Land-Based RAS and Open Pen Salmon Aquaculture: Comparative Environmental Assessment

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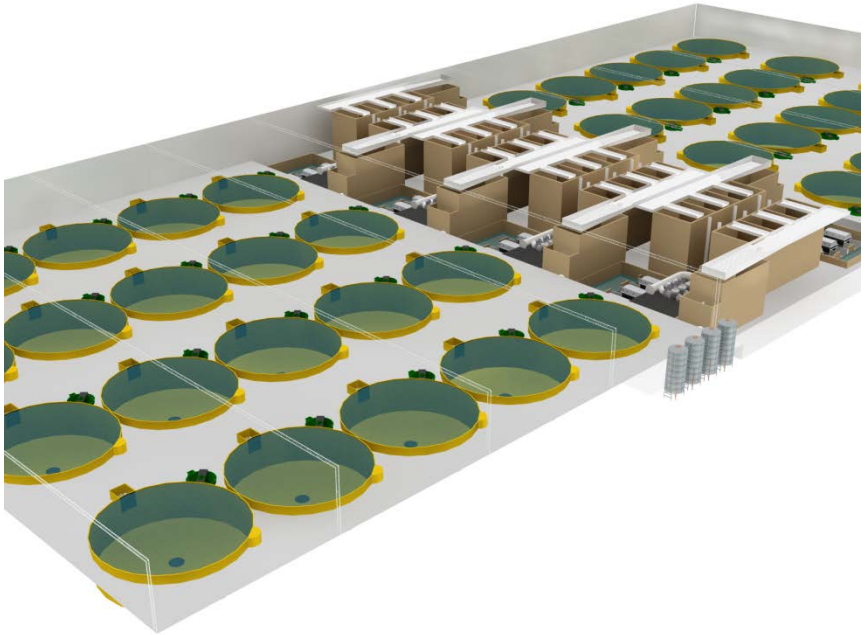
Outline

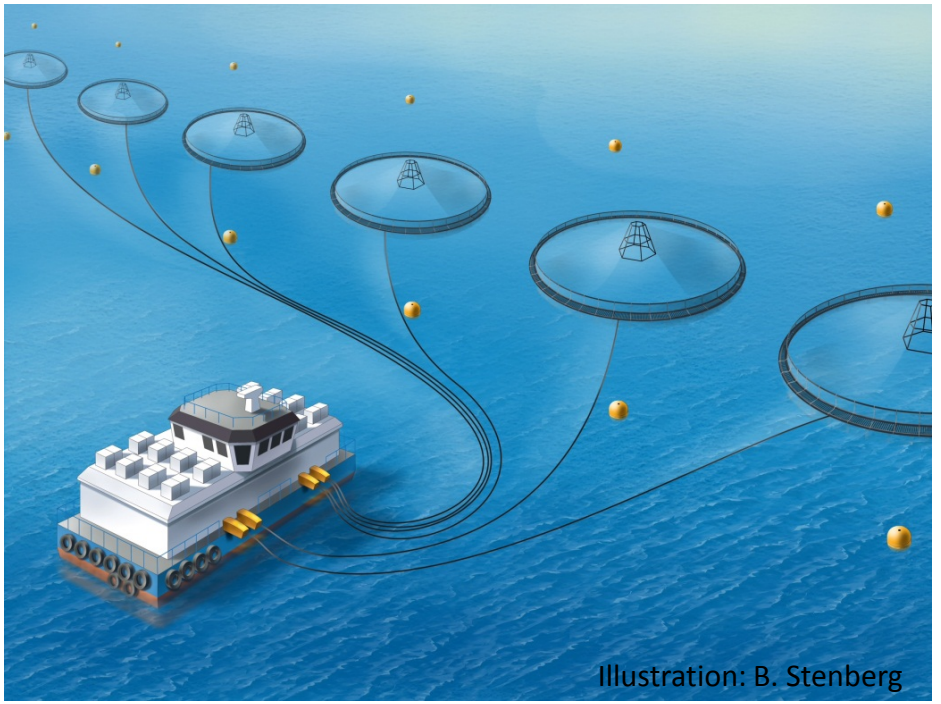
- **Hypothesis**
  - Assumptions
- **Description of Production Facilities/Methods**
- **Comparative Environmental Assessment: GHG Assessment and Comparison**
  - LCA Method Assumptions
  - LCA Method Results
- **Conclusions**

Hypothesis

- Land-based production of Atlantic salmon in the Model RAS has a higher CO_2 footprint than production in the Model Net Pen

Production Models





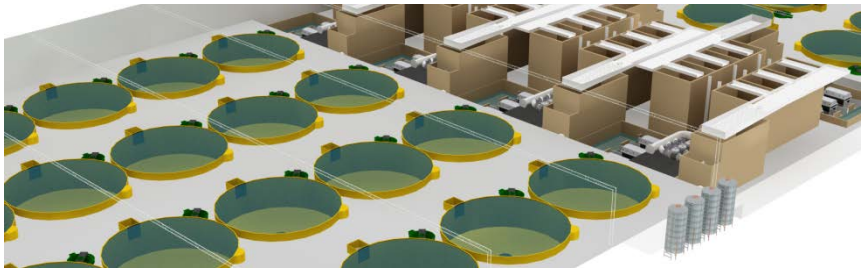
Land-based RAS farm

Producing 3,300 M.tons HOG Atlantic Salmon

Model Net Pen farm

Producing 3,300 M.tons HOG Atlantic Salmon

Facilities



Model Land-based RAS farm (32 million US $)

One production site

Invested equipment:

- 40,000 m^3 of rearing tank volume
- 25,500 m^2 of building area
- 2,500 m^2 processing facility
- 885 m^3/min of pumped RAS flow
  - Pumps and Piping
  - Screen filters
  - Biofilters
  - Gas Conditioning Filters
- 1.08 – 1.26 kg feed per m^3 supply water
- Feeding Systems
- Backup Generators

Investments in total: 32 M US $ - approximately 192 MNOK

Maintenance and reinvestments set equal to the depreciations

Model Net Pen farm (12.3 million US $):

Two production sites, each with six net pen cages.

- ≈587,000 m^3 net-volume
- 120,000 m^2 area footprint visible at sea
  - ≈179,000 m^2 area footprint incl. no thoroughfare zone
  - ≈463,000 m^2 area footprint incl. no fishing zone

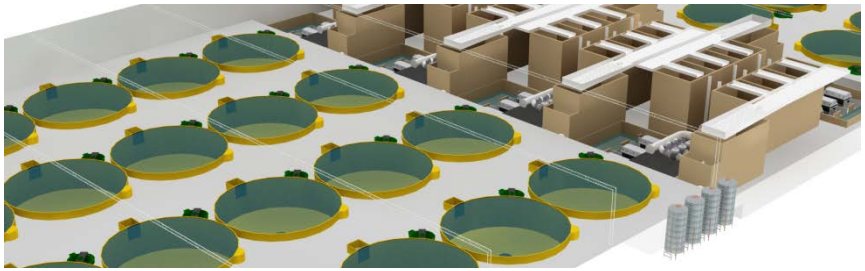
Invested equipment:

- 3 licences
- 12 Floating rings (157m Ø)
- 24 nets (25 m deep)
- 2 mooring systems
- 2 boats
- 2 feed barges (150 Mtons)
- 12 camera systems
- 12 feed distributors
- 12 power systems

Investments in total: 72.9 MNOK – approximately 12.3 M US $

Maintenance and reinvestments set equal to the depreciations

Biological Production



Model Land-based RAS farm

- One production site for all life-stages
- Four cohorts per year

- Growth based on thermal growth coefficients from Freshwater Institute growout trials, adjusted down by 10%:
  - 1.1 for Fry
  - 1.25 for Smolt
  - 1.8 for Pre-growout
  - 2.2 for Growout

- Mortality per generation 16%

- Feed conversion ratios:
  - 0.75 for Fry
  - 0.90 for Smolt
  - 1.0 for Pre-Growout
  - 1.1 for Growout
- Overall Feed to Whole Fish Produced (kg/kg): 1.09

Model Net Pen farm:

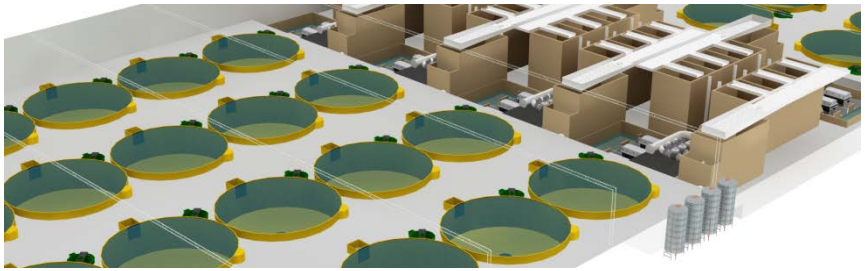
- 2 production sites & 3 licences of 780 M.tons of maximum total biomass at sea.
- Two transfers of smolts to sea annually, to one site
  - S1 at 1st of April, 100 grams, 520' smolts in three cages
  - S0 at 1st of August, 75 grams, 520' smolts in three cages

- Growth based on the Skretting table, Specific Growth Rate (SGR), adjusted down by 12 %.

- Mortality per generation approximately 16.1 % (average in Mid-Norway in 2011) (Norwegian Food Safety Authority 2011).

- Economic feed conversion ratio: 1.27 (average in Norway over the last ten years) (Directorate of Fisheries 2013).

Biological Production



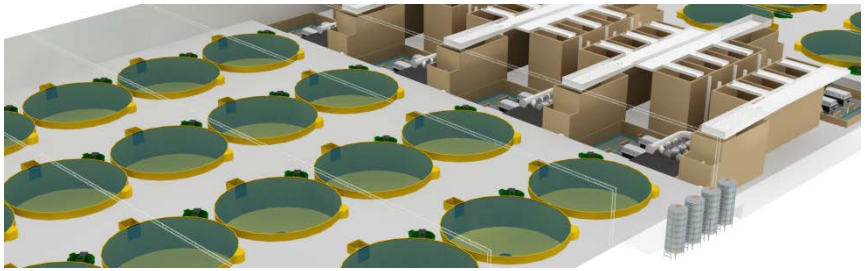
Model Land-based RAS farm

- Rearing Density
  - 80 kg/m^3 maximum
- Harvesting:
  - Time from first feeding to first harvest: 21 months
  - Harvest every week of the year
    - Each cohort harvested over 13 weeks
    - One grisle harvest at ~1.2 kg for 50% of males
  - Harvest in total: 3,947 M.tons LWE; 3,300 M.tons HOG (5 % purge loss / 12 % HOG loss)
  - Initial harvest weight (whole fish): 4.5 kg
  - Average harvest weight (whole fish): 5.1 kg
- No downtime in the bioplan

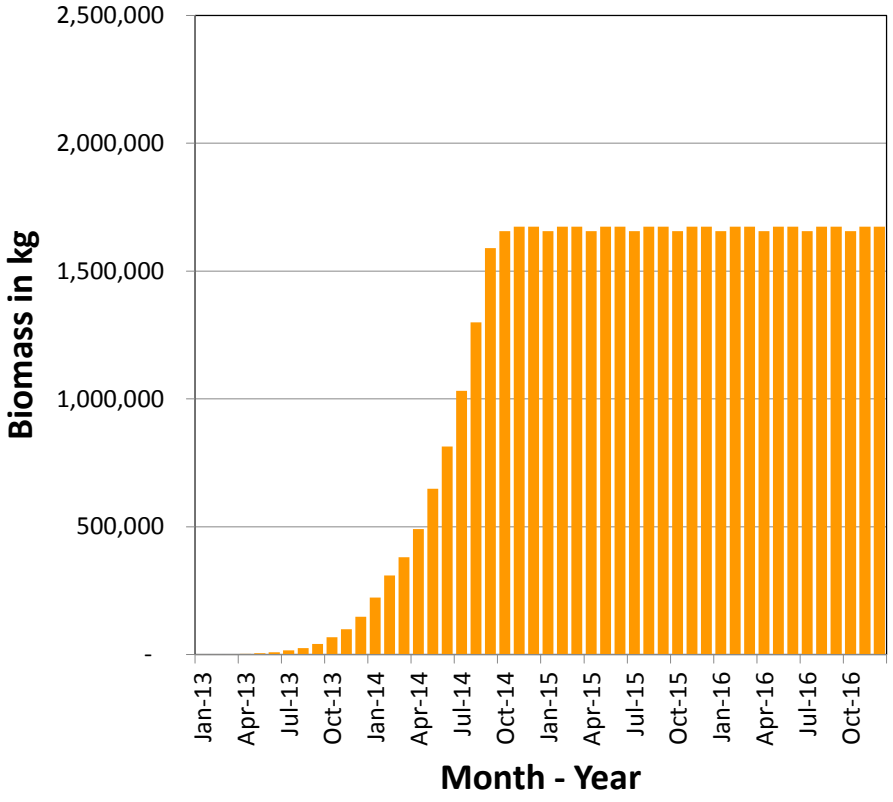
Model Net Pen farm:

- Rearing Density
  - 25 kg/m^3 maximum
- Harvesting:
  - Time from first feeding to first harvest: 24–31 months
  - Time at sea before first harvest: 16 months
  - Harvest 8 months of the year
    - Harvest S1 from July to October
    - Harvest S0 from November to February
  - Harvest in total: 3,975 M.tons LWE; 3,299 M.tons HOG (5 % purge loss /12 % HOG loss)
  - Average harvest weight (whole fish) : 4.5 kg
- Two months of fallowing between production cycles

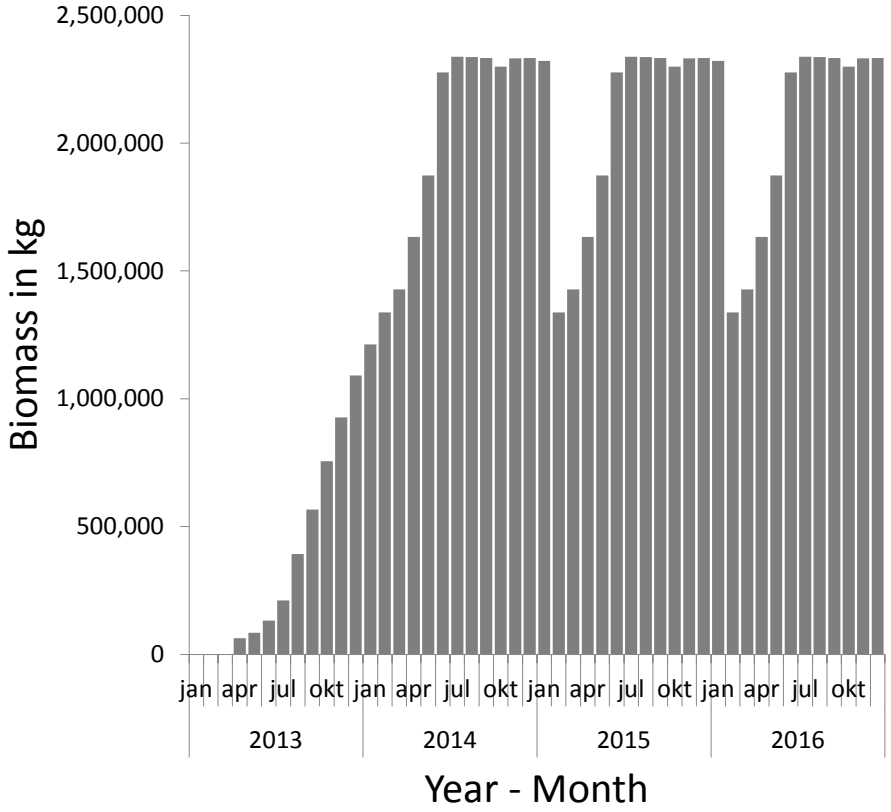
Biomass



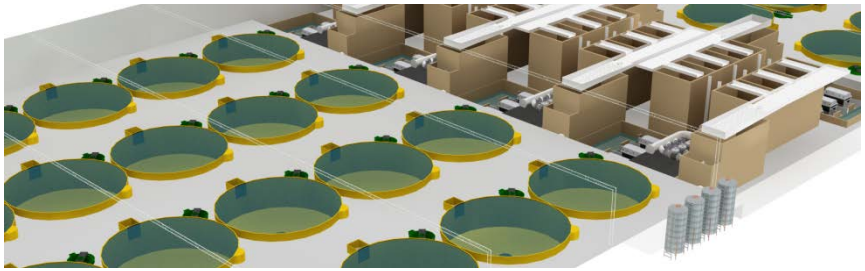
Model Land-based RAS farm



Model Net Pen farm



Feeding



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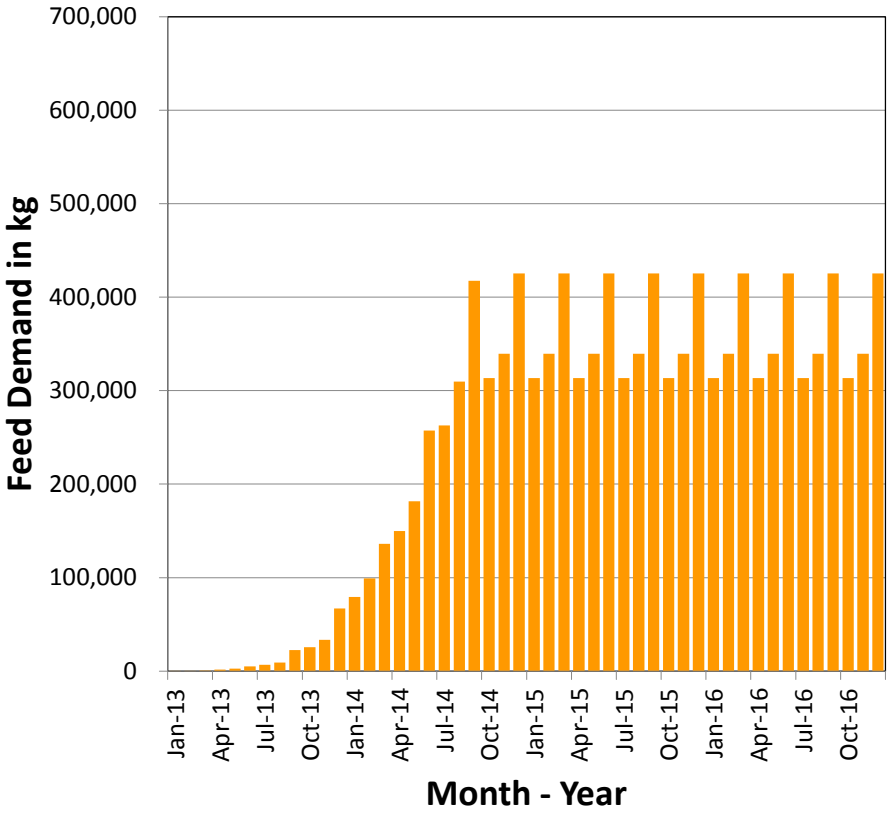
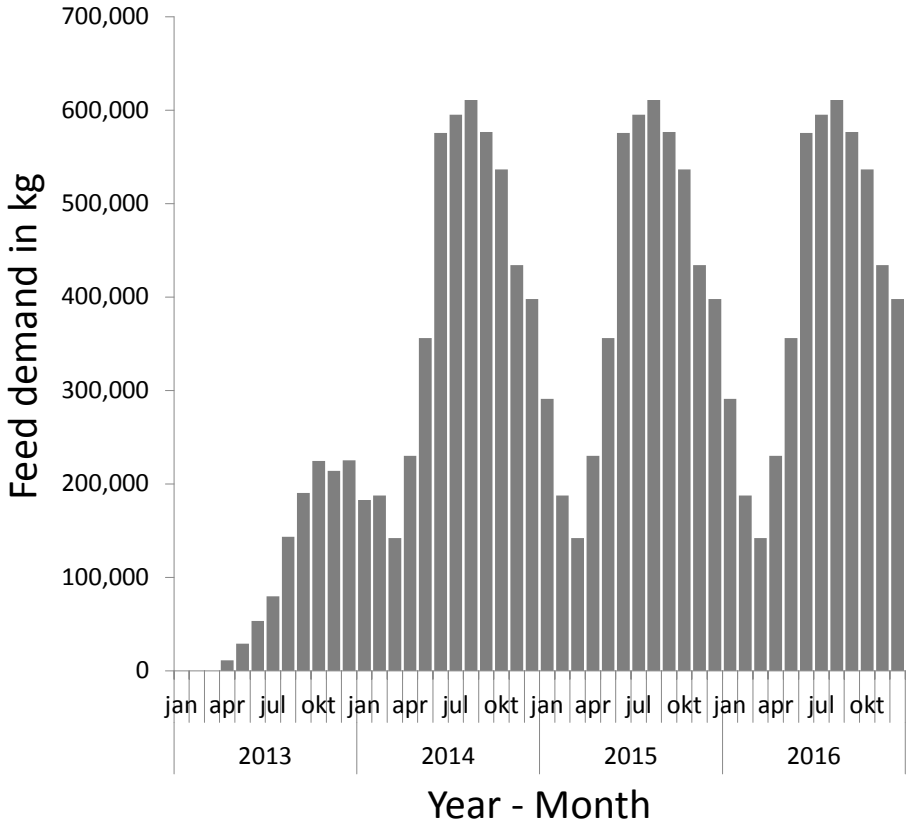
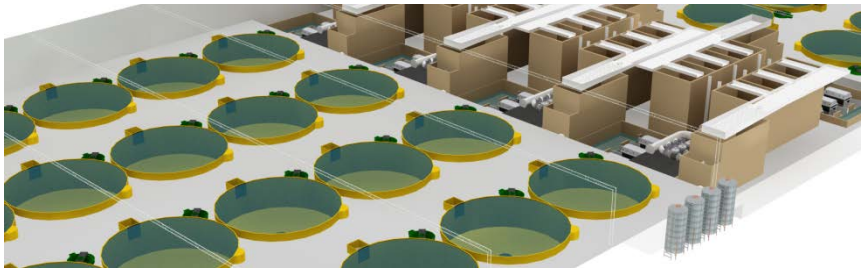


Model Net Pen farm



Harvest



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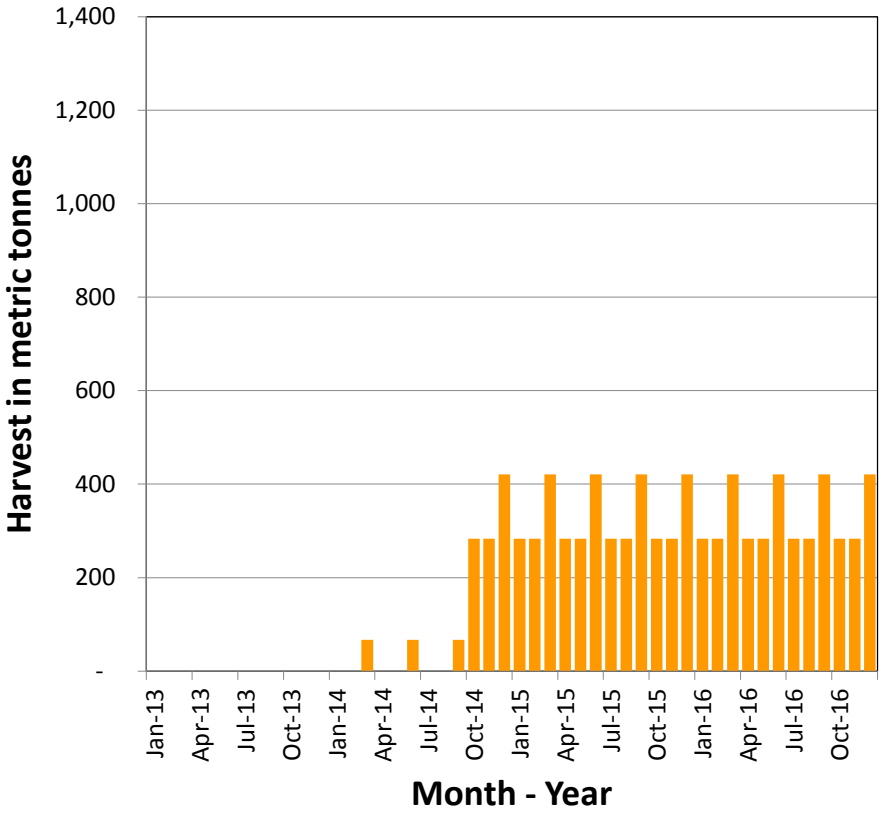
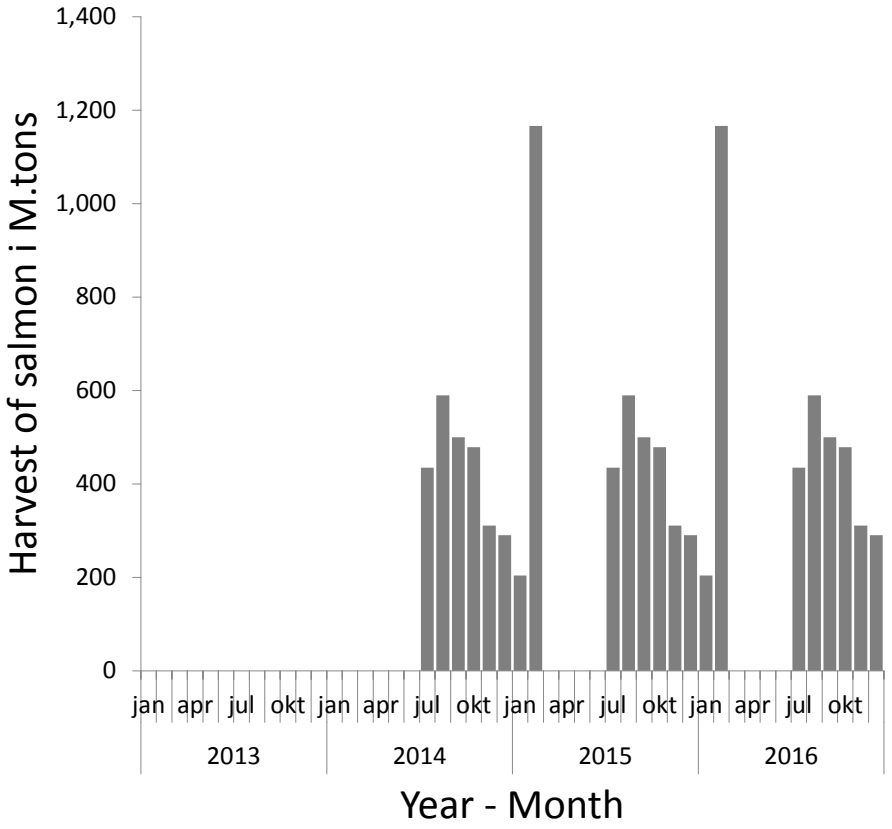


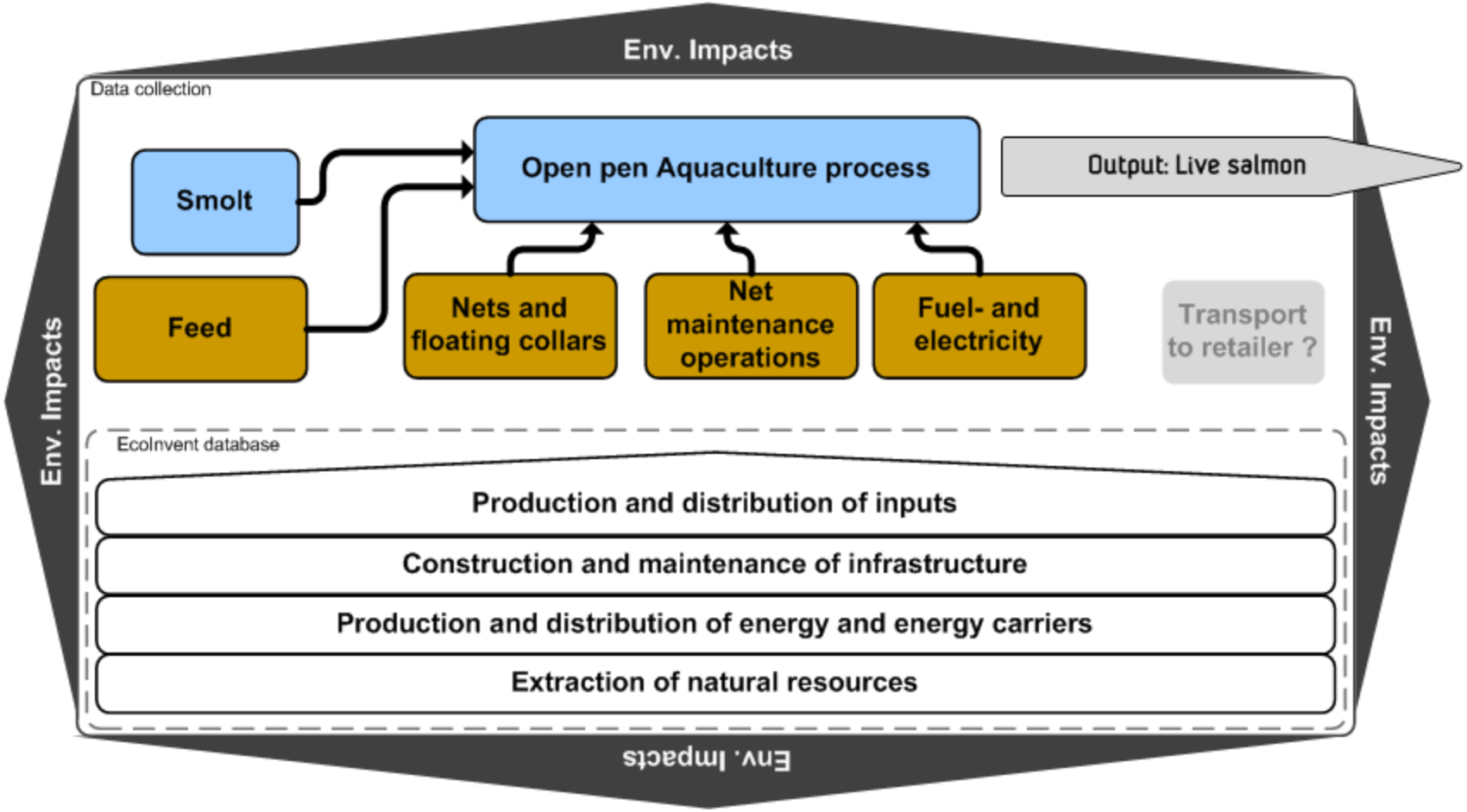
Model Net Pen farm



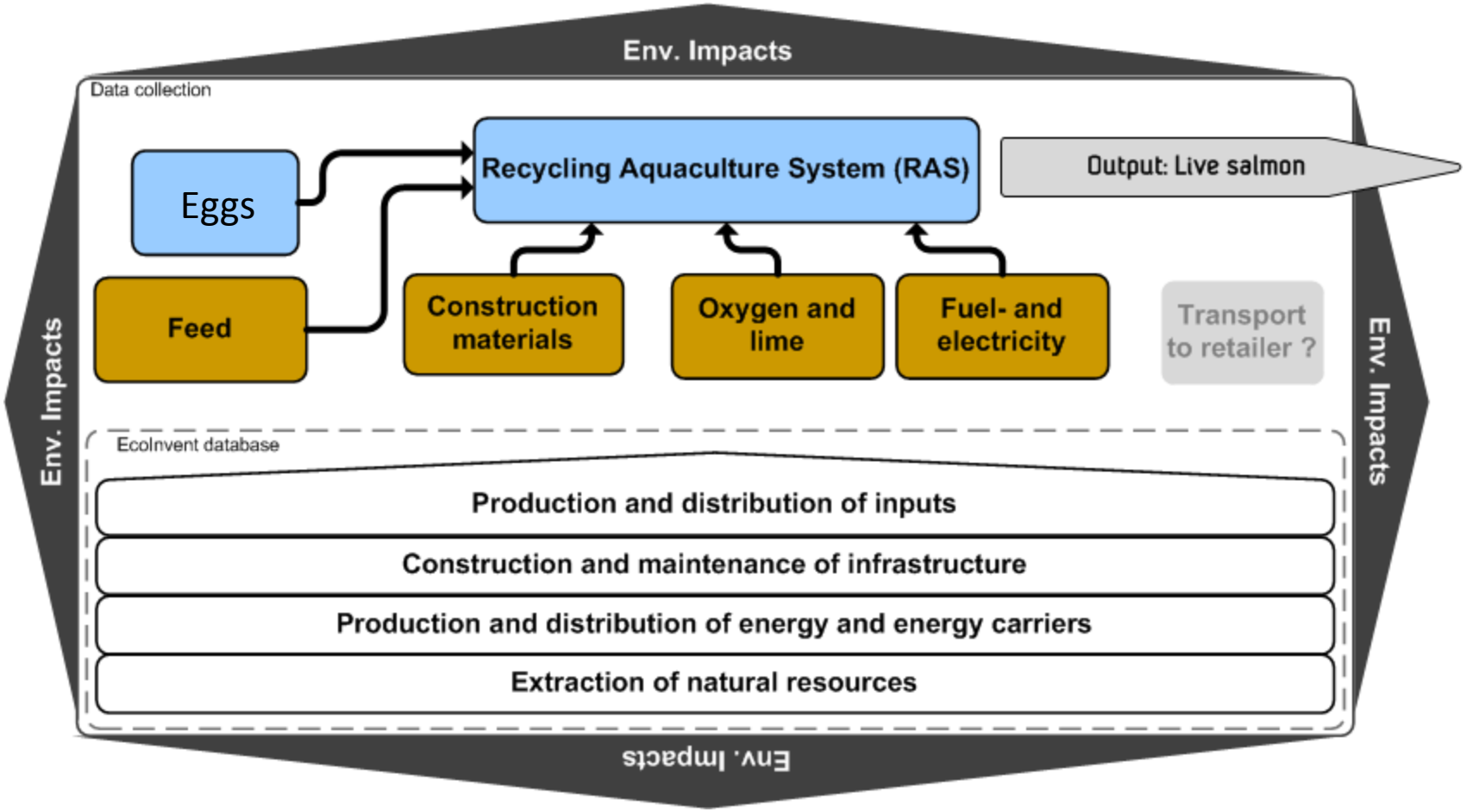
GHG Assessment of Model RAS and Model PEN Salmon Production: Goal and Scope

- **Goal:** To study the potential climate impact from the production of 1 kg of salmon in live weight
- **Method:** GHG assessment performed with the Life Cycle Assessment (LCA) method. Impact assessment calculates the potential climate impact in CO2 equivalents (CO2e) according to IPPC guidelines
- **System Boundaries:** The assessment includes resources used in the production of feed ingredients up through salmon being ready for slaughter at the production site. Construction of production equipment and production facilities are included.

System boundaries for the PEN system



System boundaries for the RAS system

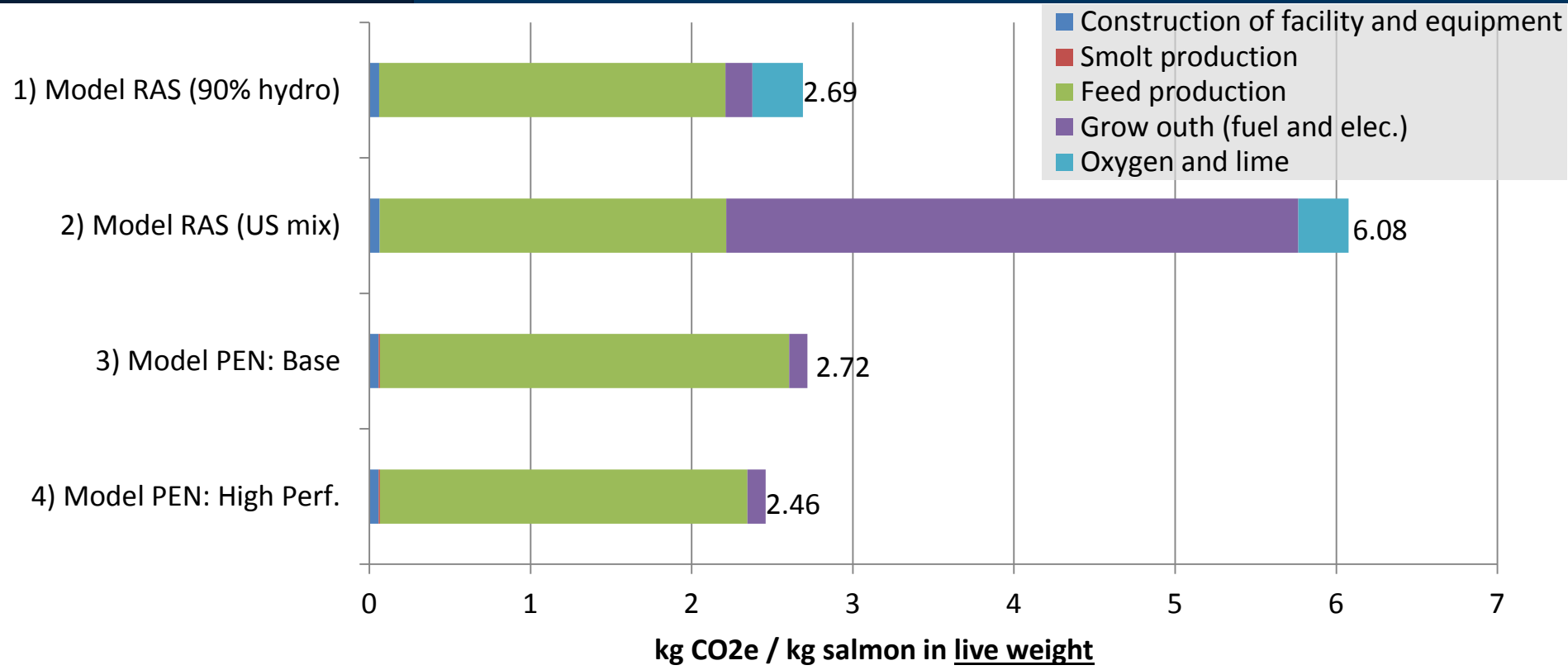


Data

- Critical data:
  - Model RAS:
    - 1.09 kg feed/kg salmon in live weight
    - Electricity input: 4.6 kWh/ kg salmon in live weight
  - Model PEN: 1.27 kg feed/kg salmon in live weight

- Feed production is modelled with data from the project "Climate impact and area use of Norwegian salmon production" (Hognes, 2011) and "Carbon footprint and energy use of Norwegian seafood products" (Winther et al., 2009)

- Other inputs to the system, e.g., electricity, oxygen, construction materials, fuel etc. are modelled with data from the EcoInvent v2.2 life cycle assessment database



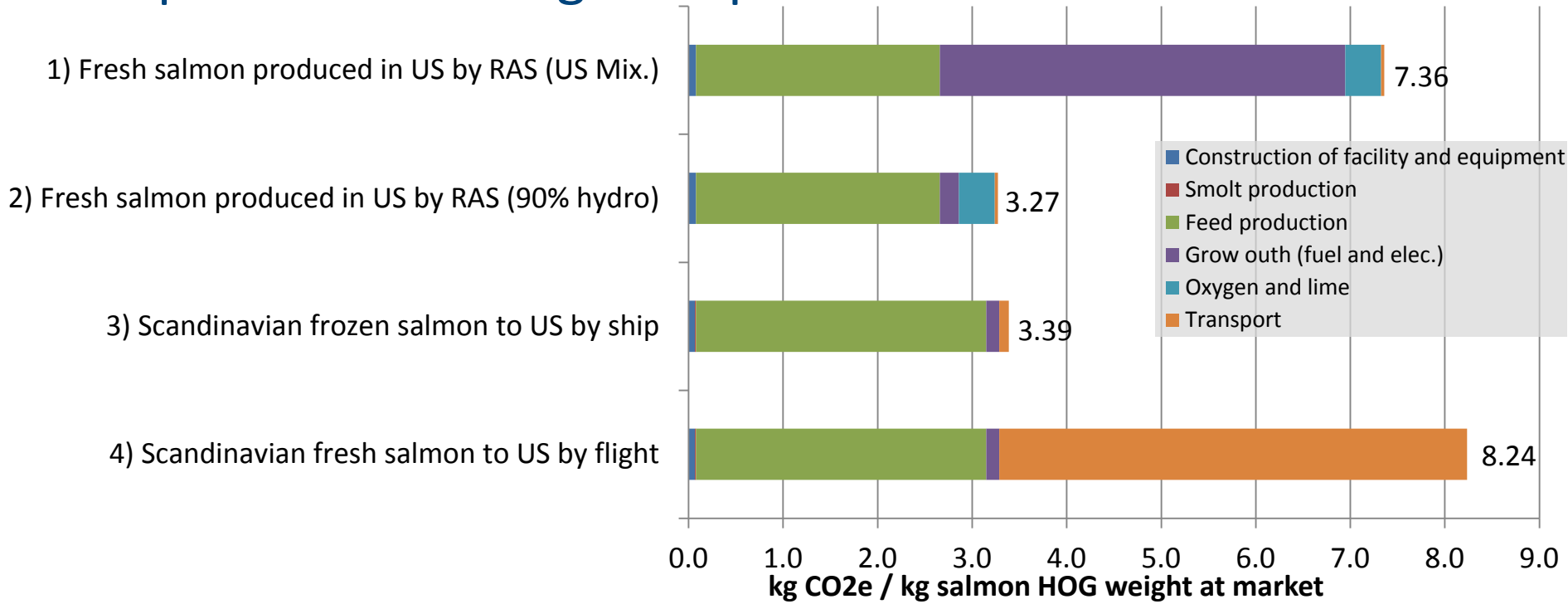
Sum of GHG emissions caused by the production of one kilo of salmon in live weight from production of feed ingredients up through salmon being ready for slaughter.

Cases:

1. Model RAS system using a 90% hydropower / 10% fossil fuel electric mix with a GWP of: 0.04 kg CO2e/kWh*
2. Model RAS system using an average electric mix for the US with a GWP of 0.77 kg CO2e/kWh*
3. Model Net Pen system with average FCR: 1.27
4. Model Net Pen system with best practice FCR: 1.14

*: Modelled with data from the EcoInvent v2.2 database

Comparison including transports to retailer in the US



Sum of GHG emissions caused by the production and transport of one kilo of salmon in head on and gutted (HOG) weight (from production of feed ingredients and up to delivery at retailer gate)

Cases:

1. **Fresh** salmon from RAS system using an average US electricity mix and transported 500 km to retailer with **efficient truck**
2. **Fresh** salmon from RAS system using 90 % hydro power electricity mix and transported 500 km to retailer with **efficient truck**
3. **Frozen** salmon from PEN system in Norway transported 5,600 km to the west coast of the US by **large container ship**
4. **Fresh** salmon from PEN system in Norway transported 5,600 km to the west coast of the US by **airfreight**

Important notes for the GHG assessment

- A GHG assessment **only assesses the potential climate impact and not the wide range of environmental impacts that food production cause** and its overall environmental sustainability. A GHG assessment is not a complete indicator of the environmental sustainability.

- Several potentially important climate aspects of food production and consumption are not included, e.g.: waste (how much of the salmon is actually eaten); processing; packaging; transport efficiency; by product utilization and nutrient recovery (e.g. phosphorus).

- The results presented here can not be compared to LCA results from other sources unless it can be proven that identical data and methodical choices have been used. According to the relevant ISO standards for LCA these results can not be used to make commercial claims.

Conclusions from the GHG assessment

- Feed and feed efficiency is the dominating parameter of the carbon footprint of salmon production

- The most straight forward and clear assumption is to use the electricity mix in the power market in which the production occur
  - In a market where electric power is a commodity in short supply, and where power markets are connected through economy and/or the grid, it is challenging to argue that power is supplied from one specific source. As a minimum there must be a consistency between the price paid for the power and the data used in the GHG assessment.

- Construction of production facility and equipment is not an important contributor to the total carbon footprint, but the ability to produce closer, or choose transport to the market is potentially important

Wrapping up - conclusions

- **Hypothesis 1:**
  The land-based production of atlantic salmon in this Model RAS system has a higher CO_2 footprint than production in a Model Net Pen farming system.
  - FALSE – with clean energy source
  - TRUE – with typical US/EU mix based on fossil fuels

Acknowledgments

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