results (Mungkung, 2005):

**Table 1: Impact Category Summary[1]**

| Author | Research | GW | Ac | Eu | PO | AE | TE | Ht | EU | BR | OD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mungkung (2005) | Thai shrimp aquaculture | CO2 | SO2 | PO4 | C2H4 | 1,4 DCB | 1,4 DCB | 1,4 DCB | Sb | | CFC |

## Energy Use

Shrimp farming required the most life cycle energy of any stage (95%) in the current production practice. The total life cycle energy for 1.8 kg of shrimp product for this scenario was 179 MJ, or 99 MJ/kg shrimp. In the shrimp farming stage, electricity consumption was the main contributor to energy

[1] Impact categories are: GW = Global Warming, Ac = Acidification, Eu = Eutrophication, PO = Photochemical Oxidant, AE = Aquatic Eco toxicity, TE = Terrestrial Eco toxicity, HT = Human Toxicity, EU = Energy Use, BR = Biotic Resource Use, OD = Ozone Depletion. Category indicators are: CO2 = Carbon Dioxide, SO2 = Sulfur Dioxide, PO4 = Phosphate, NO3 = Nitrate, O2 = Oxygen, 1,4 DCB = 1,4 Dichlorobenzene, H2O = Water, MJ = Mega Joules, Sb = Antimony, NPP = Net Primary Productivity, CFC = Chlorofluorocarbon

use, while feed production also played important roles. The electricity requirements of equipment at the shrimp farm were 4.2 kWh/kg shrimp, mainly consumed by water pumps (59%), foam fractionator pumps (17%), and oxygen generators (24%). Feed production energy was primarily distributed between fishmeal production (60%) and the feed manufacturing process (24.5%), while production of the other ingredients consumed only 15.4% of the energy (Appendix C). Moreover, energy intensity was 2.4 MJ/kg for crop ingredient production while it was 10.2 MJ/kg for fishmeal and fish oil production, which appears more energy intensive (Sun, 2009).

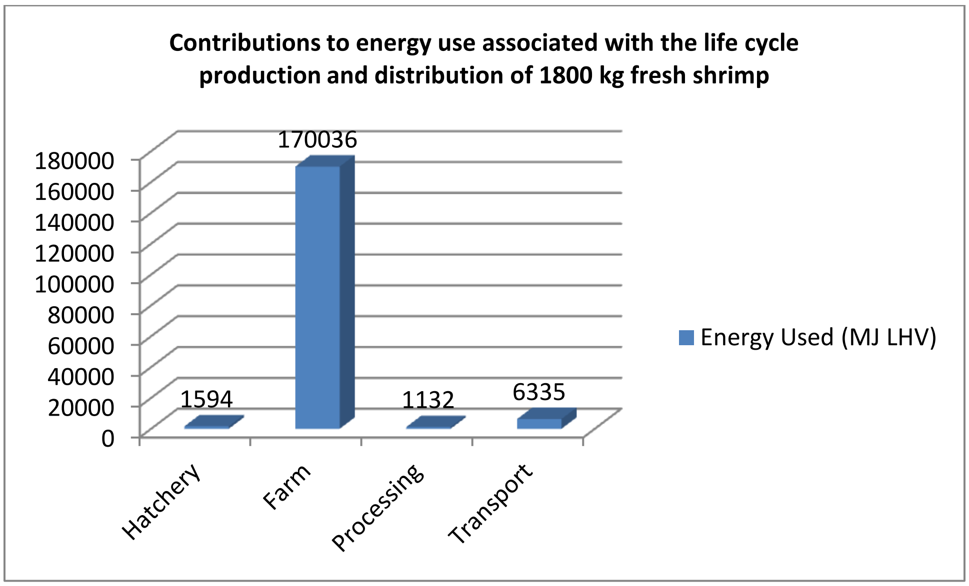



**Figure 3:** Contributions to energy use associated with the life cycle production and distribution of 1800 kg fresh shrimp produced in the US (Sun, 2009)

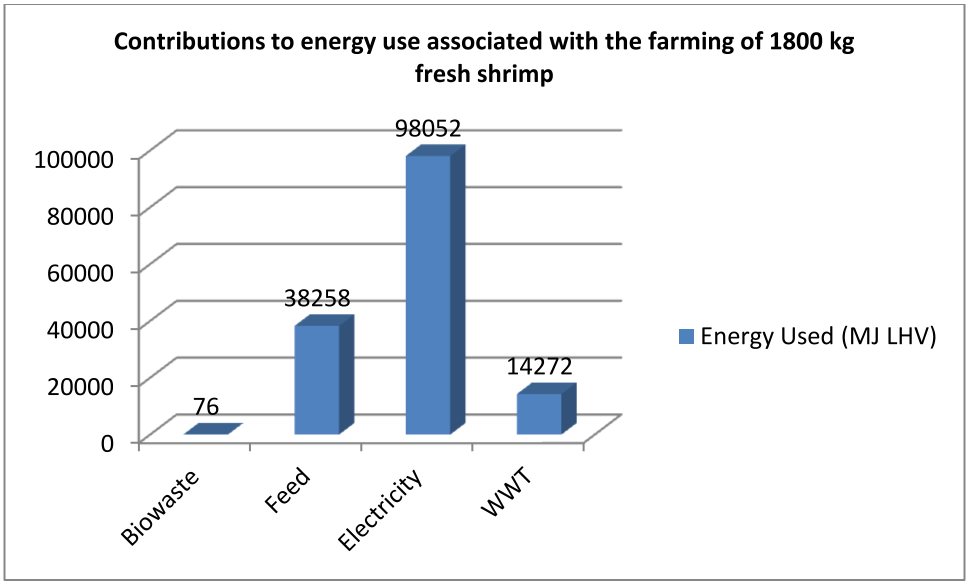



**Figure 4**: Contributions to energy use associated with the farming of 1800 kg fresh shrimp produced in the US (Sun, 2009)

## Impact Assessment

The impact assessment results of this study is derived from Mungkung's (2002) primary data collected in Thailand, to the maximum extent possible based on the shrimp production cycle in 2003. The foreground data are supplemented by secondary data, such as describing the electricity supply system in Thailand, and by data from the SimaPro database (version 5.1) where necessary. As a functional unit, a standard consumer package containing 1.8 kg of block-frozen shrimp is taken (plus 1.2 kg of ice, to a total package weight of 3 kg). This functional unit requires production of 3 kg of adult shrimp at the farm. The environmental impact categories assessed in this study are the standard LCA categories based on the CML 2 Baseline 2000 method (CML 2002): abiotic depletion potential (ADP), global warming potential (GWP), ozone layer depletion potential (ODP), human toxicity potential (HTP), freshwater toxicity potential (FTP), marine toxicity potential (MTP), terrestrial toxicity potential (TTP), photochemical oxidant formation potential (POCP), acidification potential (AP) and eutrophication potential (EP) (Mungkung et al., 2006).

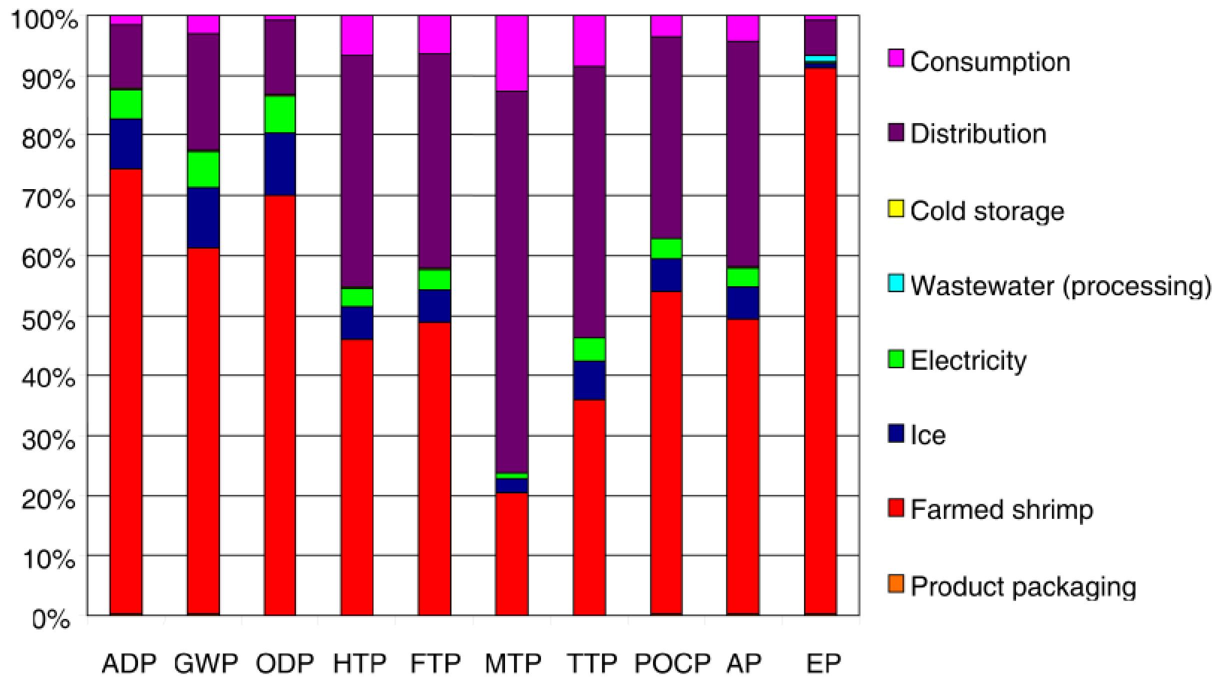
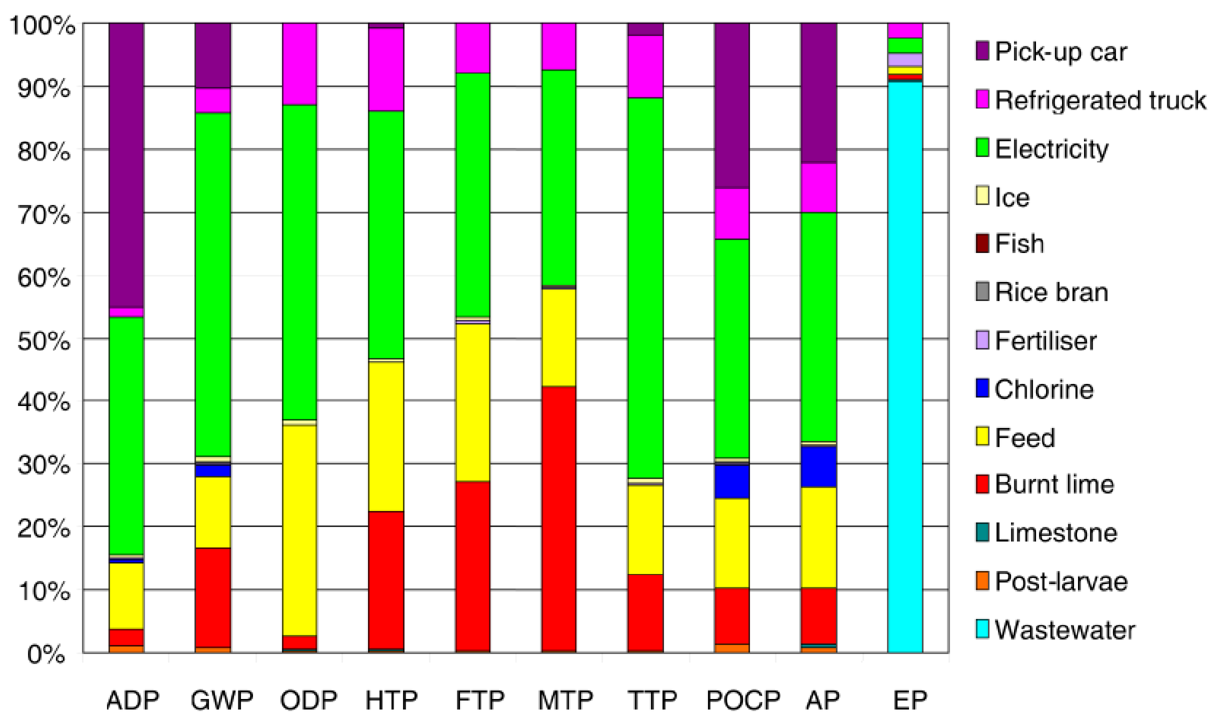
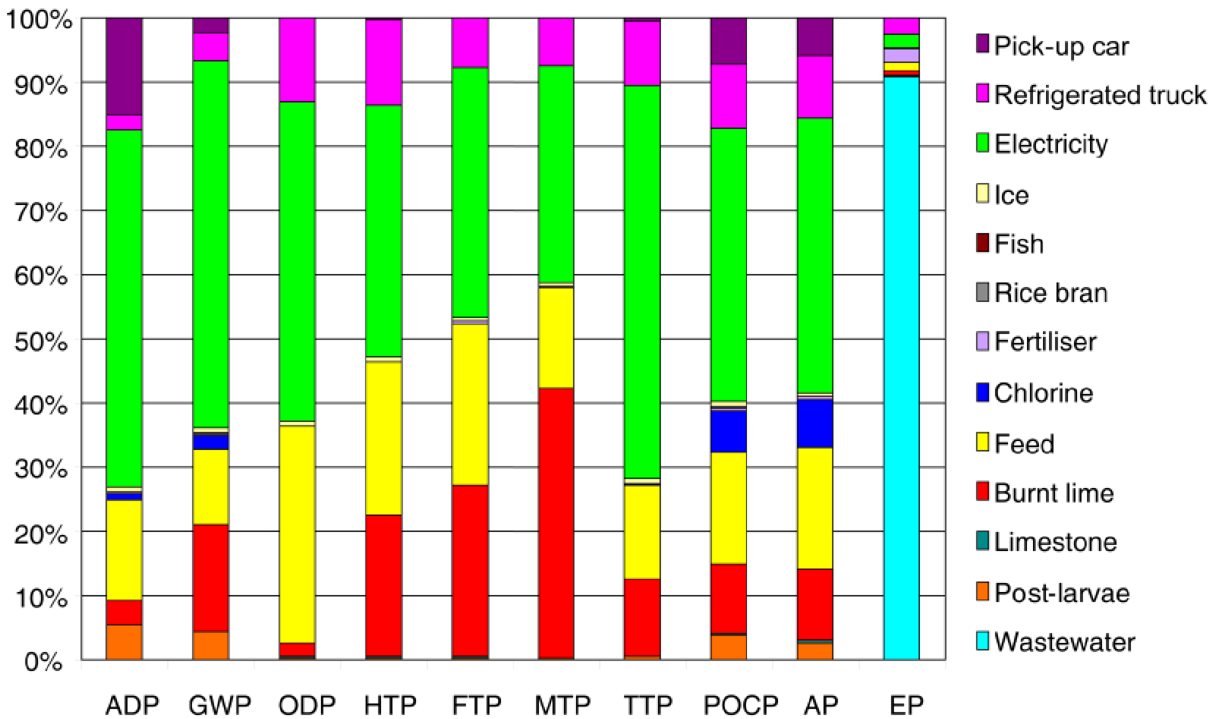



**Figure 5**: Contributions to impacts associated with the life cycle production of one block-frozen shrimp, using the post-larvae from Phuket hatchery and the shrimps are farmed by Conventional & CoC (Note: the contributions from waste management and sewage treatment are too small to be discernible). Using the post-larvae from Chacheongsao hatchery also gave a similar trend (Mungkung et al., 2006)



a) Phuket hatchery




b) Chacheongsao hatchery

**Figure 6**: Contributions to the environmental impacts of different life cycle stages for the shrimp produced by Conventional & CoC farm, using post larvae from (a) Phuket and (b) Chacheongsao hatcheries (Mungkung et al., 2006)

## Interpretation

The major takeaway from these results conducted by Mungkung (2006) and Sun (2009) show that energy use and environmental impacts take place at the farming stage of the shrimp farming life cycle. The farming stage of this life cycle dominates all the impact categories with exception to marine toxicity potential (MTP). There has been extensive research in Thailand in regards to shrimp farms destroying local mangroves and the link to Mungkung's results can supplement these claims using LCA tools creating saliency and legitimacy for intervention.

Exploring the impacts within the shrimp farming life cycle stages (Figure 6), electricity dominated all of the categories with exception to eutrophication potential (EP). To reduce the impacts at the farm, the focus of the intervention would need to include reduction in energy use or finding alternative energy sources for production as this is the main source to unsustainable production practices.

Some uncertainty in the study comes from the interpretation done by Sun and other authors derived from Mungkung's LCA study as well as a lack of methodology from Mungkung's dissertation that was not accessible. Uncertainty also exists temporally, since the original study was conducted in 2002. There is a high probability that there have been technological breakthroughs that have not been published that are already in place towards sustainable shrimp aquiculture due to proprietary information or other legalities. In addition to the temporal aspect, scale is also important in how the largest exporter of shrimp to the US and Europe can easily convert from the status quo to a sustainable production process.

## Recommendations

To address the question of where and when to intervene in the life cycle of shrimp farming, Arquitt & Cornwell (2007) suggest eco-labeling to help developed nations (primary consumers of shrimp), while Leepaisomboon et al. (2009) focus on GLOBALG.A.P.[2] standards. Current compliance rates in Thailand are roughly around 50%, which is a good starting point (Leepaisomboon et al., 2009). Exploring eco-labels as an option, the trade-off of compliance and participation will have to be considered and whether or not this will change buying/consumption behavior. The option of eco-labels would have to incorporate both studies as this would align with all the stakeholders involved in the shrimp farming supply chain. If intervention is feasible, what type of incentives will have to be implemented and who will be the stakeholders involved in this decision making process?

To explore the transition from the current unsustainable state to a sustainable system the question remains, is organic shrimp farming the option, and most importantly is it viable right now given the current demands in Thailand? Research was done in the particular studies by Hatanaka (2010) and Sandifer (1996), but both these studies explore organic farming practice, but do not necessarily provide normative recommendations and instructional action. Equator claims to be the first organic shrimp farm in the world with Europe being the primary importer of this shrimp product, but private investigations recently revealed the negative social and environmental impacts of this organic farm[3]. Identification of standards not only applies to shrimp farming practice, but also in identifying what defines, "organic

[2] The Global Partnership for Good Agriculture Practices (GLOBALG.A.P.), previously known as EurepGAP.
[3] Source: http://www.naturskyddsforeningen.se/in-english/marine-ecosystems-and-fisheries/organic-shrimp-farming Accessed Jan 28 2012

shrimp farming." Would this be defined as using organic feed, renewable energy sources, or both? Clear goals and metrics are crucial for compliance as this need to be transparent throughout the supply chain.

Though the major impacts of shrimp farming takes place at the farm itself, the implementation of eco-labeling and standards will have to involve all aspects of the supply chain, especially the ones responsible for driving demand (shrimp exporters and consumers). Eco-labels would not be the end all solution for sustainable shrimp farming, but an intermediate step towards that goal. In order to establish the vision of a sustainable shrimp farming practice, all stakeholders need to be in agreement bearing the responsibility and accountability of their actions.

The guiding force to ensure compliance by all parties would be policy implementation locally (Thai government) as well as globally (international trade laws) to prevent black markets and unregulated trade. In developing policy, participatory stakeholder engagement would be crucial in incorporating the top-down structure of the government and the bottom-up representation of the shrimp farmers and consumers. This could take place through various workshops identifying an incentive structure to produce the change towards a sustainable future state. LCA results should be used to inform stakeholders of the adverse effects supplementing existing research that has already been done and aid in the collaboration process.

Future research opportunities include an updated shrimp LCA to Mungkung's study reflecting current data for comparison. Also to incorporate organic shrimp farming as a viable option, another LCA of an organic shrimp farm in Thailand would be beneficial to identify the effects with a side-by-side comparison.

# References


Arquitt, S. P., & Cornwell, T. B. (2007). Micro-Macro Linking Using System Dynamics Modeling: An Examination of Eco-Labeling Effects for Farmed Shrimp. *Journal of Macromarketing*, *27*(3), 243-255. doi:10.1177/0276146707302780

Ayer, N. W., Tyedmers, P. H., Pelletier, N. L., Sonesson, U., & Scholz, A. (2007). Co-Product Allocation in Life Cycle Assessments of Seafood Production Systems: Review of Problems and Strategies. *International Journal*, *12*(7), 480-487.

Boyd, C. E., & Clay, J. W. (1998). Shrimp Aquaculture and the Environment. *Scientific American*, *278*(6), 58-65. doi:10.1038/scientificamerican0698-58

Flaherty, M., Szuster, B., & Miller, P. (2000). Low Salinity Inland Shrimp Farming in Thailand. *Exchange Organizational Behavior Teaching Journal*, *29*(3), 174-179.

Hatanaka, M. (2010). Certification, Partnership, and Morality in an Organic Shrimp Network: Rethinking Transnational Alternative Agrifood Networks. *World Development*, *38*(5), 706-716. Elsevier Ltd. doi:10.1016/j.worlddev.2009.11.001

Huitric, M., Folke, C., & Kautsky, N. (2002). Development and government policies of the shrimp farming industry in Thailand in relation to mangrove ecosystems. *Ecological Economics*, *40*(3), 441-455. doi:10.1016/S0921-8009(02)00011-3

Lebel, L., Mungkung, R., Gheewala, S. H., & Lebel, P. (2010). Innovation cycles, niches and sustainability in the shrimp aquaculture industry in Thailand. *Environmental Science & Policy*, *13*(4), 291-302. Elsevier Ltd. doi:10.1016/j.envsci.2010.03.005

Lebel, L., Tri, N. H., Saengnoree, A., Pasong, S., Buatama, U., & Thoa, L. K. (2002). Industrial transformation and shrimp aquaculture in Thailand and Vietnam: pathways to ecological, social, and economic sustainability? *Ambio*, *31*(4), 311-23. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12174602

Leepaisomboon, T., Chuchird, N., Limsuwan, C., Steenbruggen, E. R., & Mungkung, R. (2009). GLOBALG.A.P. standard in Thai shrimp farms: Mission (im)possible? *Aquculture Asia Magazine*, 4-6.

Mungkung, R. (2005). *Shrimp Aquaculture in Thailand: Application of Life Cycle Assessment to Support Sustainable Development (hardcopy)*. University of Surrey.

Mungkung, R., & Clift, R. (2003). Qualitative Life Cycle Assessment of Thai Shrimp Product. *Agricultural Engineering*.

Mungkung, R., Udo de Haes, H., & Clift, R. (2006). Potentials and Limitations of Life Cycle Assessment in Setting Ecolabelling Criteria: A Case Study of Thai Shrimp Aquaculture Product (5 pp). *The International Journal of Life Cycle Assessment*, *11*(1), 55-59. doi:10.1065/lca2006.01.238

Pelletier, N. L., Ayer, N. W., Tyedmers, P. H., Kruse, S. A., Flysjo, A., Robillard, G., Ziegler, F., et al. (2007). Impact Categories for Life Cycle Assessment Research of Seafood Production System�: Review and Prospectus. *Challenges*, *12*(6), 414-421.

Ronnback, P. (2002). Environmentally Sustainable Shrimp Aquaculture. *Swedish Society for Nature Conservation*. Retrieved from http://www.naturskyddsforeningen.se/upload/Foreningsdokument/Rapporter/rap-inter-rakodlingar2.pdf

Sandifer, P. (1996). Conceptual design of a sustainable pond-based shrimp culture system. *Aquacultural Engineering*, *15*(1), 41-52. Retrieved from http://www.sciencedirect.com/science/article/pii/014486099500003W

Sriboonchitta, S., & Wiboonpongse, A. (n.d.). Analysis of Contract Farming in Thailand. *Social Development*, *2004*.

Sun, W. (2009). *Life Cycle Assessment of Indoor Recirculating Shrimp Aquaculture System*.

Tunsutapanich, S., Mungkung, R., & Gheewala, S. H. (2006). Energy Performance Evaluation of Aerators for Shrimp Farming, *070*(November), 1-7.

Wells, S. (2006). In the front line Shoreline protection and other ecosystem services from mangroves and coral reefs. *The United nations Environment Programme World Conservation Monitoring Center*. doi:10.1089/bfm.2011.0071

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., Jackson, J. B. C., et al. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science (New York, N.Y.)*, *314*(5800), 787-90. doi:10.1126/science.1132294

## Appendix A: Feed

The waste output data (Table 1) were derived from Hernández et al. (2008) and Silvenius and Grönroos (2003) showing the energy used in the shrimp feed of 1 metric ton of shrimp feed. Since electricity consumption was determined primarily by the concentration of nutrients and organic matter in the wastewater, the electricity used for wastewater treatment was calculated based on net electrical consumption associated with treatment of organic matter, set as 1.1 kWh per kg COD removed based on the LCA food DK database (www.lcafood.dk).

**Table A:** Raw materials, electricity use and waste emissions for producing 1 metric ton of shrimp feed

| **Raw Materials** | **%** | **kg** |
|---|---|---|
| fishmeal | 42.20 | 422 |
| wheat flour/gluten | 26.00 | 260 |
| core starch | 12.61 | 126 |
| soybean meal | 6.44 | 64 |
| fish oil | 2.80 | 28 |
| squid meal | 2.00 | 20 |
| Binder | 2.00 | 20 |
| soybean lecithin | 1.75 | 18 |
| Vitamin premix | 1.50 | 15 |
| mineral premix | 1.50 | 15 |
| Cholesterol | 0.50 | 5 |
| Chromic oxide | 0.50 | 5 |
| Vitamin C | 0.20 | 2 |
| total | 100.00 | 1,000 |
| **Electricity** | **kWh** | |
| Feed Production | 2,646 | |
| Waste Treatment | 0.343 | |
| **Waste Outputs** | **kg** | |
| Airborne emissions | | |
| particulates | 0.48 | |
| Waterborne emissions | | |
| COD | 0.312 | |
| waste water | 180 | |
| Solid wastes | | |
| waste to rubbish dump | 5.186 | |
| waste, composted | 2.078 | |
| waste, hazardous waste | 0.243 | |
| waste, water sludge | 1.172 | |

## Appendix B: Hatchery

Production of 1000 PLs required 0.0074 broodstock. The output and emission data in the table were taken from the Thailand shrimp LCA study (Mungkung, 2005).

**Table B**: Inputs, outputs and electricity consumption for production of 1000 PLs in the hatchery. Data were from Chinese shrimp hatcheries (Sun 2009) and Thailand shrimp hatcheries (Mungkung, 2005)

| Inputs | | | | |
|---|---|---|---|---|
| Hatchery | A | B | C | average |
| Hatchery size | large | middle | small | |
| broodstock (each) | | | | 0.0074 |
| seawater ($m^3$) | 0.143 | 0.834 | 0.193 | 0.390 |
| feed (kg) | 1.2 | | | 1.200 |
| electricity (kWh) | 0.320 | 0.247 | 0.498 | 0.355 |
| Outputs/Emissions | | | | |
| Suspended Solids (g) | 2.76 | | | |
| BOD (g) | 0.16 | | | |
| $NO_2$ (g) | 0.001 | | | |
| $NO_3$ (g) | 0.013 | | | |
| Ammonia (g) | 0.002 | | | |
| Total P (g) | 0.005 | | | |
| electricity used to treat wastewater (kWh) | 0.00022 | | | |

## Appendix C: Energy Consumption

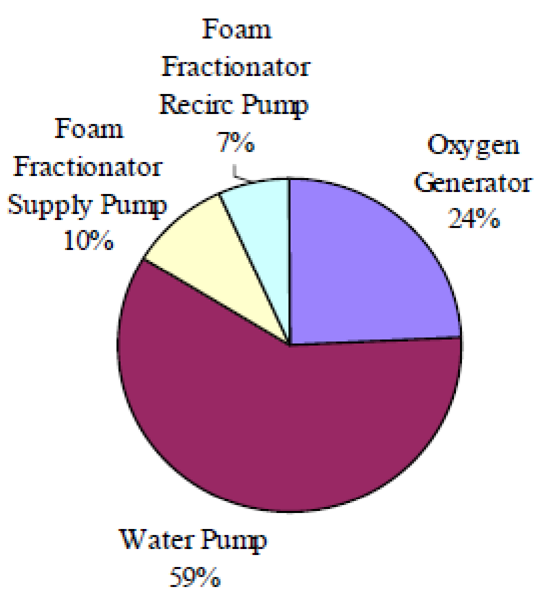


**Figure C1**: Electricity consumption for shrimp farming (Sun 2009)

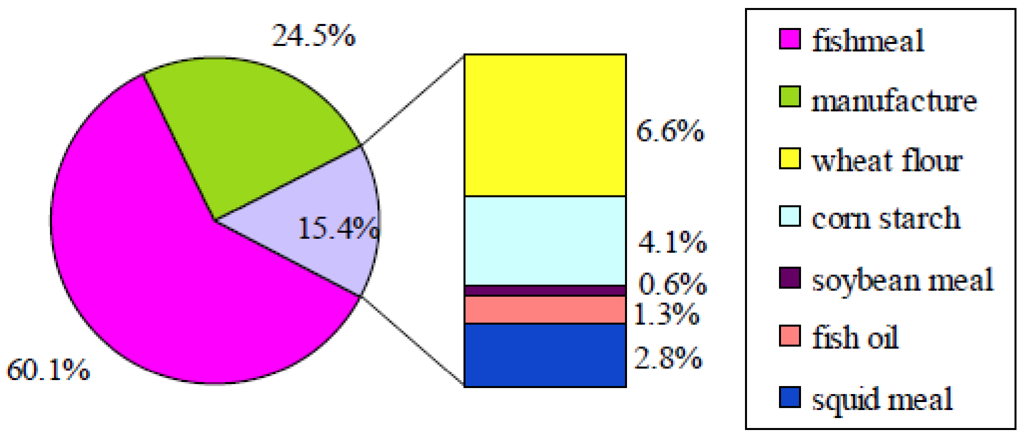
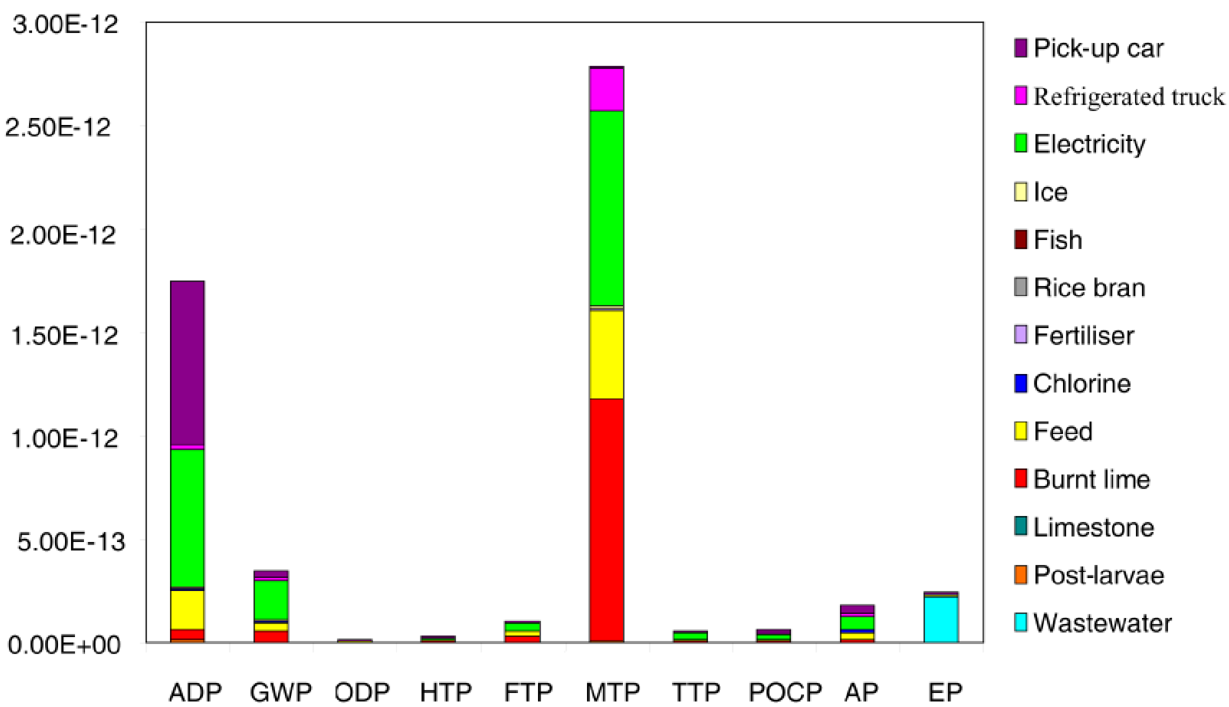
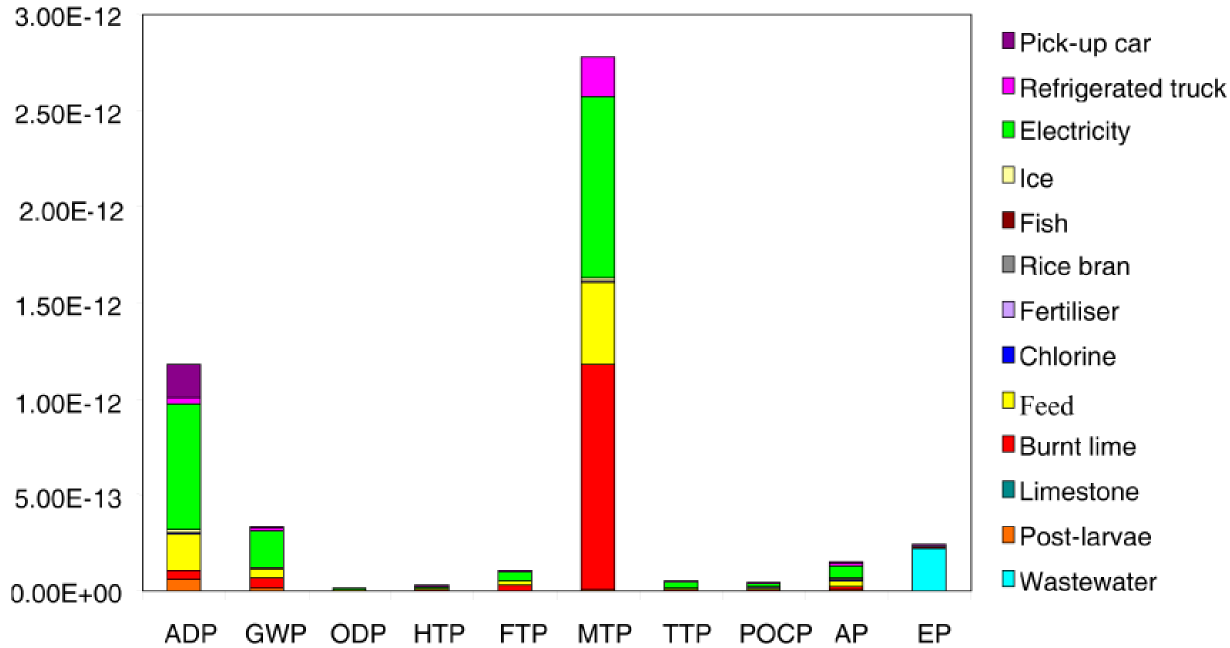



**Figure C2**: Energy consumption for feed raw material production (Sun 2009)

## Appendix D: Impact Assessment




a) Phuket




b) Chacheongsao

**Figure D**: Normalized LCA results for 1.8 kg of block-frozen shrimp, using post-larvae from (a) Phuket and (b) Chacheongsao hatcheries with shrimps produced by Conventional & CoC farm (Mungkung 2006)