How do we measure the sustainability of products and their supply chains?

Introduction to Life Cycle Assessment with special reference to aquaculture and marine ingredients

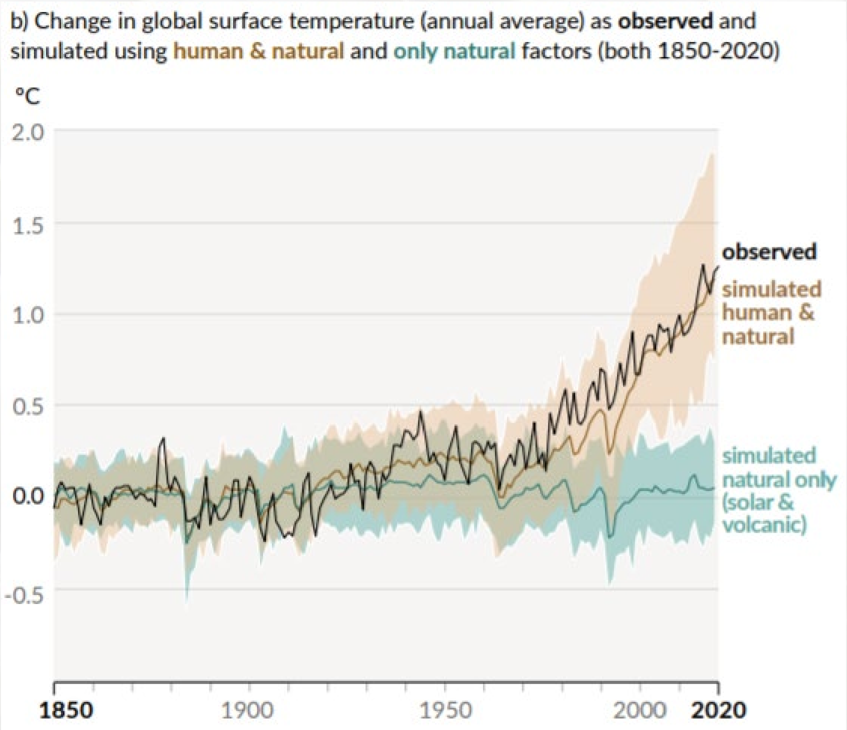
Richard Newton, Institute of Aquaculture, University of Stirling
richard.newton@stir.ac.uk

Session overview

- Presentation on LCA principles and methodology
- Short Q&A/ discussion
- Presentation on marine ingredients LCAs
- Final discussion and wrap up

Why measure sustainability?

- Environmental impact high in consumer consciousness
- Retail and consumer organisations want more transparency over responsible sourcing of products
- EU looking to benchmark products – Product Environmental Footprint (PEF) "Single market for green products"
- Certification bodies want to develop more harmonised sustainability metrics
- Value chain actors want more traceability concerning sustainability



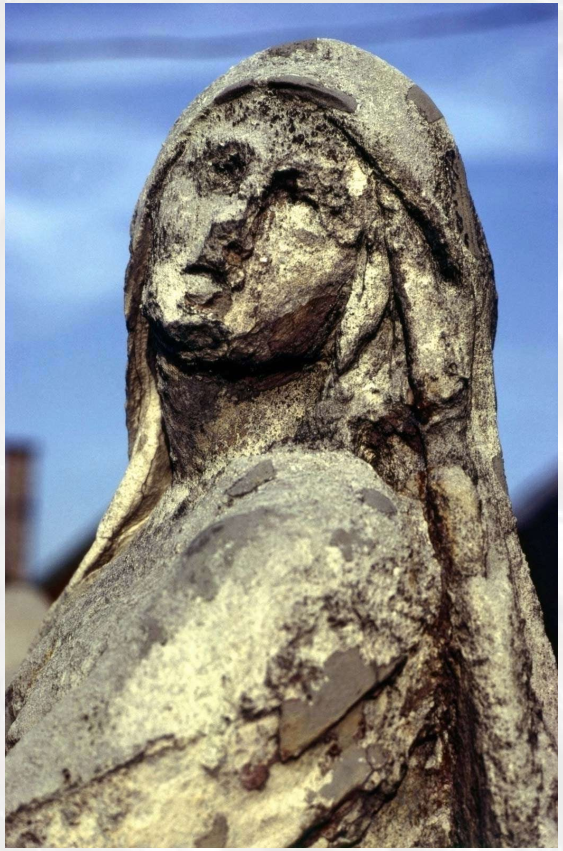
IPCC 2021 – Climate Change Report

LCA impact categories – Carbon Footprint and much more!

- Global Warming Potential (carbon footprint)

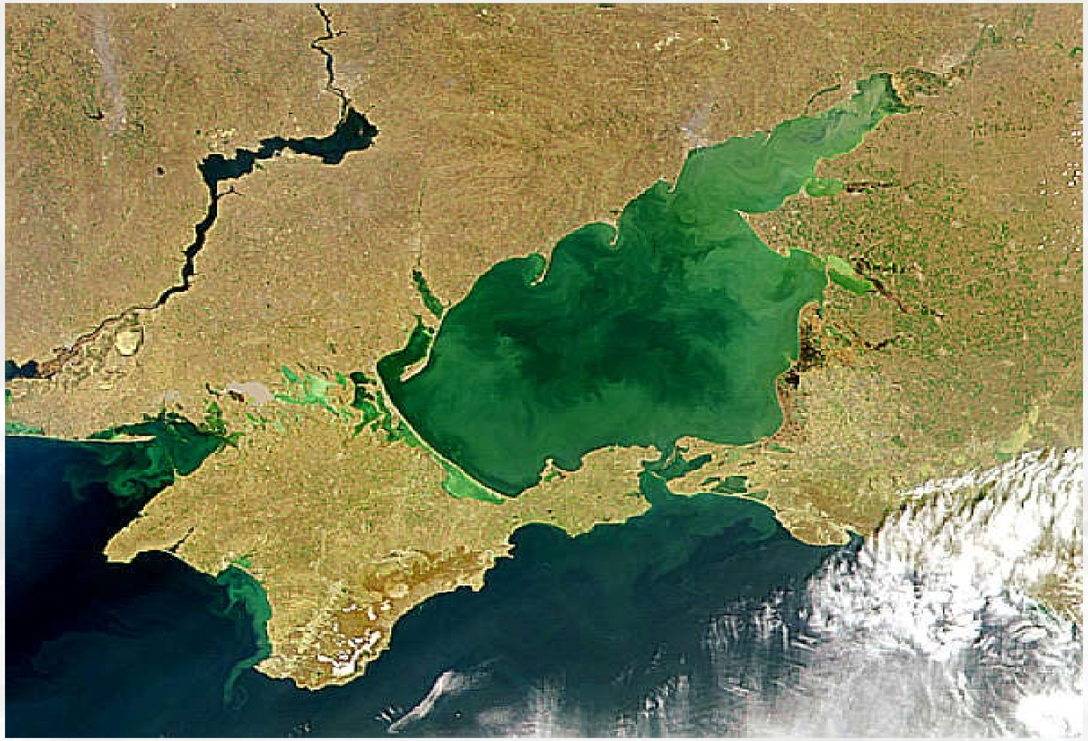
LCA impact categories

- Acidification Potential



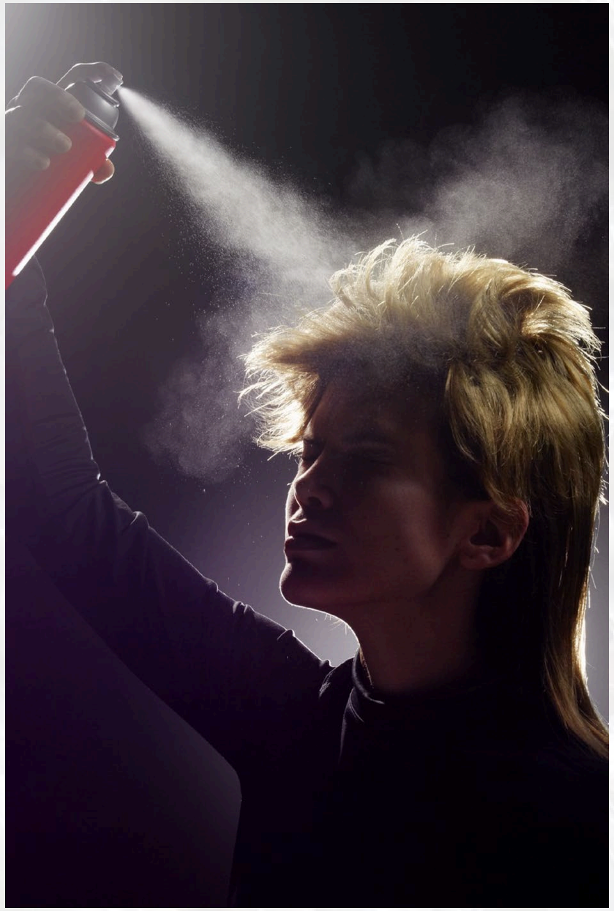
LCA impact categories

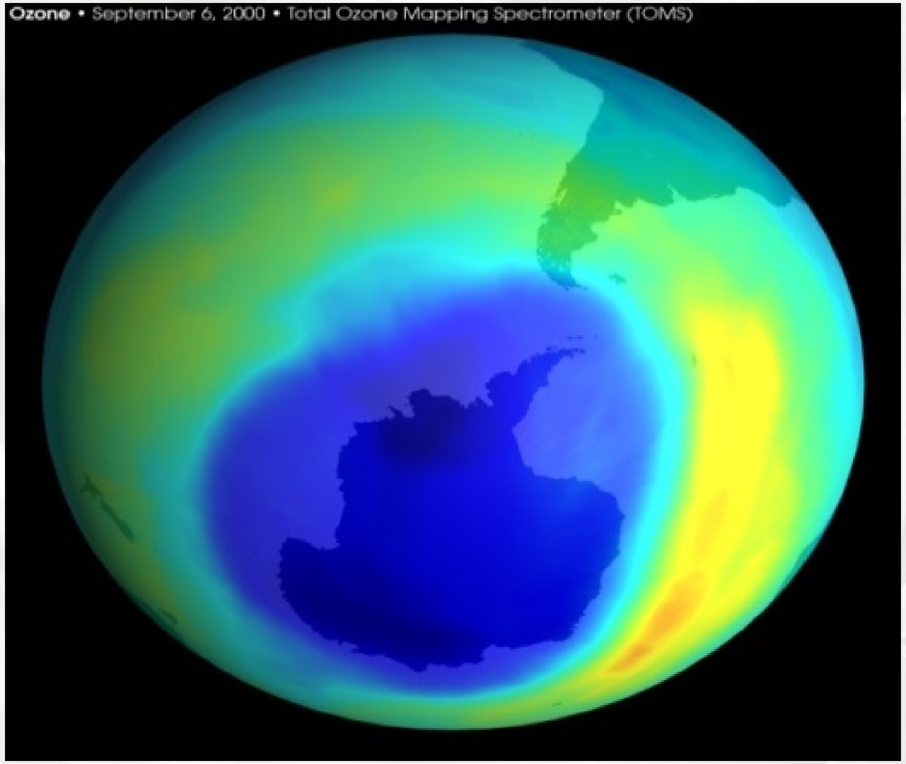
- Eutrophication Potential



LCA impact categories

- Ozone Depletion Potential





LCA impact categories

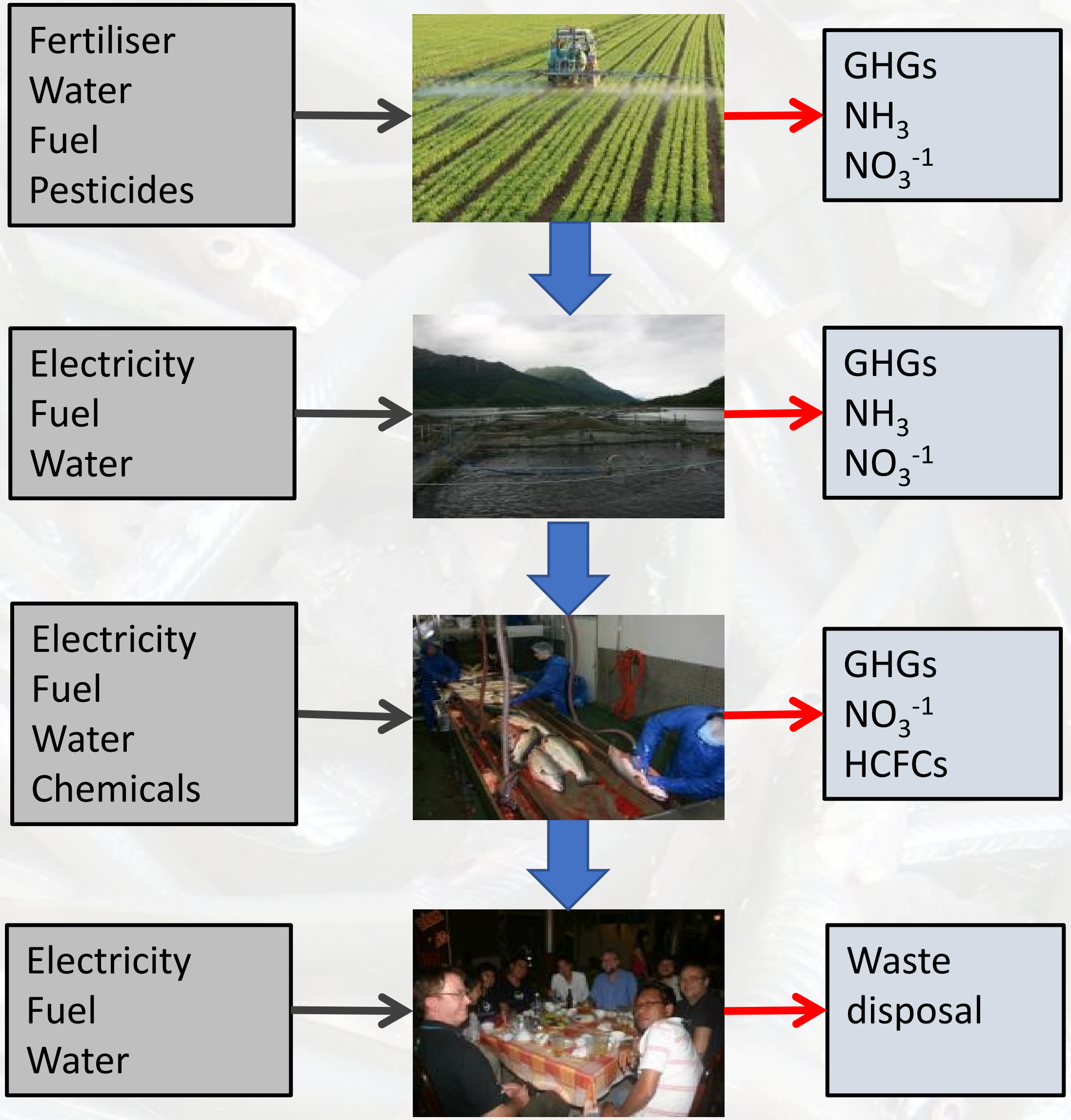
- Typically:
  - Global warming potential
  - Acidification potential
  - Eutrophication potential
  - Photochemical oxidant formation
  - Aquatic/terrestrial/human toxicity potential
  - Cumulative energy use
  - Abiotic resource use
  - Biotic resource use
  - Ozone depletion potential
  - Consumptive water use
  - Land use
  - Novel categories? E.g. Fish In Fish Out ratio

  - Provides comprehensive assessment of global impact and avoids trade-offs

Measure the sustainability of the value/supply chain, not just production

Life cycle approach to impact assessment - LCA

- Environmental impacts do not just occur on the production unit
  - Feed ingredients
  - Feed processing
  - On farm production
  - Processing
  - Distribution
  - Consumption
  - Waste disposal
- All require land, water, raw materials and energy, and can lead to harmful emissions



Life Cycle Inventories – only part of the story

Label	Name	Value	Unit	Uncertainty
[E10]	NMVOC, non-methane volatile organic co	0.00012	kg	L(0.206)
[E11]	Carbon dioxide, fossil[air]	0.19	kg	L(0.0345)
[E12]	Ammonia[air]	2.61E-5	kg	L(0.108)
[E13]	Nitrogen oxides[air]	5.13E-5	kg	L(0.206)
[E14]	Particulates, < 2.5 um[air]	8.48E-6	kg	L(0.554)
[E15]	Particulates, > 10 um[air]	7.81E-5	kg	L(0.215)
[E16]	Particulates, > 2.5 um, and < 10um[air]	1.35E-5	kg	L(0.354)
[E17]	Zinc, ion[fresh water]	2.7E-7	kg	L(0.864)
[E18]	Lead[fresh water]	3.93E-9	kg	L(0.864)
[E19]	Nickel, ion[fresh water]	1.23E-9	kg	L(0.864)
[E21]	Copper, ion[fresh water]	6.39E-9	kg	L(0.633)
[E22]	Chromium, ion[fresh water]	4.55E-10	kg	L(0.633)
[E23]	Cadmium, ion[fresh water]	9.55E-11	kg	L(0.633)
[E42]	Carbon monoxide, fossil[air]	0.000984	kg	L(0.806)
[E44]	Dinitrogen monoxide[air]	2.66E-6	kg	L(0.211)
[E57]	Methane, fossil[air]	5.42E-6	kg	L(0.206)
[E64]	Sulfur dioxide[air]	6.03E-6	kg	L(0.0588)
[E67]	Toluene[air]	1.05E-5	kg	L(0.206)
[E153]	Benzene[air]	7.28E-6	kg	L(0.206)
[E206]	Cadmium[air]	1.33E-9	kg	L(0.845)
[E207]	Chromium[air]	9.57E-9	kg	L(0.845)
[E208]	Copper[air]	1.14E-7	kg	L(0.845)
[E209]	Nickel[air]	1.01E-8	kg	L(0.845)

Label	Name	Value	Unit	Uncertainty
[E10]	NMVOC, non-methane volatile organic co	0.00013	kg	L(0.206)
[E11]	Carbon dioxide, fossil[air]	0.175	kg	L(0.0345)
[E12]	Ammonia[air]	1E-6	kg	L(0.108)
[E13]	Nitrogen oxides[air]	0.000518	kg	L(0.206)
[E14]	Particulates, < 2.5 um[air]	3.71E-5	kg	L(0.554)
[E15]	Particulates, > 10 um[air]	7.93E-5	kg	L(0.215)
[E16]	Particulates, > 2.5 um, and < 10um[air]	1.59E-5	kg	L(0.354)
[E17]	Zinc, ion[fresh water]	2.7E-7	kg	L(0.864)
[E18]	Lead[fresh water]	3.93E-9	kg	L(0.864)
[E19]	Nickel, ion[fresh water]	1.23E-9	kg	L(0.864)
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[E208]	Copper[air]	1.05E-7	kg	L(0.845)
[E209]	Nickel[air]	9.71E-9	kg	L(0.845)

Characterisation – making sense of the emissions

- How do we make sense of the long list of emissions?
- Characterisation compares the effect of an emission to a reference compound e.g. Global Warming Potential (GWP) to carbon dioxide

Compound	CO_2 eq.
CO_2	1
CH_4	25
N_2O	298
CHF_3	14800
CCl_3F	4750

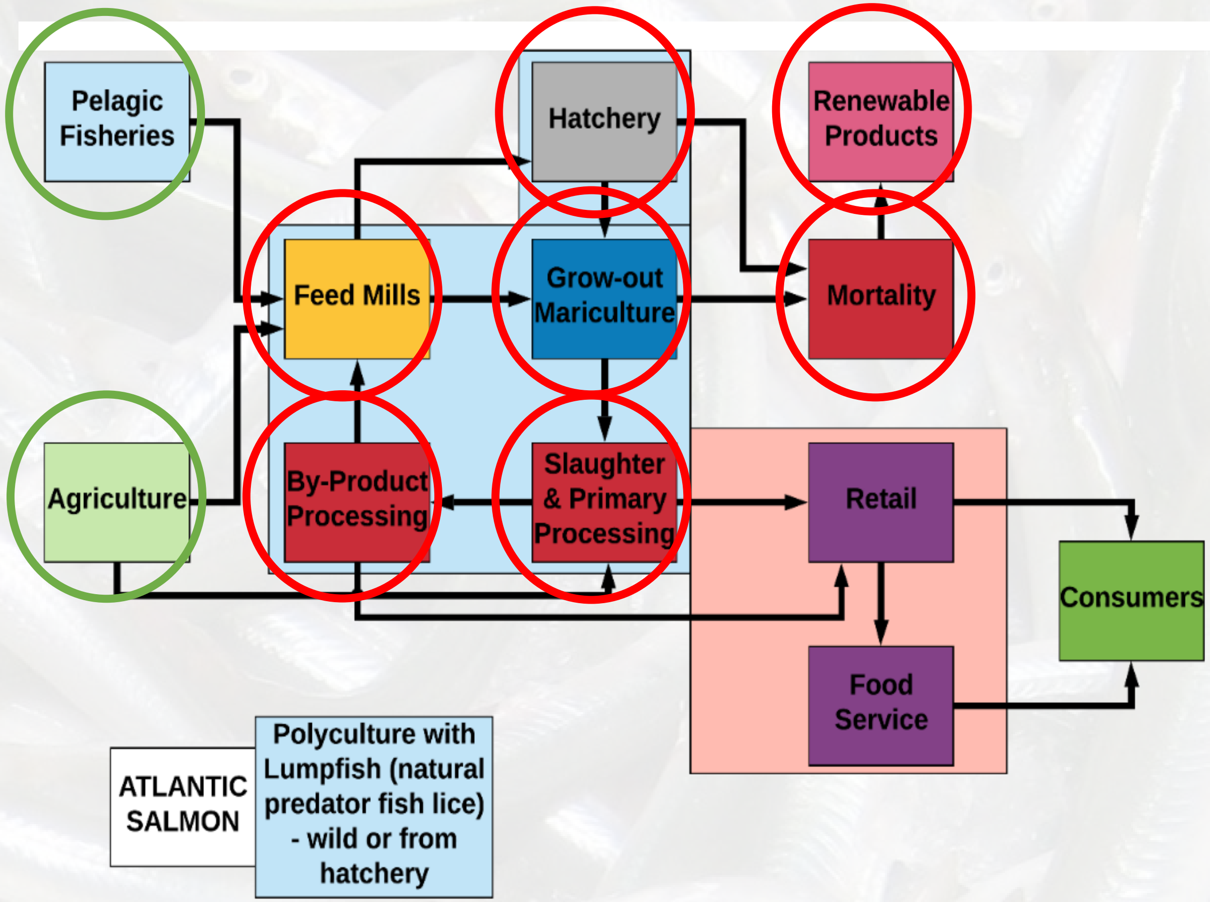
- Use standardise “characterisation factors” for each emission – e.g. CO_2eq
- Every kg of methane released has the same effect as 25kg of CO_2 etc.
- Other emissions can be characterised to other “impact categories”

What are we measuring? - Functional unit (FU)

- LCA measures the “function” of products
- E.g. Plastic disposable vs. ceramic mug
- Ceramic mug manufacture uses a lot more resources than a plastic cup but is used many more times
- How many uses before it breaks?
- Vessel manufacture
- Disposal/recycling of plastic…
- Washing of ceramic
    - Energy, water, detergents
- FU = 1000 cups of coffee in either ceramic or plastic cups?
- FU choice depends on goal of study

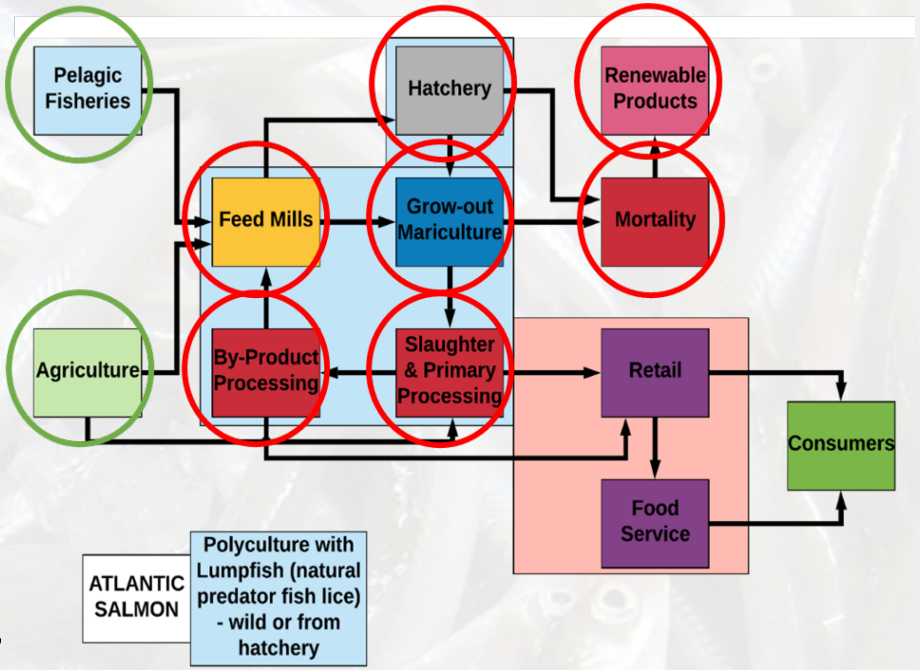
LCA – where does the data come from?? Considerations….

- What is the boundary of the study?
  - The value chain up to processing?
- What is the "functional unit"?
  - Processed products at the processor gate?
- Where is the data coming from at each point in the study?
  - Surveys (primary)
  - Literature (secondary)
  - Background (database)



Data collection for typical aquaculture LCA

- Primary data – collected from surveys
  - Feed – Formulation of feed (ingredient inclusions), energy, water, packaging, waste, ingredient transport type and distances
  - Farm – Feed use, energy, water, effluent
  - Processor – Energy and water use, amount of fish processed, yields of different (co)products (fillets etc), packaging, waste/ effluent
- Secondary data – from literature, online resources
  - Feed ingredients (marine, soy, wheat etc) –yields, fertiliser use, energy, water, direct emissions
- Background data – from databases (in LCA software)
  - National energy mixes and emissions from power stations
  - Emissions from machinery, vehicles, boilers/burners etc
  - Emissions from raw material extraction and refining



Data entry to Simapro software e.g. a test diet "process"

Inputs from technosphere: materials/fuels	Amount	Unit
Fish FF meal industry mix (NO)	150	kg
Krill meal (UR) at mill (NO)	40	kg
Soy bean concentrate (BR) at feed mill (NO)	150	kg
Pea protein (RER) at feed mill (NO)	100	kg
Wheat gluten (NL) at feed mill (NO)	100	kg
Maize gluten meal (FR) at mill (UK)	45	kg
Wheat HP (DE) at feed mill (NO)	105.75	kg
Fish FF oil industry mix (NO)	65	kg
Rapeseed oil (UK) at feed mill (NO)	185	kg
Vitamins and minerals at feed mill (NO)	15.25	kg
Sodium phosphate {RER}| market for sodiun	30	kg
L-Lysine (NL) at feed mill (NO)	12	kg
Methionine (NL) at feed mill (NO)	2	kg

Add line

Inputs from technosphere: electricity/heat	Amount	Unit
Electricity, medium voltage {NO}| market for	172.6	kWh
Heat, district or industrial, natural gas {Europ	363.4	MJ
Diesel, burned in agricultural machinery {GL(	8.55	MJ

Formulation

Primary

Ingredients production

Secondary

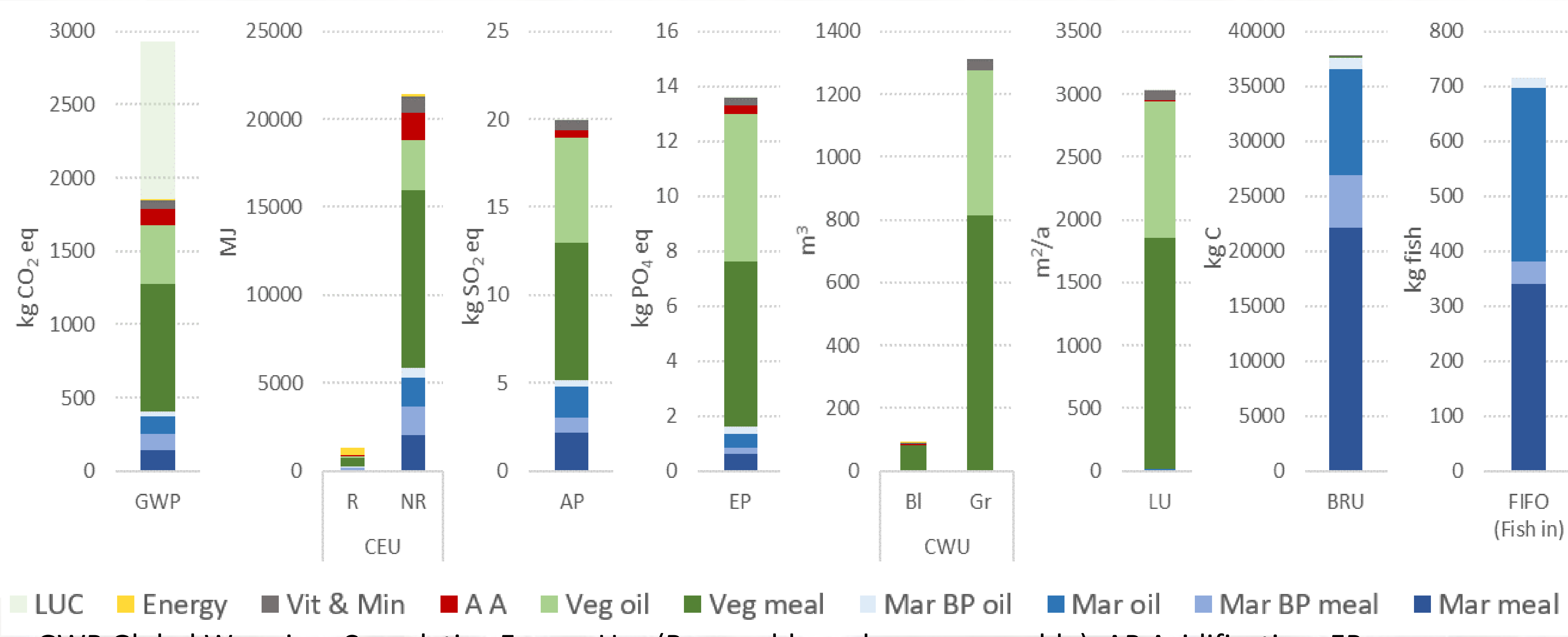
Industrial emissions

Background

Software output for test diet

Impact category	Unit	Total	Salmon T1	Fish FF meal	Krill meal	Soy bean	Pea protein	Wheat gluten	Maize gluten	Wheat HP (DE)	Fish FF oil	Rapesee oil (UK)	Vitamins and
Cumulative Energy use (non renewa	MJ	2.23E4	x	3.58E3	2.28E3	3.31E3	1.58E3	3.67E3	615	306	1.16E3	2.69E3	303
Consumptive Water Use Blue	m3	27.7	x	0.913	0.575	0.438	7.39	0.971	1.44	0.0417	0.286	0.641	2.02
Biotic Resource Use	kg C	5.31E4	x	4.53E4	472	77.3	x	x	x	x	7.25E3	x	0.00997
Land competition	m2a	2.83E3	x	8	17.6	622	597	348	58.9	109	1.25	1.03E3	5.17
Cumulative energy use (renewables	MJ	1.41E3	x	67.6	43	366	55	52.7	12.9	3.51	18.4	24.4	15.6
Global warming (GWP100a)	kg CO2 eq	1.9E3	x	247	175	201	132	355	42.6	41.8	79.9	380	18.5
Ozone layer depletion (ODP)	kg CFC-11 eq	0.000134	x	3.97E-5	2.46E-5	6.37E-6	1.08E-5	7.29E-6	5.6E-6	6.22E-7	1.15E-5	5.41E-6	1.8E-6
Photochemical Oxidation Potential	kg C2H4 eq	1.3	x	0.0955	0.0796	0.838	0.027	0.0329	0.00472	0.00544	0.0294	0.129	0.00796
Acidification	kg SO2 eq	20.3	x	3.38	2.4	1.33	1.27	2.66	0.364	0.622	1.02	5.83	0.121
Eutrophication	kg PO4--- eq	12.8	x	0.689	0.425	1.14	1.29	2.2	0.316	0.584	0.208	5.22	0.034
Embodied Fish	kg Fish In	1.13E3	x	630	268	x	x	x	x	x	235	x	x
GWP LUC	kg CO2 eq	845	x	0.182	0.168	820	3.4	5.97	0.0229	2.02	0.0379	12.7	0.126
Consumptive Water Use Green	m3	1.29E3	x	x	x	387	307	112	25.4	49.5	x	409	x

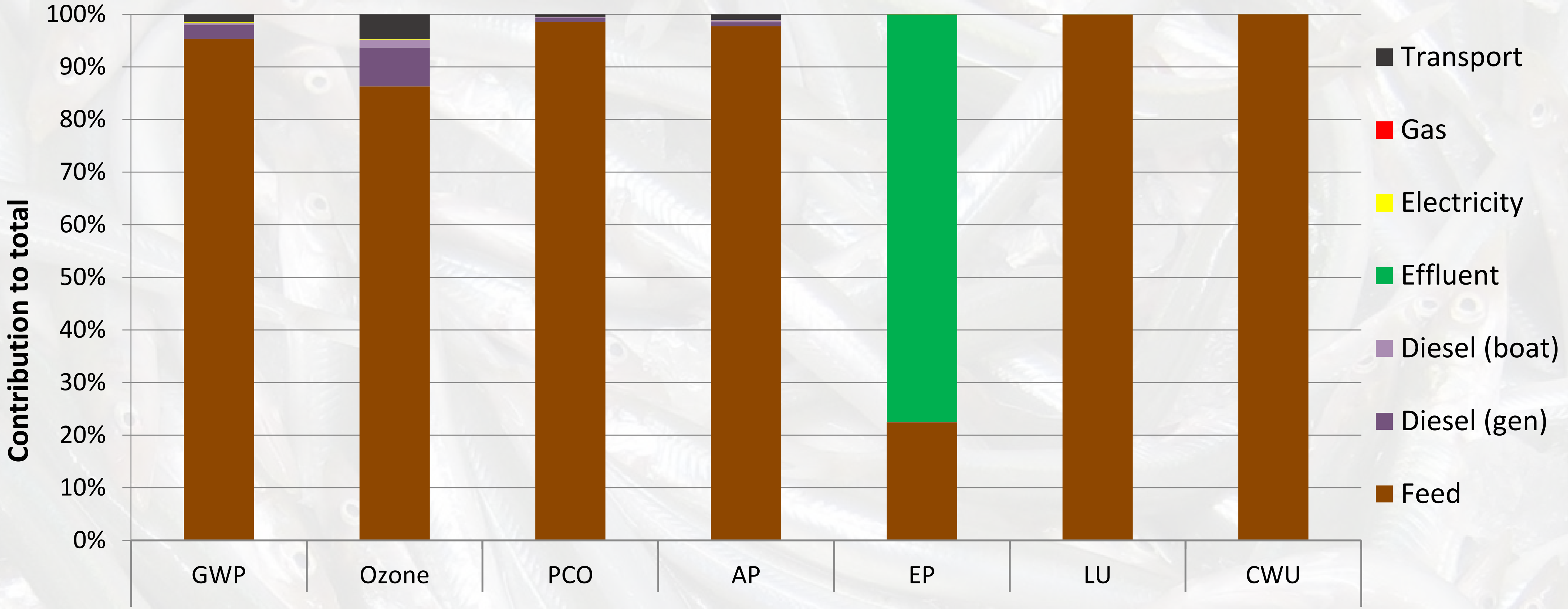
Example LCA of 1MT Norwegian feed industry average



- GWP Global Warming, Cumulative Energy Use (Renewable and non-renewable), AP Acidification, EP Eutrophication, LU Land Use, CWU Consumptive Water Use (Blue and Green), BRU Biotic Resource Use, FIFO Fish In Fish Out

The importance of feed in aquaculture LCAs

Most of the environmental impacts up to farm-gate are related to feed supply (raw materials production and processing) and use (FCR)



Newton and Little 2018, Mapping the impacts of farmed Scottish salmon from a life cycle perspective

End of first presentation

- Any questions?

LCA of marine ingredients

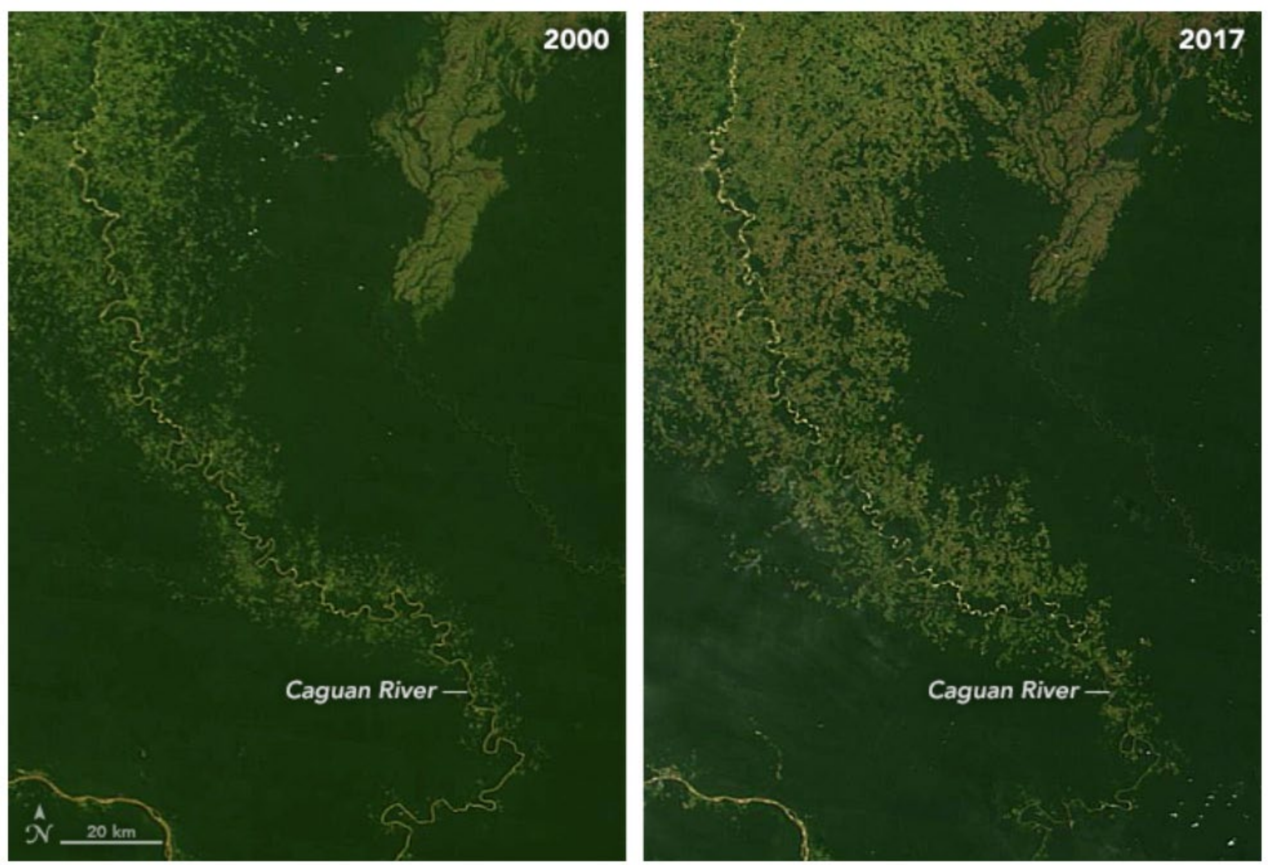
- Controversial issue of aquaculture
- “Marine ingredients are unsustainable”
- FIFOs can be integrated into LCAs

- The footprint of marine ingredients depends on “fuel intensity”, boat and gear maintenance, and rendering yields (% meal and oil per unit raw material)

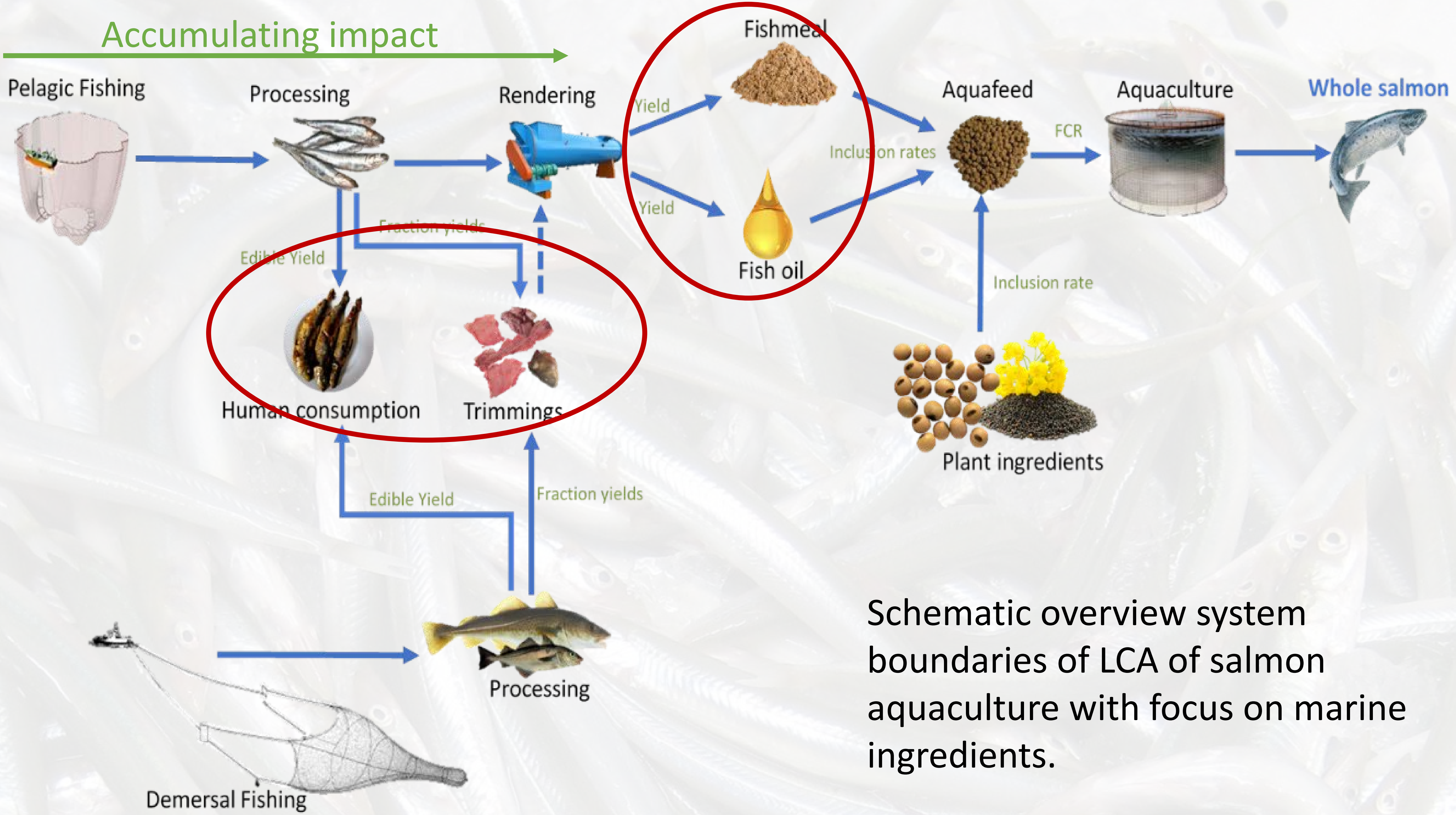
Terrestrial ingredient substitutes

Land Use, Land Use Change and water consumption

- Substitutes have different sustainability concerns
- LUC is the effect on C footprint caused by forest clearance etc.
- Terrestrial ingredients have large impact on land use and water consumption
- Affects habitat loss, biodiversity, drought and public health
- “Marine ingredients are unsustainable”?
- Marine vs terrestrial ingredient trade-off



Land use change in Brazil from 2000 to 2017 linked to soyabean and cattle ranching (source: Nasa accessed 8/5/21)

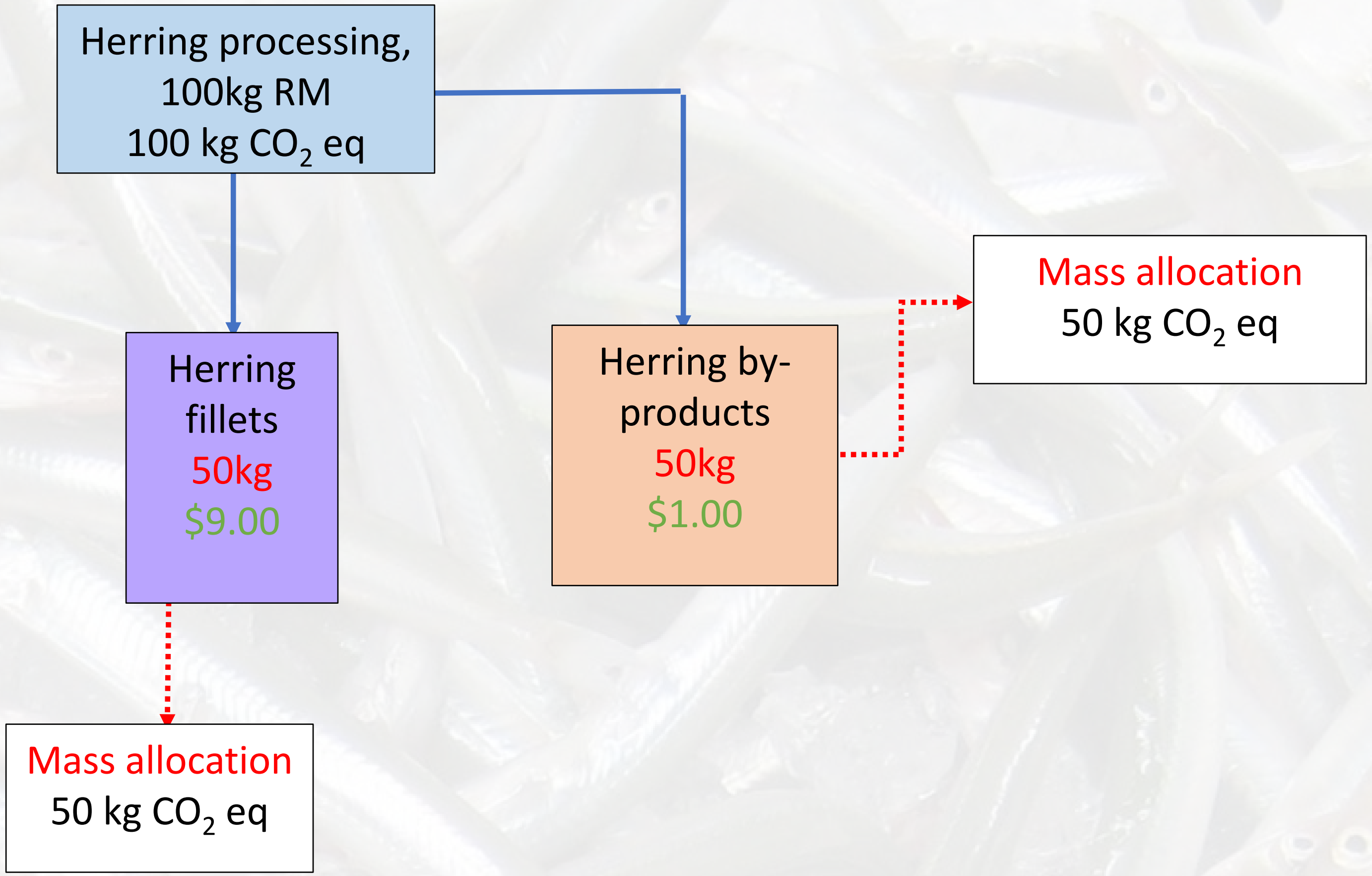


Schematic overview system boundaries of LCA of salmon aquaculture with focus on marine ingredients.

Co-product Allocation

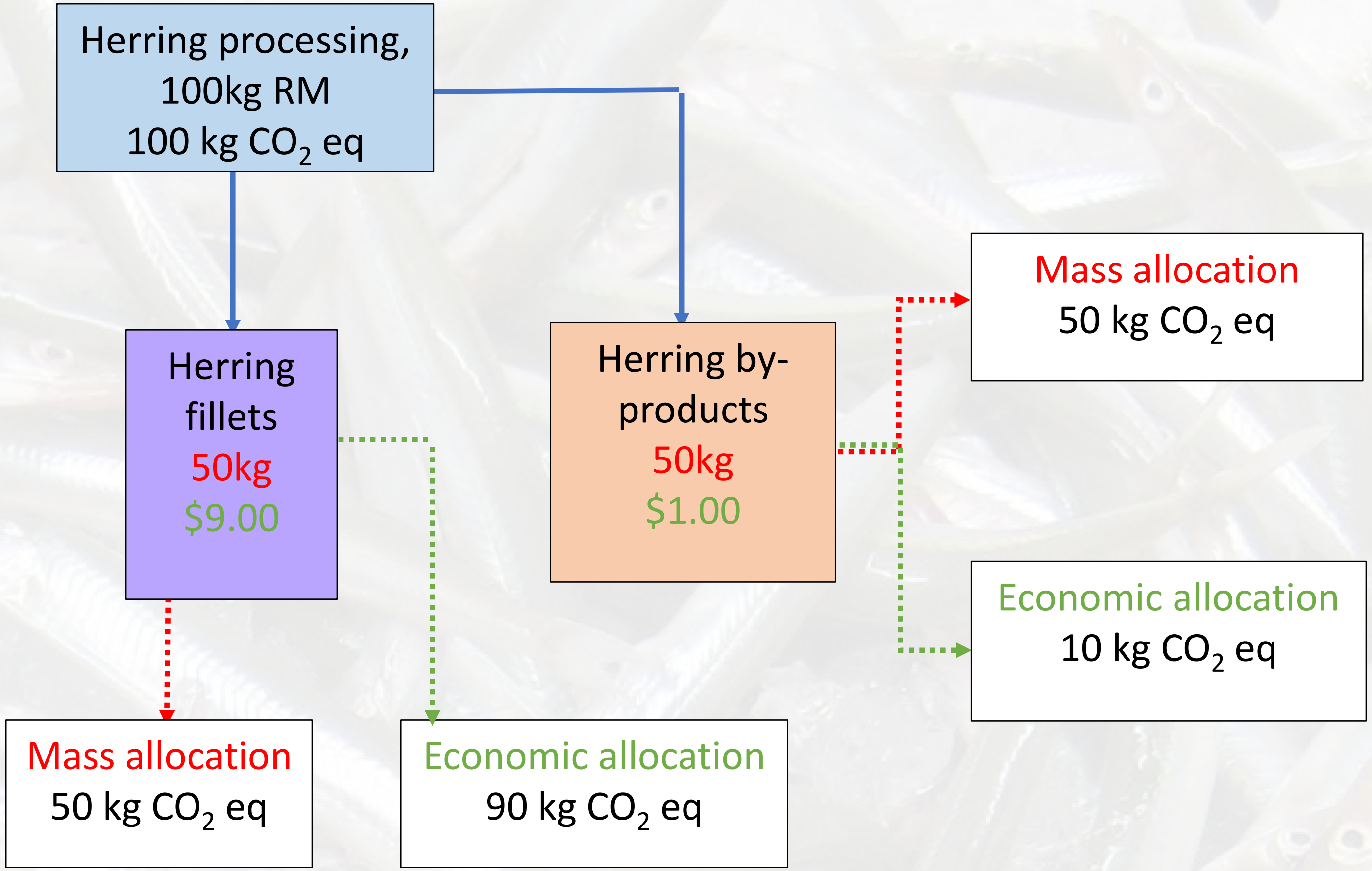
Critical for data collection and interpretation

Fishing
Processing
Rendering



Co-product Allocation

Critical for data collection and interpretation

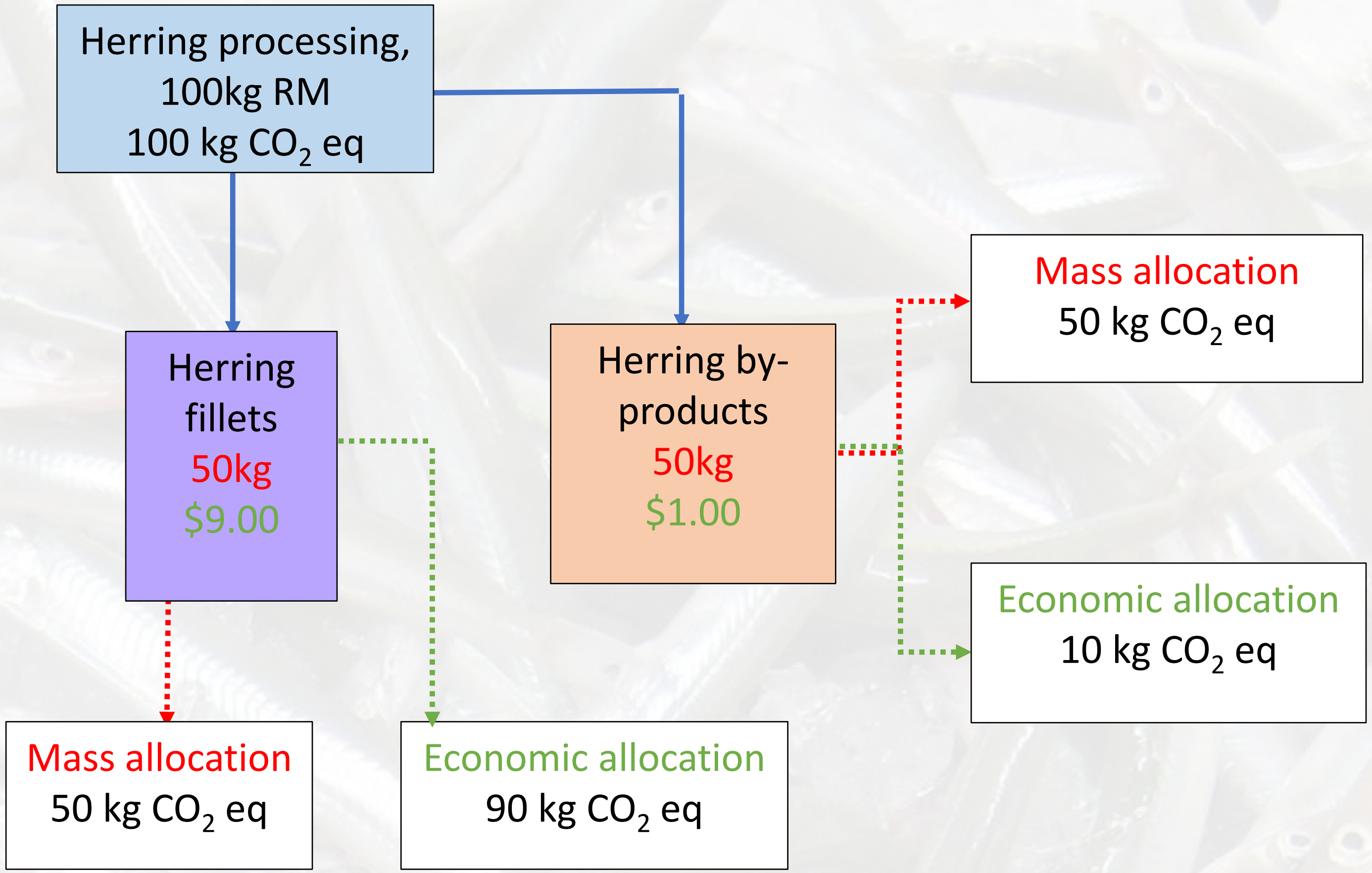


Fishing
Processing
Rendering

Economic allocation

- Reflects the motivation of the industry (to produce fillets not by-products)
- Supports the use of by-products as feed ingredients
- Encourages processors to find better markets for by-products
- Is supported by EU PEF Category Rules
- ....but requires more sensitive data

Co-product Allocation



Critical for data collection and interpretation

Example from fishing industry

Species	Catch, kg/tonne	Price, $/kg	Price x catch	Mass allocation %	Economic allocation %
Atlantic Mackerel	210	0.65	135.48	21.0	10.5%
Blue Whiting	430	1.03	443.53	43.0	34.4%
European hake	180	2.89	520.07	18.0	40.3%
Horse mackerel	180	1.06	191.12	18.0	14.8%

Recent EU and Centre for Innovation Excellence in Livestock (CIEL) funded projects

- Required LCA data on marine ingredients (MIs)
- Databases hold poor quality info
- Needed to construct LCIs for MIs – mostly from secondary data!
- Fisheries data for major species used in EU
- Processing data for by-products used as MIs
- Rendering data for producing fishmeal and fish oils
- Price data at every stage

CIEL

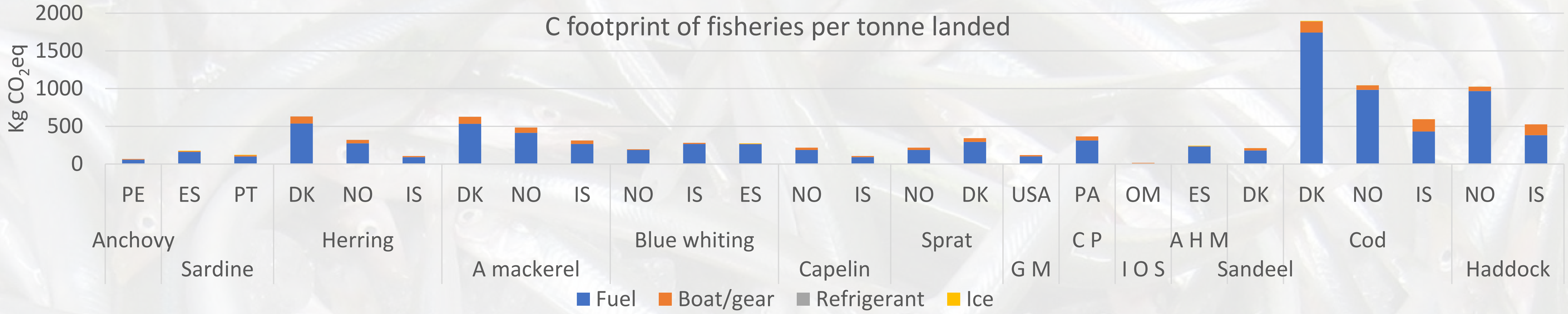
GAIN Green Aquaculture Intensification

Source	Species/ raw material used in MIs	Fishing method	Origin	Data coverage	Allocation
Fréon et al. (2014)	Anchoveta	PS	Peru	FI, OI, BCM, R	NA
Almeida et al. (2013)	Sardine	PS	Portugal	FI, OI	M
Ramos et al. (2011)	Atlantic mackerel Sardine	PS	Spain	FI, OI, BCM	SE
Vázquez-Rowe et al. (2011)	Atlantic mackerel Atlantic horse mackerel Blue whiting Sardine	PS, BT	Spain	FI, OI, BCM	M, E
Vazquez-Rowe et al. (2013)	Atlantic mackerel Atlantic horse mackerel Blue whiting	PS	Spain	FI, OI, BCM	M
Thrane (2004)	Atlantic herring Atlantic mackerel Sandeel Mixed white fish	PS, BT	Denmark	FI, OI	M, E, SE
SINTEF (2020)	Atlantic herring Atlantic mackerel Mixed white fish	PS, BT	Norway	FI, Pr	M
Svanes et al. (2011b)	Mixed white fish	LL	Norway	FI, OI, BCM, Pr	M, E
Fulton (2010}	Mixed white fish	LL	Iceland	FI, OI, BCM	M
Das and Edwin (2016)*	Indian Oil Sardine	RS	India	FI, OI, BCM	M
Fisheries Iceland (2017)	Blue whiting Capelin Herring Mackerel	MW PS PS MW	Iceland	FI	NM
Schau et al. (2009)	Blue whiting Capelin European sprat	MW PS PS	Norway	FI	M, E
Tyedmers (2004)	European sprat	PS	Denmark	FI	M
Cashion et al. (2016)	Gulf menhaden	PS	USA	FI, R	M

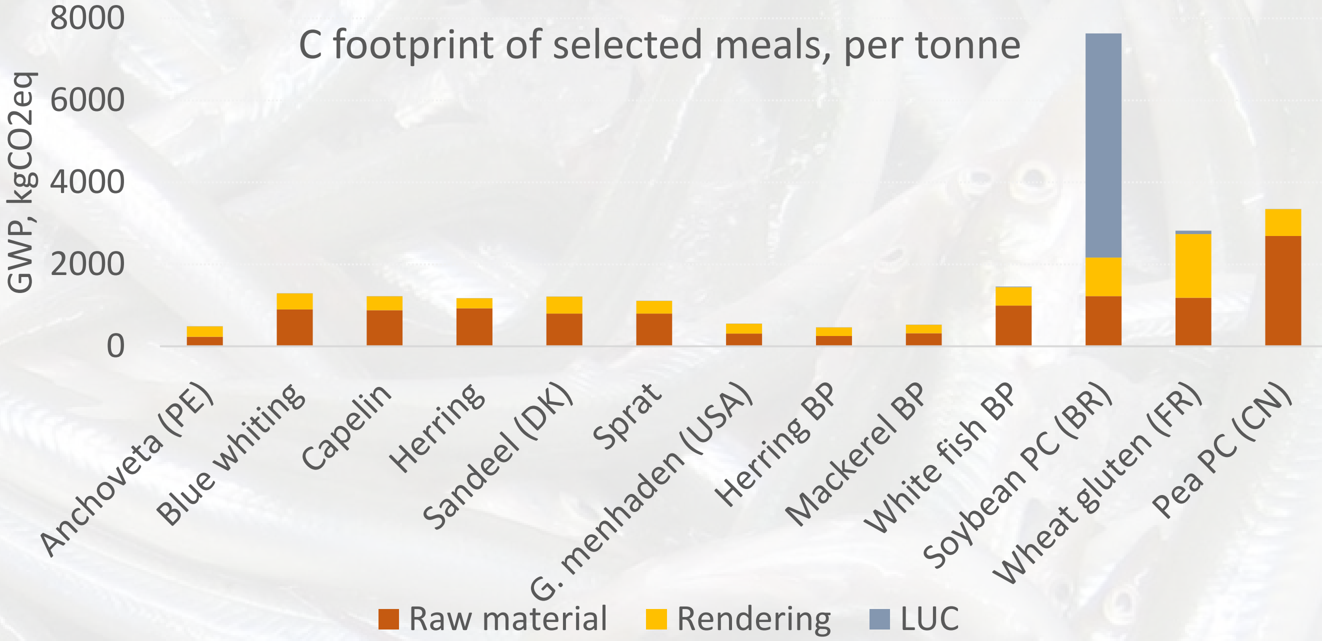
Data gaps and assumptions

- Fisheries
  - Most only included fuel use per unit catch
  - Few provided economic data
  - Only one year, but fisheries are volatile
- Processing
  - Little available but collected primary data for white fish
  - Little price data for pelagic or demersal
- Rendering
  - Only available for anchoveta and sandeel
  - Poor yield data
- Assumptions, defaults and proxies used

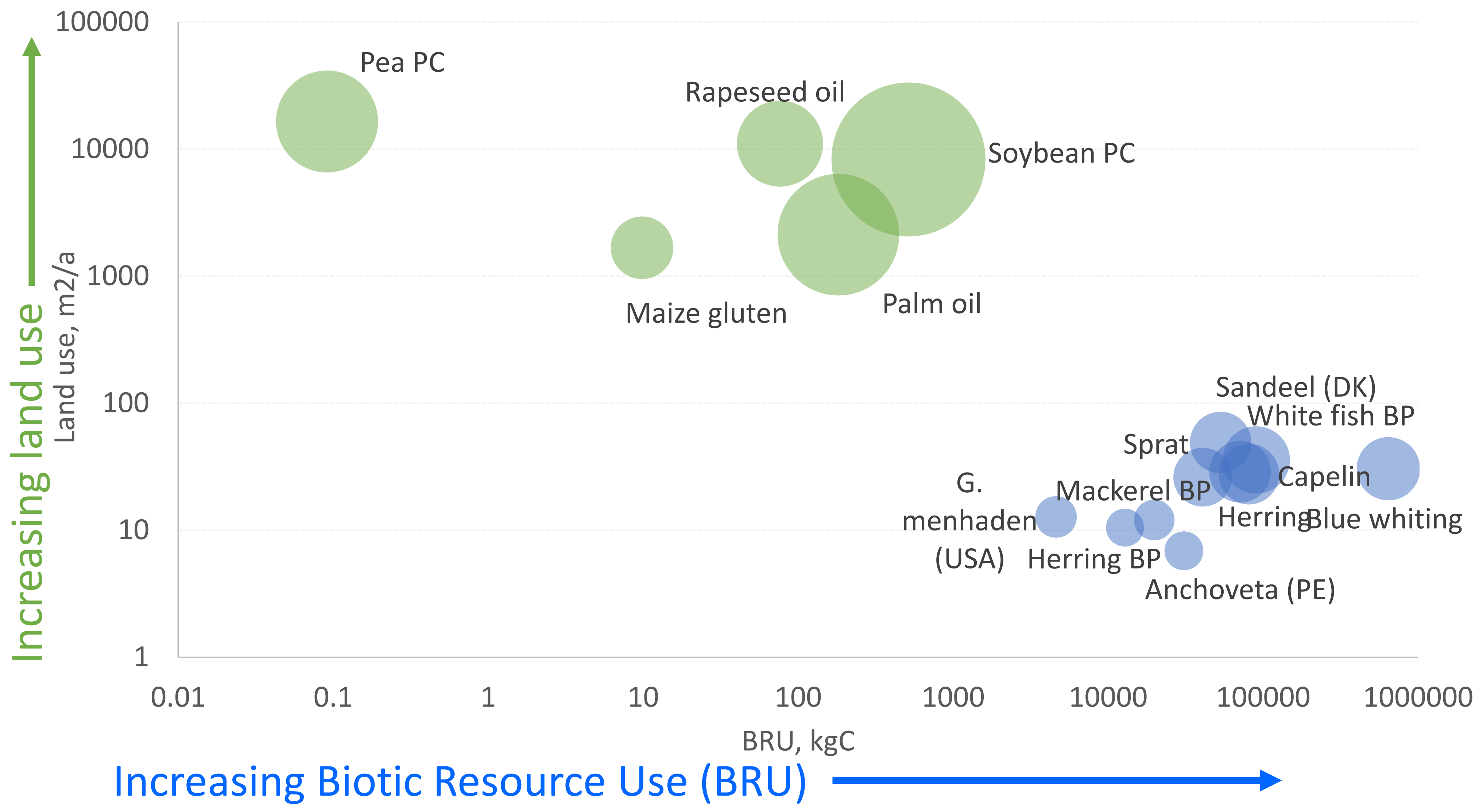
Results from LCA work in EU GAIN and CIEL projects



- Global Warming Potential related mainly to fuel use
- Big difference between fisheries locations, gear types and species
- MIs generally better than terrestrial ingredients

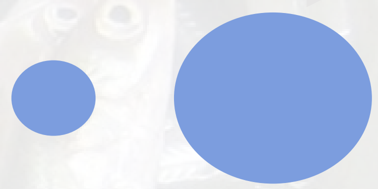


Marine ingredients sustainability trade-offs



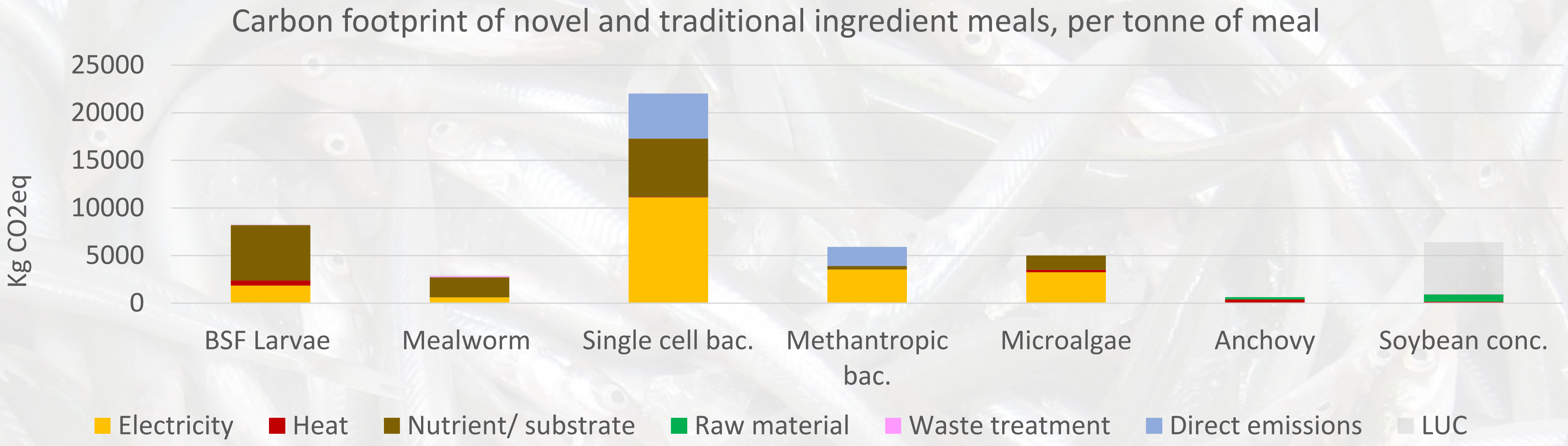
Land Use, Biotic Resource Use and Global Warming Potential (bubble size) major feed ingredient (1 tonne production)

Bubble size: increasing carbon footprint



Novel feed ingredients – C footprints

- Novel ingredient are still at their pilot stage in many cases



Smetanan et al (2019) Sustainable use of *Hermetia illucens* insect biomass for feed and food Attributional and consequential life cycle assessment
Thevenot et al (2018) Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects
Smetana et al (2017) Autotrophic and heterotrophic microalgae and cyanobacteria cultivation for food and feed: life cycle assessment
Järviö et al (2021) An attributional life cycle assessment of microbial protein production: A case study on using hydrogen-oxidizing bacteria
Maiolo et al (2020) Fishmeal partial substitution within aquafeed formulations: life cycle assessment of four alternative protein sources
Abbadi et al (in press) Displacing fishmeal with protein derived from stranded methane
Freon et al (2017) Life cycle assessment of three Peruvian fishmeal plants: Toward a cleaner production
Soybean from AgriFootprint data base (2017)

Ok, it looks good but so many assumptions!

- Data requirements for an accurate assessment of marine ingredients from different species

- Fisheries:
  - Catch data over several years; composition, fuel intensity, boat maintenance, prices
- Processing:
  - Production yields, energy, water, effluent, product prices (typically 1 year of data)
- Rendering:
  - Meal and oil yields, energy, prices (1 year of data)

Take home messages

- Marine ingredients have good environmental footprints compared to many substitutes
- There are a lot of differences between different marine ingredients
- There are a lot of data gaps that we need to fill to provide an accurate assessment
- A lot of work needed on better perceptions and communication

Thanks for your attention, any questions?