Measuring and Mitigating GHGs: **Shrimp**

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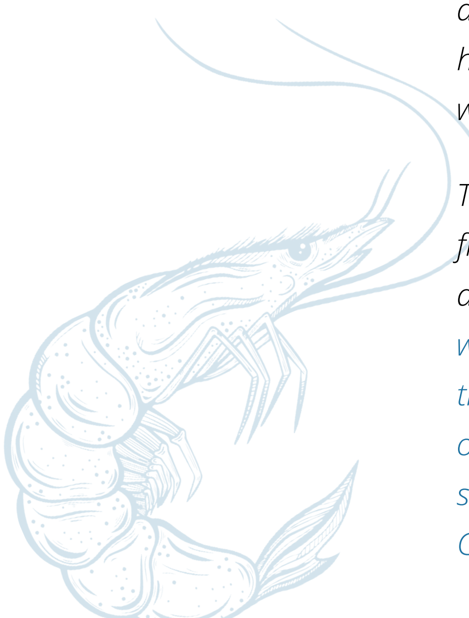

There are millions of farms globally, each using a unique set of practices to cultivate their products in the local climate and soil. Thus, for any commodity, there are many thousands of different production systems and many thousands of different sources of greenhouse gases (GHGs). The relative GHG emissions of producing the same product may differ drastically depending on how and where it is grown. To fully understand how to mitigate emissions and on which farms to focus mitigation efforts, we need a better grasp of the variations and gaps in data.

The authors do not think all the information to quantify GHG emissions from the shrimp value chain exists – at the very least, not in one place. This document is our attempt to collate currently available information. This is a working draft; debate, discussion, and comments are welcomed to advance the understanding of this topic. WWF will be producing similar pieces on other key food commodities to stimulate similar discussions. All comments should be justified with evidence and data and sent to Emily Moberg at GHGCommodities@wwfus.org.

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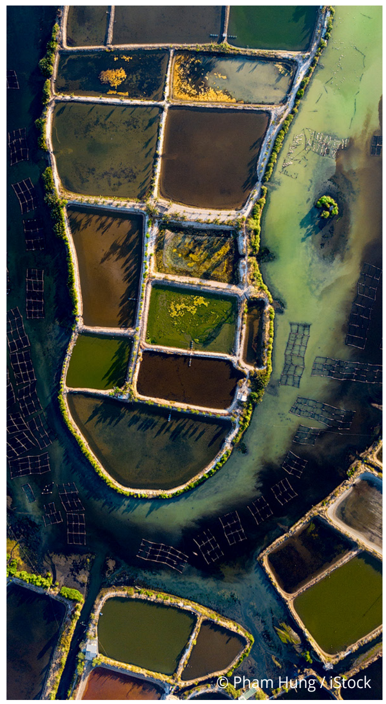
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ABOUT SHRIMP

About 10 million tonnes (Mt) of shrimp are caught or reared each year, of which about 70% come from aquaculture.[1] Shrimp aquaculture has dramatically increased over the past several decades, transitioning shrimp from a rare luxury good to a relatively common restaurant (and even home) food. Shrimp aquaculture is concentrated in Asia and Central America. Shrimp represents roughly 5% of global aquaculture production.

Shrimp aquaculture is varied – production methods range from large extensive ponds to smaller intensive facilities – and the environmental impacts are similarly variable. Shrimp aquaculture has long been an environmental concern, as mangroves were often converted for farming ponds, and pond effluent caused significant damage to surrounding ecosystems.

AQUACULTURE SHRIMP SUPPLY CHAINS

Like many aquaculture species, shrimp are first reared in a hatchery before being stocked in ponds. These hatcheries are often a different business and may be located internationally. The shrimp are then grown to larger sizes. The intensity of production largely determines what inputs are needed, with more intensive production requiring significant feed and aeration. In general, more intensive production is geared toward export.[2]

National production characteristics of a few major producing countries are shown in Table 1.

Shrimp may be sold whole or headless and are often frozen. Packaging is often thin plastic. Various domestic and international destinations for the final product mean that shrimp may travel by boat, train, truck, or plane.

Table 1: Shrimp production statistics for selected countries

	Production (1,000 t/yr)[3]	Export (%)[4]	Percentage farmed (vs. wild-caught)[5]
Ecuador	457	85	98
India	616	46	59
China	1,957	10	53
Thailand	350	51	89
Vietnam	706	45	85
Indonesia	839	20	74

GHG EMISSIONS FROM AQUACULTURE SHRIMP SUPPLY CHAINS

The main sources of emissions vary depending on the intensity of production and include feed ingredients, direct farm energy use, land-use change (LUC), and direct pond emissions. Post-farm emissions are typically small relative to the on-farm footprint.

The range of reported GHG intensity values is between 2 and 99 kilograms of carbon dioxide equivalent (CO_2e) per kilogram of retail product. The shrimp producers that have lower emissions within this range appear to have products with emissions similar to those from pork, poultry, eggs, and other farmed fish.[6] Typical values are likely at the lower end of this range.[7]

Average emissions are likely about **13.5 kgCO_2e/kg edible weight (EW)**,[8] largely because most shrimp are produced using semi-intensive and intensive production methods, which are less GHG-intensive. Shrimp produced in extensive systems emit, by EW, twice as many GHGs as semi-intensive or intensive production.


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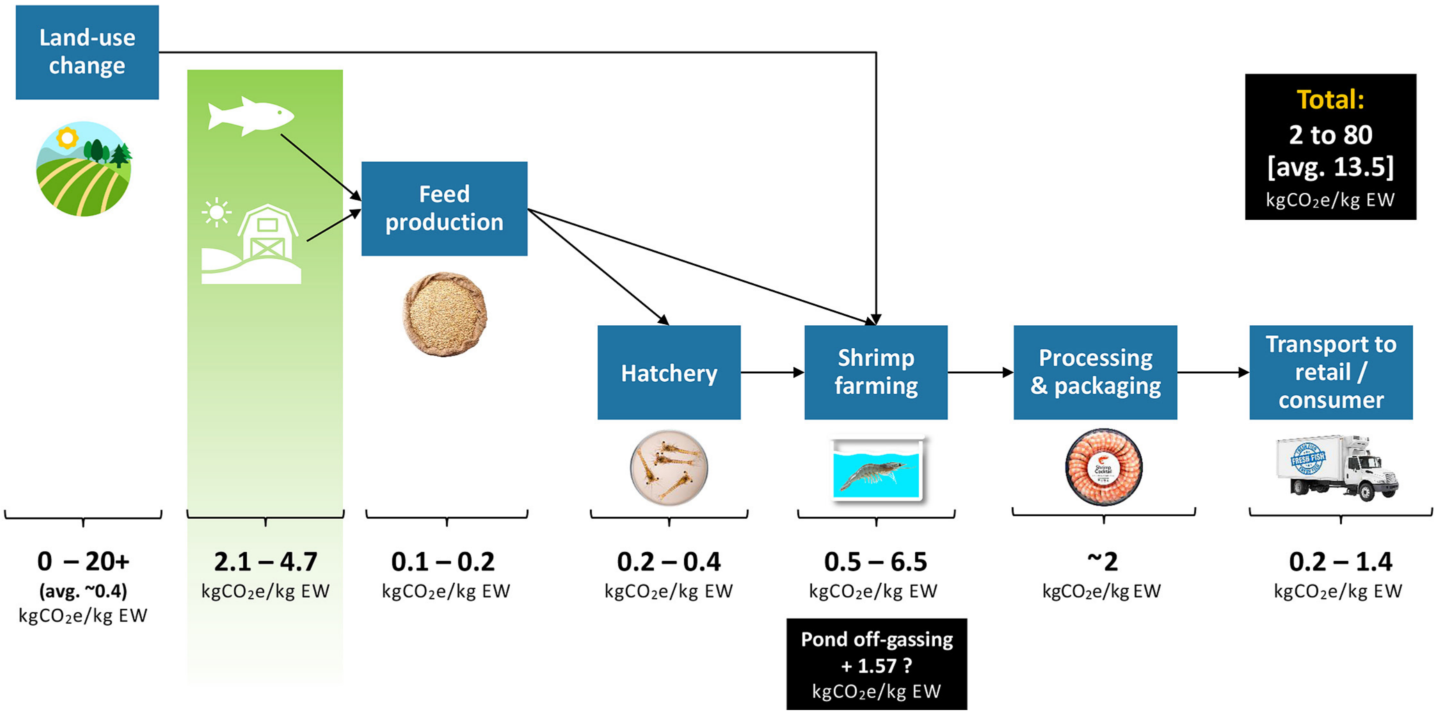
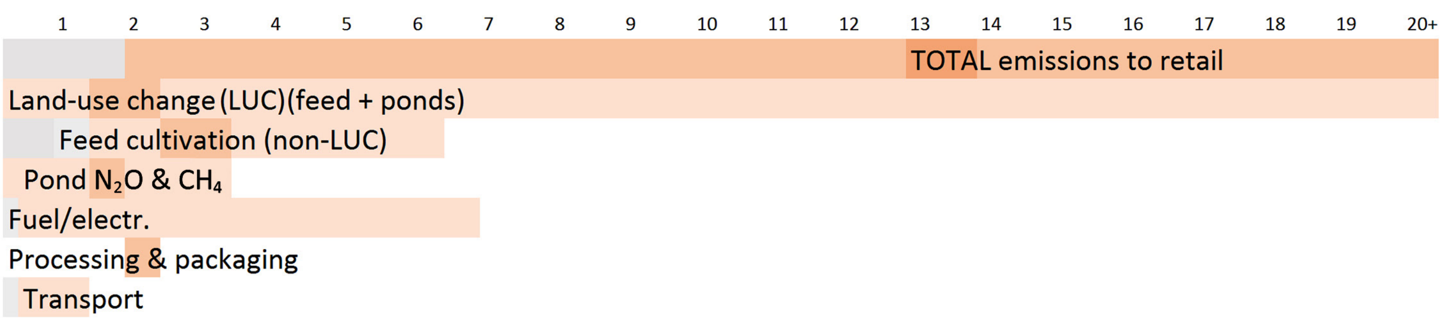
Figure 1: Range of GHG emissions from aquaculture shrimp supply chains



This variability arises from variable emissions across each stage of production. The full range of impacts (in kgCO_2e/kg edible meat) is shown below, with the typical range highlighted in darker orange.



LUC

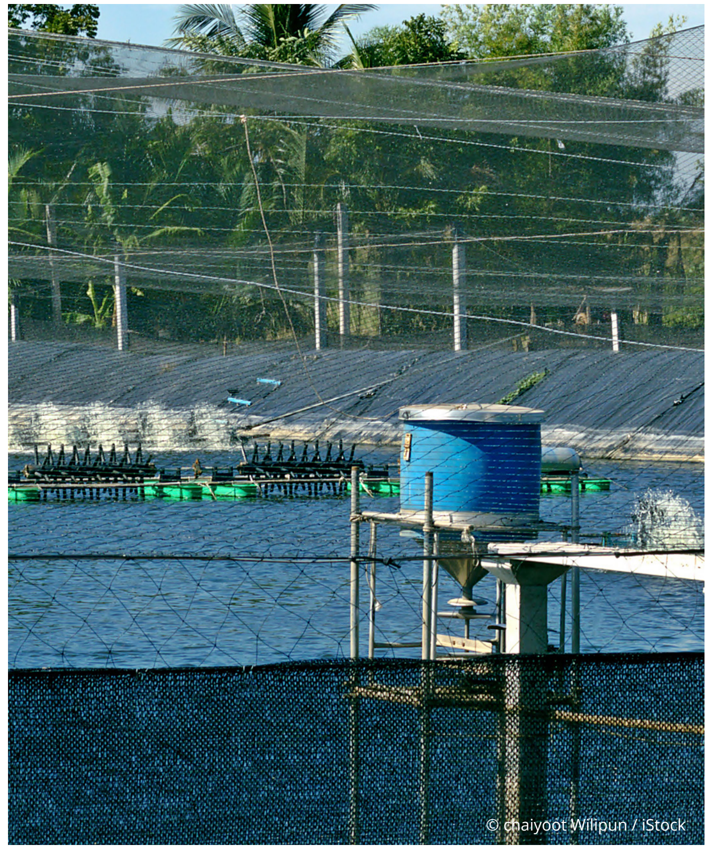
In the past, large areas of mangroves were cleared to make space for shrimp ponds. Extensive farmers have traditionally cleared large amounts of land for aquaculture ponds. Ponds built in cleared mangrove coastal regions receive particular attention, as the conversion generates large GHG emissions from the loss of carbon from the trees, leaf litter, and soil carbon in those ecosystems. Mangroves are among the most carbon-rich ecosystems on the planet, and conversion may cause the emission of over 80% of that stored carbon (which would take over 150 years to replenish).[9] Although mangrove clearing for shrimp ponds has decreased dramatically over the past three to four decades,[10] even amortized over the life span of the shrimp ponds, these emissions can be orders of magnitude larger than other sources of emissions in extensive systems.[11] Currently, other wetland systems are often cleared for shrimp ponds.

Table 2: GHGs from pond clearing

Added emissions ($kgCO_2e$/kg live shrimp) from hypothetical pond clearing, assuming 1,000 tC/ha and 175 tC/ha are lost for mangrove and other wetland, respectively.		
	Mangrove cleared	Other coastal wetlands cleared
Low productivity pond (1 t/ha/yr)	184	32
High productivity pond (20 t/ha/yr)	9	2

The emissions from LUC depend on both the amount of carbon in the original ecosystem and the productivity of the pond. The table above has a few illustrative examples, with emissions amortized over 20 years. Note that for a high-carbon ecosystem that is lost, emissions from this conversion dwarf feed and electricity emissions.

The conversion of mangroves and other wetlands to shrimp ponds likely contributes an average of about 0.4 $kgCO_2e$/kg EW,[12] although this can vary from 0 to well over 50 $kgCO_2e$/kg EW depending on the productivity of the pond.



Feed

The GHGs embedded in shrimp feed are a major component of intensive and semi-intensive operations and can account for over 60% of production emissions. For extensive (unfed) systems, these emissions may be 0. Other extensive farmers will use fertilizers until the shrimp reach a certain size and then finish them on feed. Of course, fertilizer application has embedded GHGs and also contributes to pond off-gassing.

Fish meal is often the largest contributor to the GHG emissions from feed,[13] although other components like soy or wheat may also have relatively high contributions. Some products that are included in shrimp feeds and their GHGs are provided in Table 3. However, note that the emissions intensity of ingredients can vary widely across sourcing regions or even farms.

Table 3: GHGs in shrimp feed

Selected GHGs embedded in feed for selected ingredients (in $kgCO_2e/kg$ dry matter). From the Food and Agriculture Organization's (FAO) FISH-e v1 tool.

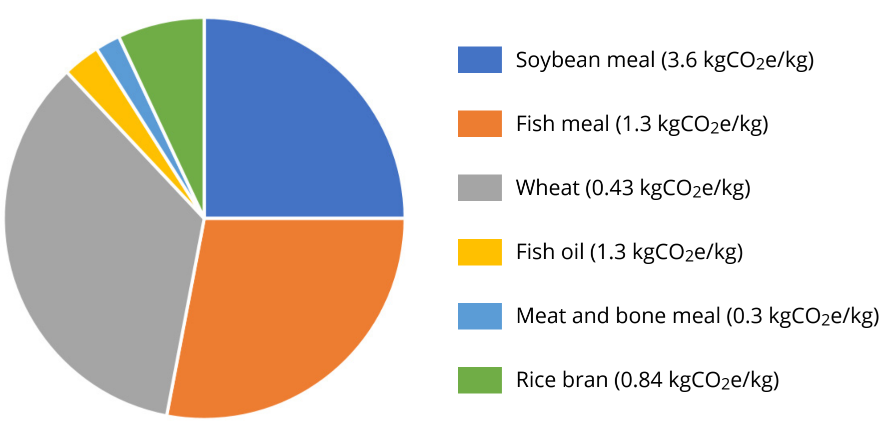
Bloodmeal	1.11	Meat and bone meal	0.36
Cassava	0.49	Poultry meal	0.36
Feather meal	0.28	Pulses	2.77
Fish meal reduction	1.24	Rice by-products	0.84
Fish oil reduction	1.95	Soy oil	6.70
Lime	0.09	Soybean	3.84
Maize	0.97	Soybean meal	3.62
Maize distillers dry grains with solubles (DDGS)	1.33	Vitamin/mineral premix	3.31
Maize gluten meal	0.77	Wheat	0.79
Oilseed meal (non-soy)	1.03	Wheat by-products	0.85

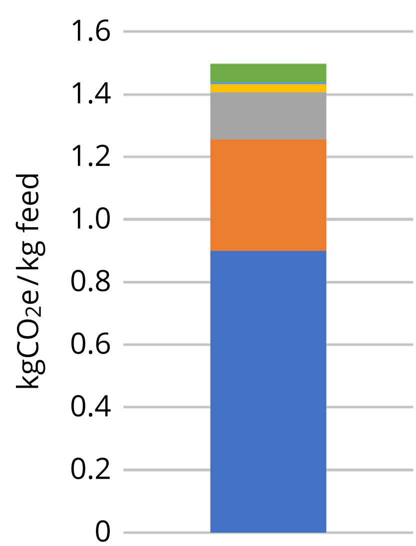
In addition, aquaculture feeds are made via least-cost formulation (based on commodity market prices, so the formulation may vary over time), and by-products are often used as feed ingredients – fish offal from wild-capture processing, wheat middlings, rice bran, etc.

It should be noted that the production methods of these feeds also influence their embedded GHG content. For example, the data in Table 3 assume much of soy products' emissions are from LUC. Soy produced without LUC would have much lower emissions (closer to 0.5 $kgCO_2e/kg$ soybean). LUC arising from shrimp feed is a major part of the overall shrimp GHG footprint.

The emissions from feed are strongly influenced by the feed conversion ratio (FCR). If shrimp in a particular pond require 50% more feed to reach the same final size, the embedded emissions from feed will also increase 50%. The range of FCR for whiteleg shrimp appears to be typically between ~0.9 and 2; freshwater prawns may be even higher.[14]

Figure 2: Emissions embedded in a stylized shrimp diet. Note that the overall contribution of an ingredient is a product of its own GHG intensity and the amount included in the composite feed.





Due to differences in FCR and mortality, if shrimp in the three feed systems were given this same diet, emissions from the semi-intensive system would be 2.4 CO_2e/kg liveweight vs. 2.1 and 1.95 for the intensive and hyper-intensive, respectively.

The emissions embedded in feed range from 2.1 to 4.7 $kgCO_2e$/kg EW. Lower footprints tend to be driven by efficient production (FCR). Note that when soy is produced without LUC, its footprint is typically less than 1 $kgCO_2e$/kg soy, bringing the soy-heavy shrimp feed footprints down significantly as well.

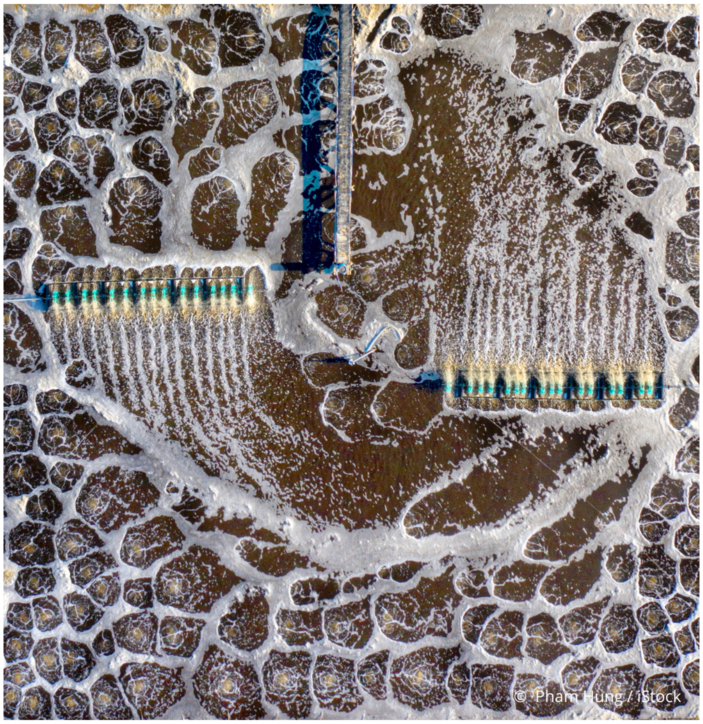
On-Farm Energy Use

Diesel fuels and electricity are used on shrimp farms to power machinery, including pumps and aerators. Electricity (for pumping and aeration) dominates GHG emissions for intensive operations (about half of total emissions) and is a significant component of semi-intensive operations (about 20%).[15] For semi-intensive operations, electricity use may be around 0.5 $kgCO_2e$/kg edible shrimp; for intensive operations, this number could be 10 times higher. This proportion can be even higher in recirculating systems.[16] Note that the GHG emissions from electricity use depend on the regional electrical grid. Primarily, coal grids will have much higher emissions per unit of electricity than regions with a renewable mix. For example, the emissions from electricity used in Latin America would be three times lower than those of East Asia.

While the use of electricity can significantly increase efficiency, animal performance (the FCR and survival) tends to dominate overall emissions because of the high footprint of feed.

Semi-intensive farms may use a large amount of diesel fuel. These emissions may be similar in magnitude to electricity emissions from intensive and hyper-intensive farms, depending on the electrical grid.

The emissions from on-farm energy use range from 0.5 to 6.5 $kgCO_2e$/kg EW. These emissions are driven by how much fuel and electricity are used, the GHG intensity of the local grid, and, most strongly, how many shrimp are produced. Efficient production brings this energy footprint to the lower end.



Direct Emissions

Emissions of methane and nitrous oxide may be significant contributors to overall GHG emissions from shrimp ponds. These emissions result largely from decomposing feces and uneaten feed.[17] Direct GHG emissions from ponds are rarely measured or even estimated as part of aquaculture life cycle assessments (LCAs). When these emissions are added, they may add between 0.1 and 61 $kgCO_2e/kg$ edible shrimp, depending on the local climate, pond depth, and amount of waste in the pond.[18] Direct measurements from ponds suggest that fluxes may be much lower in some shrimp systems[19] (as the anoxic conditions that produce methane would be deadly for shrimp) or aerated ponds.[20] However, there is a dearth of information about these emissions. Global average emissions are likely adding 1.6 $kgCO_2e/kg$ edible shrimp.[21] Emerging standards like the Product Environmental Footprint Category Rules (PEFCR) for Marine Fish, drafted in 2021, include emissions from decomposing waste.

Emissions from extensive and semi-intensive ponds are likely non-negligible but are poorly quantified. Future quantification and responsibility for these emissions are likely.

Other Processes

Shrimp are harvested from ponds by draining. Typical practice is to allow ponds to dry for a period for quicker oxidation of organic matter. While it is important for organic matter to be removed or oxidized for the success of subsequent crops, this oxidation releases GHGs. Some producers seek to remedy the dry-out of ponds by using plastic liners where organic matter can be removed. However, the plastic liners require a large amount of energy to produce, and depending where and how organic matter is disposed, GHGs will be emitted if left to oxidize. Depending on system type and farm management, pond amendments may account for large contributions to GHG emissions (>10%).[22] For example, burnt lime, hydrated lime, fertilizers, and antimicrobials are produced with large amounts of energy.

Post-Farm Emissions

Post-farm emissions arise from transportation and processing, as well as packaging. Most of these emissions are from the fossil fuel emissions in producing electricity or directly burned as fuel.

- **Processing and packaging:** Processing is rarely characterized in LCAs for shrimp. Emissions from packaging depend on the type of packaging and arise largely from energy use in production. From studies of other meats, plastic packaging emits about 0.14 $kgCO_2e/kg$ EW,[23] while aluminum packaging (tray) tends to be higher (~0.4 $kgCO_2e/kg$ EW).[24] Shrimp are likely similar, although the overall emissions can be altered by how much product is typically contained in per-unit packaging.
- **Transport:** Emissions for transportation depend

on both the distance traveled and the mode of transit; per kilogram-kilometer, boats and trains have much lower emissions than trucks, which are then lower than those from airplanes. From studies of transport, this may range from 0.2 to 1.4 kgCO_2e/kg EW, although specific supply chains likely differ.

Overall, post-farm emissions contribute about 2–3 kgCO_2e/kg EW. Light packaging produced in renewable heavy grids and traveling short distances will have a lower footprint.

PRODUCTION SYSTEMS

The key differences in shrimp production are in the intensity of production, which may range from unfed extensive production to very intensive production with aeration and tailored feeding. Brief descriptions of each system follow, and a stylized summary of performance is listed in Table 4 (top of page 10).

Extensive: Unfed shrimp aquaculture typically has low productivity (0.5–1 t/ha shrimp).[25] GHG intensity is typically high, especially for freshwater species (4.1–46 kgCO_2e/kg edible shrimp).[26] Historically, these high emissions have been from LUC (mangrove clearing) and may still threaten wetland ecosystems. The off-gassing of methane and nitrous oxide is otherwise the main source of emissions. Shrimp survival is typically low in these systems.[27] About 10% of shrimp production is extensive, but over 50% of shrimp pond area is extensive.[28]

Semi-intensive: Common form of shrimp aquaculture, encompassing a range of practices; shrimp are typically fed and fertilized. Typically has higher productivity than extensive production. GHG intensity has a very large range (2–23 kgCO_2e/kg edible shrimp),[29] determined largely by the FCR. About 10% of shrimp production is semi-intensive.

Intensive: Fed and aerated shrimp aquaculture. Production can exceed 50 t/ha. These shrimp are often raised for export. GHG intensity has a large range (4.3–28 kgCO_2e/kg edible shrimp),[30] with emissions arising from both feed and electricity use on-farm. In general, as shrimp production is more intensive, the GHG emissions per unit of product decrease. About 80% of shrimp production is intensive.

Hyper-intensive: Fed and aerated shrimp aquaculture at high density. While large amounts of shrimp are produced, electricity use is also large. When the electrical grid is largely fossil fuel-based, this may result in high GHG emissions, although limited data are available on the holistic performance of these systems per kilogram of shrimp produced.

Table 4: Selected characteristics of four intensities of shrimp production systems

Characteristic	Extensive	Semi-intensive	Intensive	Hyper-intensive
Crops/yr	2	3	3.5	4
Survival rate (%)	50	60	65	70
Yield (t/ha/crop)	0.5	1.5	8	20
FCR	--	1.6	1.4	1.3
Farm electricity use (kWh/yr)	--	87,000	439,098	1,277,232
Diesel + gasoline (1,000 L/yr)	.09	538.2	2.3	2.3

REGIONAL VARIATION

Shrimp aquaculture is conducted largely in Asia, with smaller amounts occurring in Latin America; minimal amounts of shrimp are grown elsewhere. Both tiger shrimp (*Penaeus monodon*) and whiteleg shrimp (*Litopenaeus vannamei*) are still produced in great volumes. In general, shrimp aquaculture began in the mid-20th century with tiger shrimp and shifted after major disease outbreaks in the late 20th century. Whiteleg shrimp, which have generally higher productivity, have become the dominant farmed species in most geographies.

Regions differ most critically in the intensity of production and, within that, the yields and feed composition. For example, based on pond area[31] and total production, Thailand produced over 11 t/ha/yr of shrimp, while Bangladesh produced only 0.3 t/ha/yr. Results from a calibrated model of yields across key countries show some of these differences (Table 5).

Table 5: Shrimp production characteristics for selected countries

	% Extensive	% Semi-intensive	Total productivity (t/ha/yr)	GHG footprint (kgCO_2e/kg EW to farm gate)
Global	10.6	9.3	2.7	10.8
Vietnam	40.9	0.0	1.1	10.3
China	1.8	26.3	4.6	12.3
Indonesia	15.8	0.0	2.4	15.2
Bangladesh	71.6	0.0	0.3	6.1
Ecuador	0.3	3.6	3.8	9.4
India	2.4	0.0	3.9	11.6
Myanmar	83.7	0.0	0.3	5.4
Mexico	0.3	7.7	1.8	9.1
Thailand	1.2	0.0	12.5	12.1

OUTLIER EMISSIONS SOURCES

The variability in emissions per kilogram of edible shrimp highlights the large mitigation potential that exists across current practices. Here we highlight the "low hanging fruit," or practices that drive unusually high emissions intensity. These practices may be good targets for initial screening for improvement.

- **LUC in feed:** Emissions from LUC in feed are a major global source of emissions and contribute to shrimp's overall footprint.
- **Optimized diet and feed use:** Improvements in animal health and productivity have a huge mitigation potential. In this analysis, we found that differences in yield per area drove the largest differences in emissions intensity.

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MITIGATION

If all shrimp globally were produced at the lowest current intensity (estimated at 4.3 $kgCO_2e/kg$ EW at farm gate), the total emissions from shrimp would drop from 52 Mt to 17 Mt (almost a 70% reduction) per year. That improvement is the same amount as the yearly emissions of New Zealand! Of that amount, over half of the improvement could be from semi-intensive and intensive improvement, given the much larger quantities of shrimp produced.

Given that many shrimp producers are not operating as efficiently as possible, there are many interventions that should increase both production and profitability, and reduce emissions. While there are many options for improving the efficiency of production, we have highlighted the metric of improved FCR here.

Because emissions coming from feed production are significant, removing deforestation and conversion from feed ingredient production could also lower footprints. For example, in the stylized diet shown earlier (25% soy), if the soy were conversion-free, the footprint for that diet could reduce by half.

Table 6: Mitigation summary

Intervention	Target	Cost	Mitigation Potential	Barriers
Improved FCR	Intensive and semi-intensive; feed producers and farmers	Globally, if whiteleg shrimp producers could reduce FCR by 0.1, it would save producers $282 million per year[32]	1.8 MtCO_2e/yr (~10% lower FCR)	Technical expertise
Avoid mangrove conversion	Governments, extensive farmers	$10 – $100/t$CO_2$e/y[33]	0.25 GtCO_2e/yr[34]	---
Conversion-free feed	Intensive and semi-intensive	?	> 1.1 kgCO_2e/kg edible shrimp[35]	Traceability
Renewable energy	Intensive farmers	?	> 4 kgCO_2e/kg edible shrimp for intensive and hyper-intensive shrimp	Cost, infrastructure

TOOLS AND DATA AVAILABILITY

GHG emissions from shrimp are relatively poorly characterized relative to those from terrestrial animal products. In particular, the emissions from decomposition of feces and feed are highly uncertain, and how aquaculture practices influence those emissions is not well studied. Despite most emissions occurring on farms, relatively few tools for on-farm calculations are available.

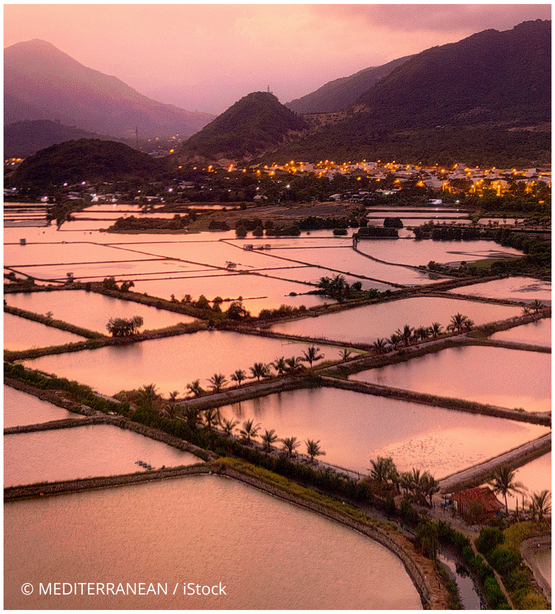
There are several tools that are in pilot or test versions:

- **FISH-e:** FAO's tool for quantifying aquaculture GHG emissions (https://www.fao.org/fishery affris/affris-home/fish-e-faos-tool-for-quantifying the-greenhouse-gas-emissions-arising-from aquaculture/en/). This is an Excel-based tool that uses local feed compositions and on-farm energy use to calculate a footprint.
- **Blonk and IDH tool:** Blonk Consultants has developed a pilot tool for tropical aquaculture, including shrimp. This tool includes feed, pond off-gassing, and energy use.

Table 7: Seafood's contribution to food-sector

	Total emissions (GtCO_2e/yr)	Seafood's contribution (GtCO_2e/yr)
Agriculture-driven LUC	4.9	**0.13 – 0.24[36] (aquaculture feed)**
Agriculture	6.2	
Non-agriculture, forestry and other land use (AFOLU) food emissions	2.6 – 5.2	**?**
Maritime fuel use	1.1[37]	0.18 – 0.38[38] (capture fisheries' fuel)
Aquatic biogenic	?	**? pond emissions 1.47 (trawling)[39]**
Global total	52	**0.435 – 0.866 (aq. and w.c. to dock)**

The relevant categories for shrimp aquaculture are highlighted.



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Seafood is also poorly represented in global food and climate models, so the trade-offs between increased seafood consumption relative to terrestrial foods are not well characterized. However, we do know that the emissions intensity of seafood must decrease regardless of the proportion of diets it comprises. In 2019, the global emissions intensity of plant and animal protein was about 75 tCO_2e/t of protein. If the per capita protein consumption stays the same but the population increases, a 30% reduction of GHG intensity will be required to keep overall emissions the same as they are today. Protein production must decline to 14 tCO_2e/t protein to reduce emissions to about 4 $GtCO_2e/yr$, which is what current modeling[40] suggests the food sector needs to be limited to by 2050. *This suggests the maximum emissions intensity from seafood will be about 14* tCO_2e/t *protein, which is at least quadruple the current intensity of shrimp.*

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31 From Boyd et al. 2021.

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34 Assuming similar conversion rates for the six focal countries from 2014–2018 (Clark Labs data) and 1,000 tC/ha carbon emitted from conversion.

35 This number represents the decrease in footprint from conversion-free soy only in a diet that has 25% soy; given other crops also have LUC embedded, the full potential for conversion-free feeds should be higher. Gephart et al. estimate the potential at 20% reduction, or about 1.9 kgCO2e/kg edible shrimp.

36 Aquaculture GHG estimates from MacLeod, M. J., Hasan, M. R., Robb, D. H. F. et al. (2020) Quantifying GHG emissions from global aquaculture. Sci Rep 10, 11679. Available: https://doi.org/10.1038/s41598-020-68231-8 and Gephart, J. A., Henriksson, P. J. G., Parker, R. W. R. et al. (2021) Environmental performance of blue foods. Nature 597, 360–365. Available: https://doi.org/10.1038/s41586-021-03889-2. Emissions from feed tend to be about half of the emissions, so each estimate was divided by two to get the probable emissions in the AFOLU sector.

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38 Parker, R. W. R., Blanchard, J. L., Gardner, C. et al. Fuel use and GHG emissions of world fisheries. *Nature Clim Change* 8, 333–337 (2018). https://doi.org/10.1038/s41558-018-0117-x and Gephart, J. A., Henriksson, P. J. G., Parker, R. W. R. et al. (2021). Environmental performance of blue foods. Nature 597, 360–365.

39 Sala, E., Mayorga, J., Bradley, D. et al. (2021) Protecting the global ocean for biodiversity, food and climate. Nature 592, 397–402. Available: https://doi.org/10.1038/s41586-021-03371-z. It is unclear how much of this mobilized carbon from trawled sediment is released into the atmosphere. For this reason, this pool is not added to the seafood global total.

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