KTH ROYAL INSTITUTE OF TECHNOLOGY

Seaweed and climate impacts

A systems perspective and comparison with other foods

SIG Seaweed 7, Trondheim

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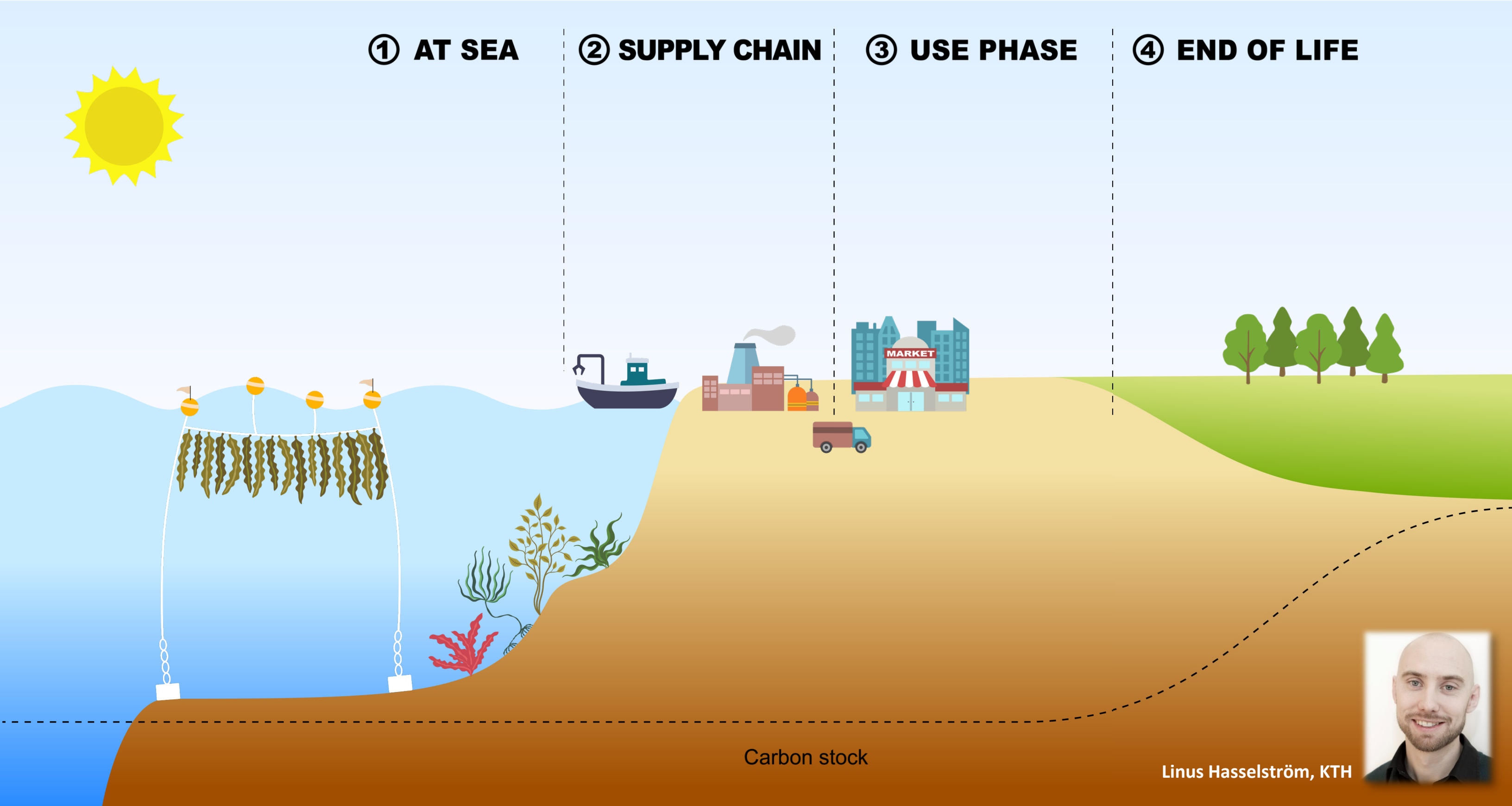
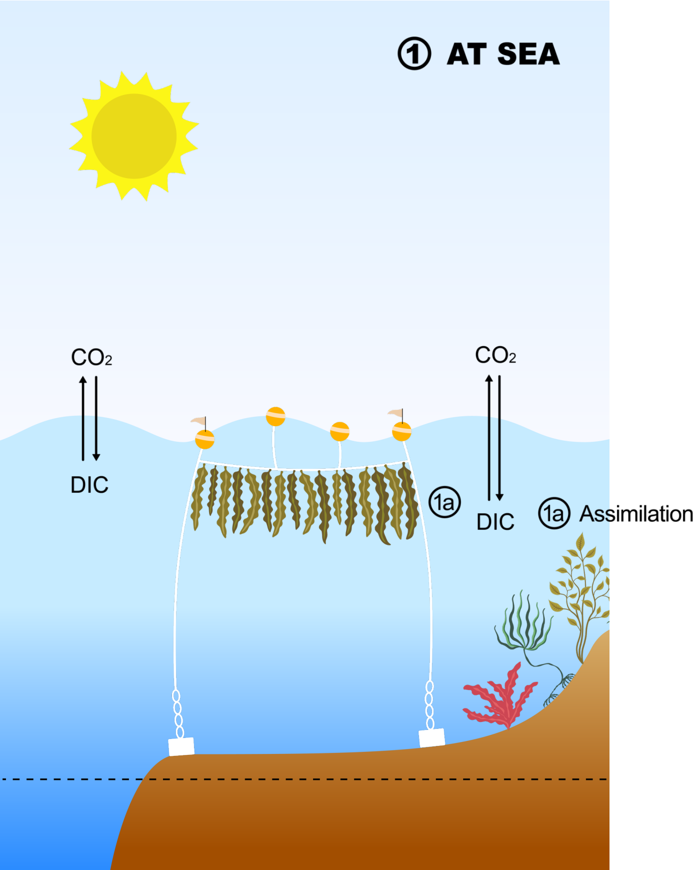

① AT SEA
② SUPPLY CHAIN
③ USE PHASE
④ END OF LIFE
MARKET
Carbon stock
Linus Hasselström, KTH



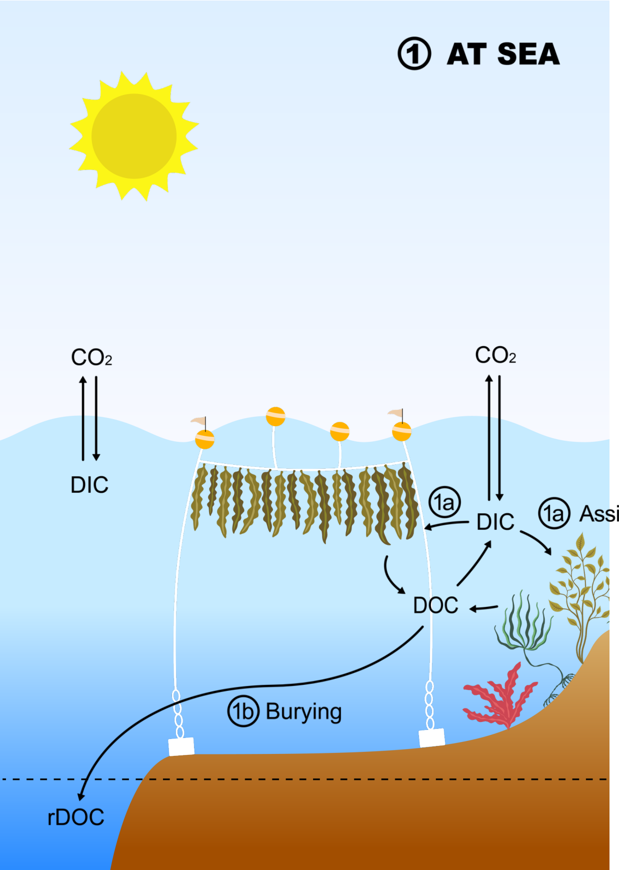
Carbon Assimilation

- Base assumption: DIC in water is replaced by CO_2 in atmosphere
- Measured and calculated from carbon content in biomass, with total carbon at a farm also being affected by yield
- Subject to very wide ranges…
- Expressed in different units, e.g. kg of C or CO_2eq per ton fresh weight, dry weight, or per unit area

Table 1
Mean values and min-max ranges of reported carbon and water content of seaweeds.

	Mean	Min	Max
Carbon content (% of dry matter)			
Saccharina latissima[1,2,4,5,7-10]	31.6%	21.1%	41.4%
Laminaria digitata[7-9]	34.7%	24.5%	39.0%
Brown algae[1,2,4,5,7-10]	31.5%	–	–
Red algae[8]	33.6%	–	–
Green algae[8]	32.7%	–	–
Water content (% of wet weight)			
Saccharina latissima[1-9]	82.5%	62.5%	93.2%
Laminaria digitata[7-9]	77.0%	68.0%	84.5%
Brown algae[2-9]	83.6%	–	–
Red algae[8]	79.1%	–	–
Green algae[8]	82.4%	–	–

[1] Boderskov et al. (2016).
[2] Bruhn et al. (2016).
[3] Forbord et al. (2020).
[4] Fossberg et al. (2018).
[5] Handå et al. (2013).
[6] Marinho et al. (2015).
[7] Nielsen et al. (2016).
[8] Olsson et al. (2020).
[9] Schiener et al. (2015).
[10] Sharma et al. (2018).



Burying in sediment

- Not all carbon fixed by photosynthesis is assimilated into the biomass: DOC and particulate organic carbon
- Critical knowledge gaps:
    - Amounts, types and triggers of DOC release
    - How much is bioavailable DOC to be consumed back into DIC by microorganisms?
    - How much is remineralization-resistant DOC that can reach the refractory DOC (rDOC) pool, leading to long-term carbon storage (and climate benefits)?

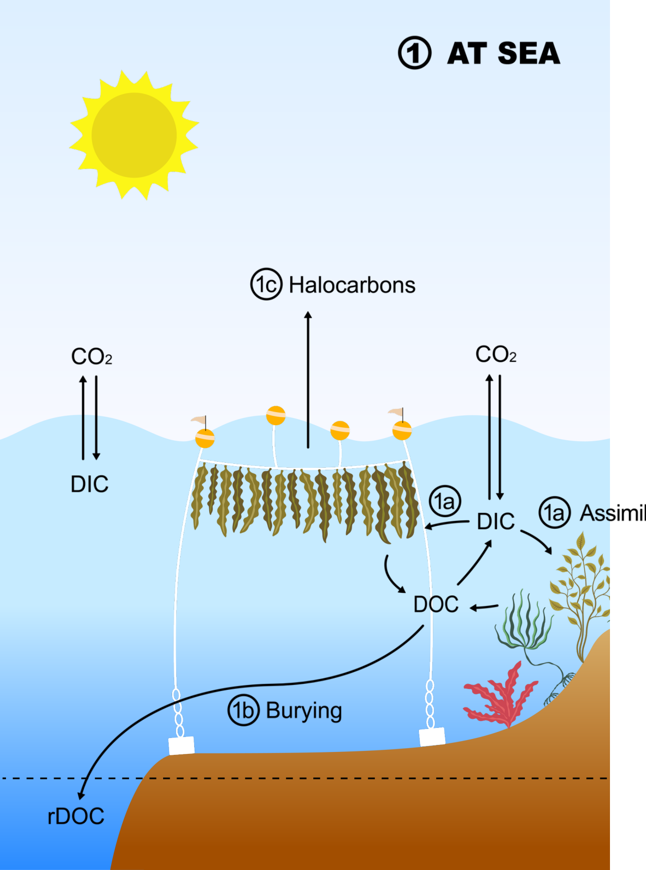
Recommended reading

Paine, E.R., Schmid, M., Boyd, P.W., Diaz-Pulido, G., Hurd, C.L., 2021. **Rate and fate of dissolved organic carbon release by seaweeds: a missing link in the coastal ocean carbon cycle**. J. Phycol. 57, 1375–1391. doi: 10.1111/jpy.13198

Hurd, C. L., Law, C. S., Bach, L. T., Britton, D., Hovenden, M., Paine, E., et al. (2022). **Forensic Carbon Accounting: Assessing the Role of Seaweeds for Carbon Sequestration**. J. Phycol. doi: 10.1111/jpy.13249.

Angles d'Auriac, M., Hancke, K., Gundersen, H., Frigstad, H., Borgersen, G., 2021. **Blue Carbon eDNA -A novel eDNA method to trace macroalgae carbon in marine sediments**. In: NIVA Report SNO 7648-2021. Norwegian Institute for Water Research. Oslo, ISBN 978-82-577-7384-7.

Ortega, A., Geraldi, N.R., Díaz-Rúa, R., Ørberg, S.B., Wesselmann, M., Krause-Jensen, D., Duarte, C.M., 2020. **A DNA mini-barcode for marine macrophytes**. Molecular Ecology Resources 20 (4), 920–935. https://doi.org/10.1111/1755-0998.13164.



Halocarbon (and other) emissions

- Biogenic halocarbons are produced as a response to biotic and abiotic stress
- Halocarbons are among the most potent greenhouse gases[1]
- Lack of consensus in the literature
  - Some[2] argue this is a non-issue
  - Others highlight the challenge to measure and trace these emissions, and the need for more research [3,4]
- VOC emissions (e.g. from seagrass meadows) have been hypothesized to include cloud forming particles

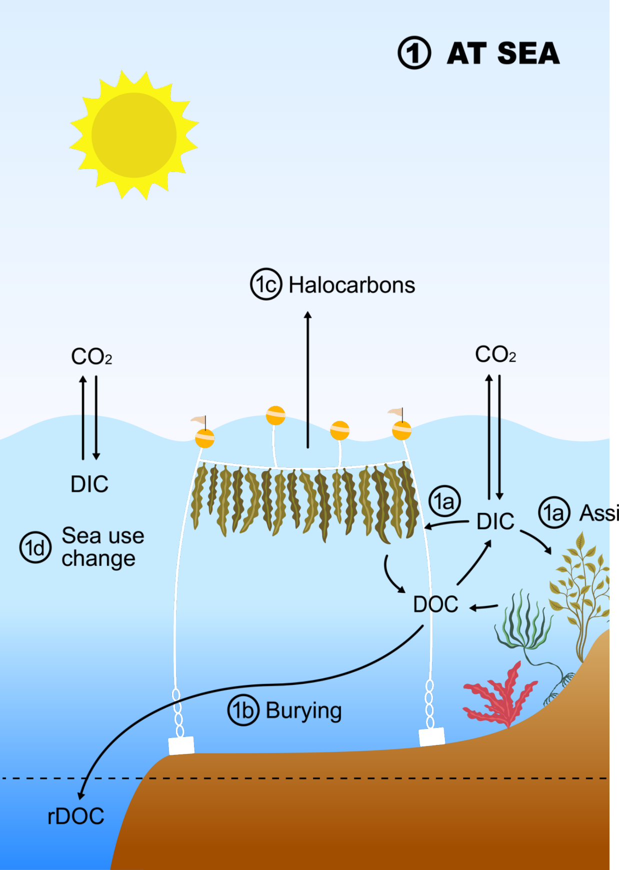
Recommended reading

1. IPCC AR5. Anthropogenic and Natural Radiative Forcing. In: **Climate Change 2013: The Physical Science Basis**. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Tech. Rep. (2013).

2. Duarte, C.M., Bruhn, A. & Krause-Jensen, D. **A seaweed aquaculture imperative to meet global sustainability targets.** Nat Sustain 5, 185–193 (2022). https://doi.org/10.1038/s41893-021-00773-9

3. Keng F.S.-L., S.-M. Phang, N. Abd Rahman, E.C. Leedham Elvidge, G. Malin, W.T. Sturges. **The emission of volatile halocarbons by seaweeds and their response towards environmental changes** J. Appl. Phycol., 32 (2) (2020), pp. 1377-1394, 10.1007/s10811-019-02026-x

4. **Phang**, S. M., Keng, F. S. L., Singh, P. K. M., Lim, Y. K., Abd Rahman, N., Leedham, E. C., ... & Sturges, W. T. (2015). **Can seaweed farming in the tropics contribute to climate change through emission of short-lived halocarbons?**. Malaysian Journal of Science, 34(1), 8-19.



Sea use change

- Land use change has been a hot topic in climate impact research for over a decade, particularly in the forest bioenergy sector
- What about sea use change?
- Natural or anthropogenic nutrients, and is a reduction of the biological carbon pump an in situ consequence of seaweed farming?

Gulf of Mexico ”dead zone” forecast for 2019, NOAA

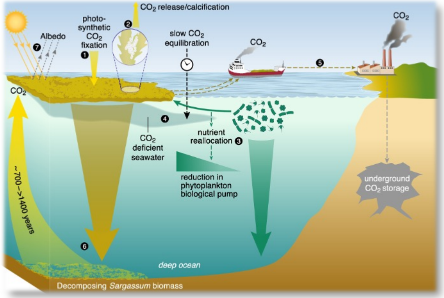


Figure 4 from Bach et al. (highly recommended!)

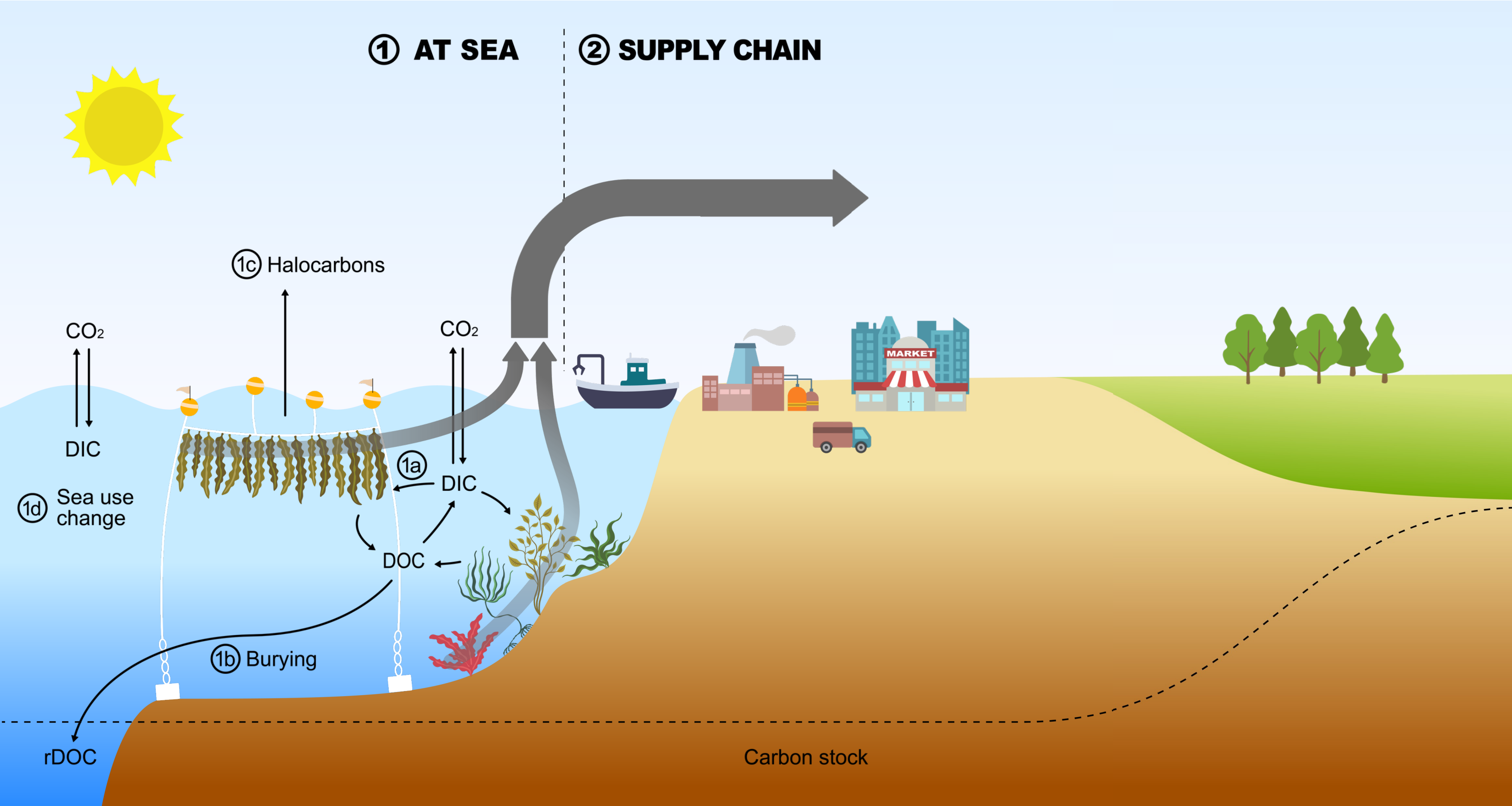
Recommended reading

Langlois, J., Fréon, P., Steyer, JP. et al. **Sea-use impact category in life cycle assessment: state of the art and perspectives**. Int J Life Cycle Assess 19, 994–1006 (2014). https://doi.org/10.1007/s11367-014-0700-y

Bach, L.T., Tamsitt, V., Gower, J. et al. **Testing the climate intervention potential of ocean afforestation using the Great Atlantic Sargassum Belt**. Nat Commun 12, 2556 (2021). https://doi.org/10.1038/s41467-021-22837-2

Cowie, A.L., Berndes, G., Bentsen, N.S., Brandão, M., … and Ximenes, F.A. (2021), **Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy**. GCB Bioenergy, 13: 1210-1231. https://doi.org/10.1111/gcbb.12844

Frieder C.A., C. Yan, M. Chamecki, D. Dauhajre, J.C. McWilliams, J. Infante, M.L. McPherson, R.M. Kudela, F. Kessouri, M. Sutula, I.B. Arzeno-Soltero, K. Davis. **A macroalgal cultivation modeling system (MACMODS): evaluating the role of physical-biological coupling on nutrients and farm yield.** Front. Mar. Sci., 9 (2022), Article 752951, 10.3389/fmars.2022.752951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Life Cycle Assessment (LCA)

Impacts assessment method for products, services or systems, focusing on function



Quantifies impacts across a range of **impact categories**

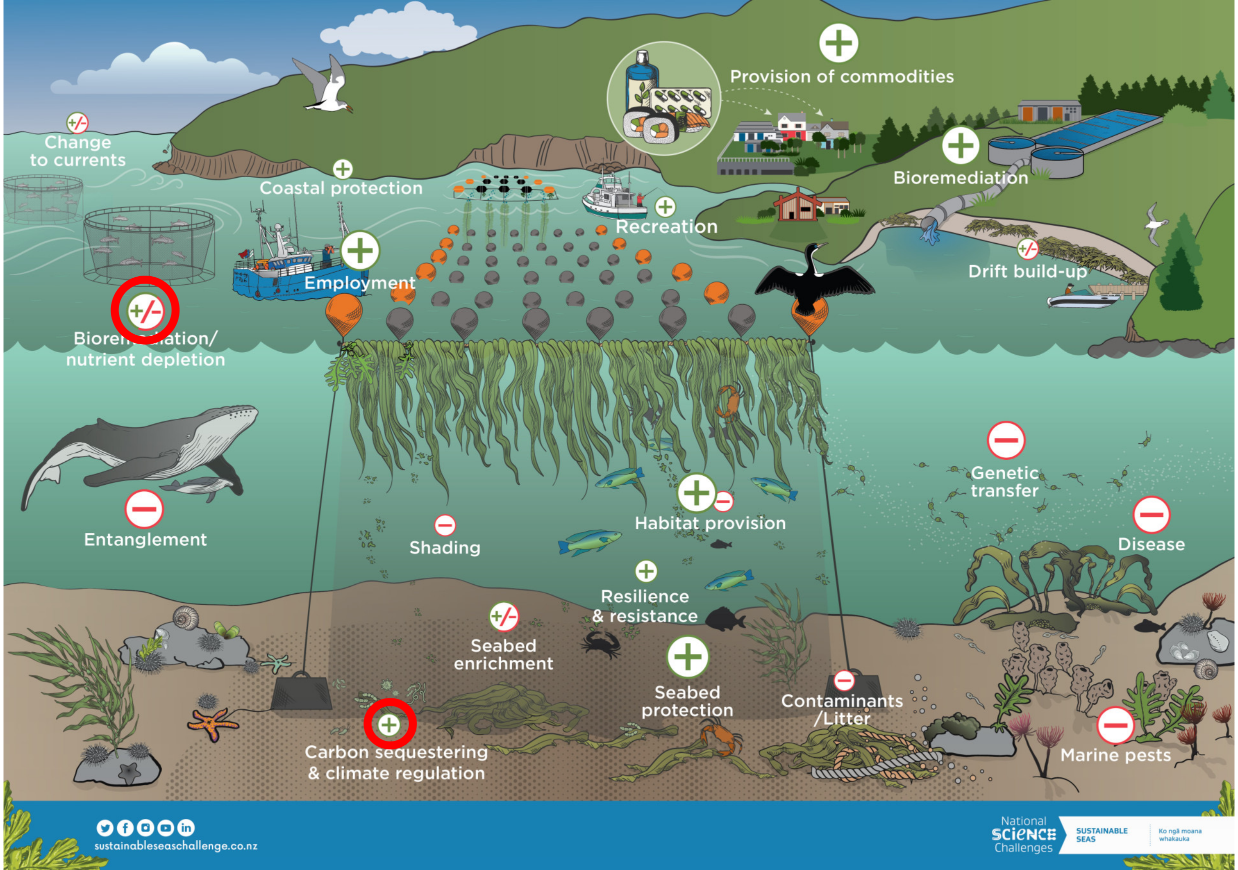
Broad scope of analysis: across its entire (or part of) its life cycle, e.g. from raw material extraction to waste (cradle to grave) or from raw material extraction to supermarket shelf (cradle to gate).

+ Provides a **holistic perspective of impacts and trade-offs** for more informed decision making

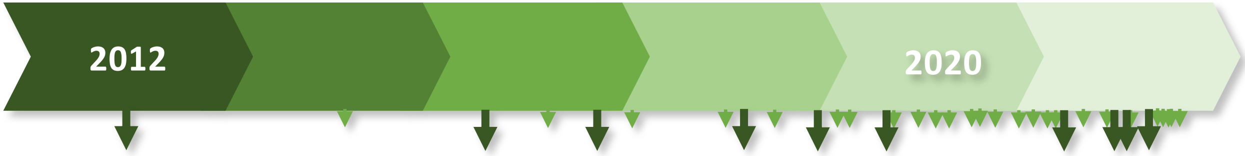
+ More scientifically accountable and detailed than carbon credit/trading methods or the GHG accounting protocol (see QR code: Arendt et al 2021)

- - **More time and resource consuming** than other methods

Arendt, Bach and Finkbeiner (2021); European Commission (2010) ILCD Handbook; ISO 14040-14044. Images: PRé-sustainability


Change to currents
Coastal protection
Provision of commodities
Bioremediation
Recreation
Employment
Drift build-up
Bioremediation/ nutrient depletion
Genetic transfer
Habitat provision
Entanglement
Shading
Disease
Resilience & resistance
Seabed enrichment
Seabed protection
Contaminants /Litter
Marine pests
Carbon sequestering & climate regulation
sustainableseaschallenge.co.nz
National Science Challenges
SUSTAINABLE SEAS
Ko ngā moana whakauka

Seaweed LCAs: an overview



More hypothetical data → Systematic case-specific data

Longline Saccharina latissima → Variety of species and farm designs

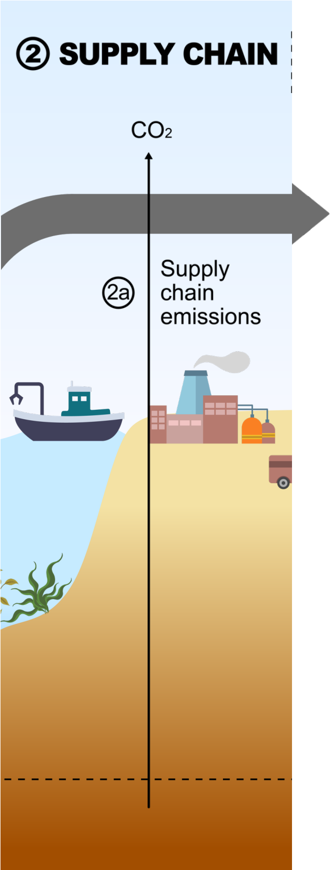
Hatchery excluded → Hatcheries & parent specimen included

Kelp for bioenergy → Biorefineries and other types of seaweed products

LCAs are increasing in complexity, analytically and in terms of inventory/input data, mirroring the increase in knowledge, interest in seaweed and sheer number of hatcheries, farms, product types and sustainability aspects

Depending on how you count them (search terms), there are **up to 40-50 seaweed-related LCAs published today**

Data from a core of around **10 LCAs are the original source** of inventory data, of which only 6 were published by 2020 when we started this review

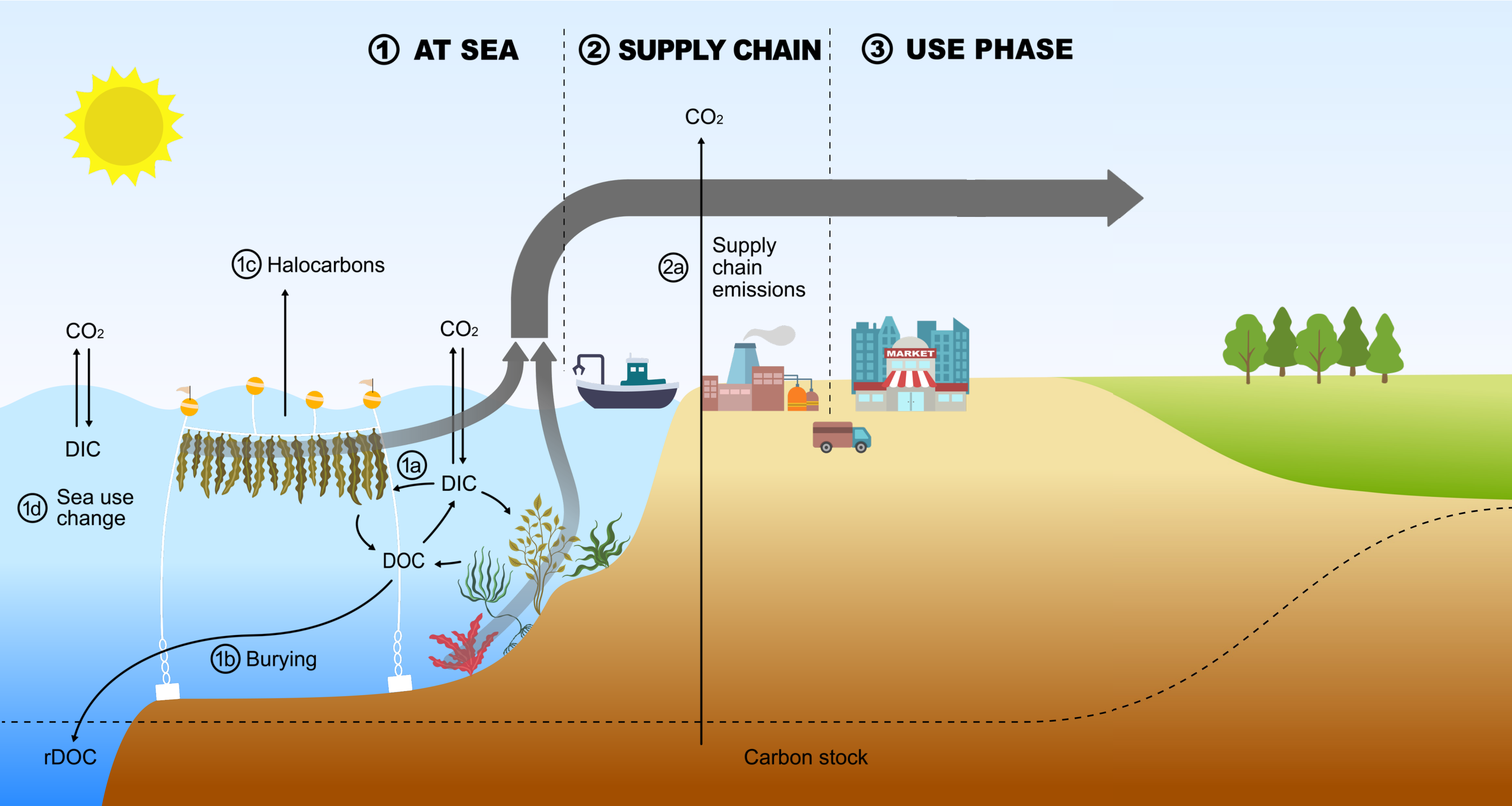


SUPPLY CHAIN EMISSIONS

- Reviewing LCA results is tricky – it is only a modelling tool so subject to wide uncertainty ranges[1], and methods choices are critical[2]
- Harmonization reviews can help to overcome some of these review challenges[3], but general take homes[4] can be extracted
    - Plastic ropes and buoys, and boat transport are key GHG emission hotspots
    - Recycling ropes and buoys at end of life, and/or chosing ropes made (partly) from recycled plastics can reduce emissions
    - Downstream processing (e.g. drying or freezing) can be other emissions hotspot
- Need for more studies to explore **scaled downstream processing and use** to grave

Recommended reading

1. **Brandao**, M., Kirschbaum, M.U.F., Cowie, A.L., Hjuler, S.V., 2019. **Quantifying the climate change effects of bioenergy systems: Comparison of 15 impact assessment methods**. GCB Bioenergy 11 (5), 727–743. https://doi.org/10.1111/gcbb.12593.
2. **Brandao**, M., Heijungs, R., Cowie, A., 2022. **On quantifying sources of uncertainty in the carbon footprint of biofuels: crop/feedstock, LCA modelling approach, land-use change, and GHG metrics**. Biofuel Research Journal 34, 1608–1616. https://doi.org/10.18331/BRJ2022.9.2.2.
3. **Ziegler**, F., Tyedmers, P.H., and Parker, R.W.R. (2022). **Methods matter: Improved practices for environmental evaluation of dietary patterns**. Global Environmental Change 73, 102482. doi: https://doi.org/10.1016/j.gloenvcha.2022.102482.
4. **Thomas**, J.-B.E., Sodr´e Ribeiro, M., Potting, J., Cervin, G., Nylund, G.M., Olsson, J., Albers, E., Undeland, I., Pavia, H., Gr¨ondahl, F., 2021. **A comparative environmental life cycle assessment of hatchery, cultivation, and preservation of the kelp Saccharina latissima**. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 78 (1), 451–467. https://doi.org/10.1093/icesjms/fsaa112.



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CO2
2a Supply chain emissions
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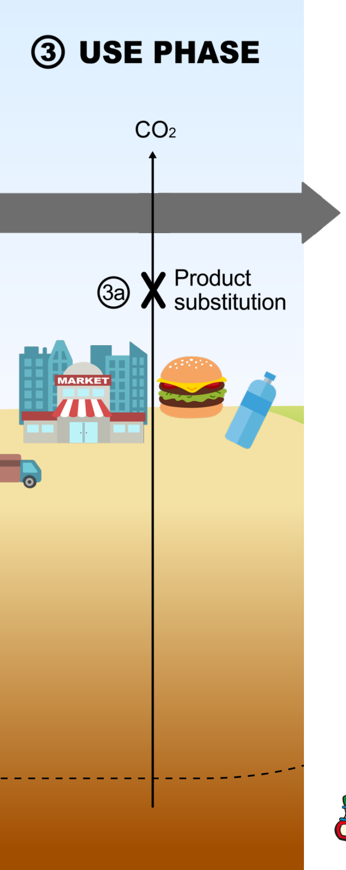
MARKET

By switching to a plant-based diet and by using seaweed, as the main source of protein, we can relieve the pressure on our ecosystems: by minimizing the impact of the meat and dairy industry, reducing greenhouse gases, saving thousands liters of fresh water and restoring thousands of acres of land – currently being used for animal farming.

INGREDIENTS WEED BURGER:
WATER, RICE FLOUR, 16.2% SOY PROTEIN, 10.1% SEAWEED, SUNFLOWER OIL, THICKENER (METHYLCELLULOSE, CARRAGEENAN), MODIFIED CORN STARCH, FLAVORING, WHEAT FLOUR, POTATO FIBER, DRIED ONION, YEAST EXTRACT, WHEAT PROTEIN, SPICES, LEMON GRANULATE, CARAMELIZED SUGAR

(Accessed Nov 12 2022)



CONSEQUENCES OF USING SEAWEED

Net emissions (including substitution)
= emissions - avoided emissions

- **Substitution** may be accounted for in LCA: [1,2]
- New guidance in latest ISO 14044 (2020) though these need clarification[3]
- Quantifying avoided emissions: which product or function is being substituted? Is performance equal? If not, how do you account for differences:
  - Is 1 PET plastic bottle = to 1 alginate-based water pouch?
  - Is 1 seaweed infused bean burger = to 1 beef burger?


Image: Guillaume Couche/PR


Image: Ari Jonsson

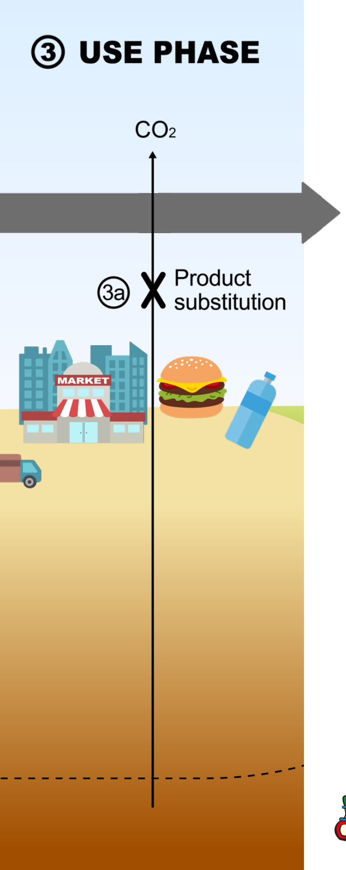

Flickr: Nadezhda Garanina

Recommended reading

1. Tanzer S.E., A. Ramírez, 2019. **When are negative emissions negative emissions?** Energy Environ. Sci., 12 (4), pp. 1210-1218, 10.1039/C8EE03338B

2. Guinée, J.B. 2002. **Handbook on life cycle assessment operational guide to the ISO standards**. Int. J. Life Cycle Assess., 7 (5), pp. 311-313

3. Heijungs R, K. Allacker, E. Benetto, M. Brandão, J. Guinée, S. Schaubroeck, T. Schaubroeck, A. Zamagni. 2021. **System expansion and substitution in LCA: a lost opportunity of ISO 14044 amendment 2** [opinion] Frontiers in Sustainability, 2 (40), 10.3389/frsus.2021.692055



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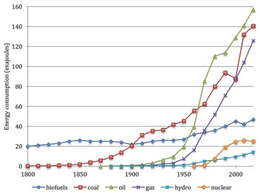
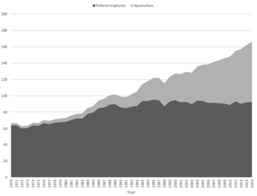
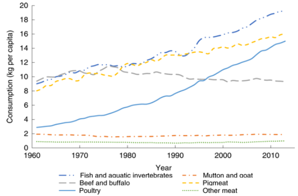


Renewable vs. fossil energy [4]



Wild capture vs aquaculture [6]



High vs lower impact meat [5]

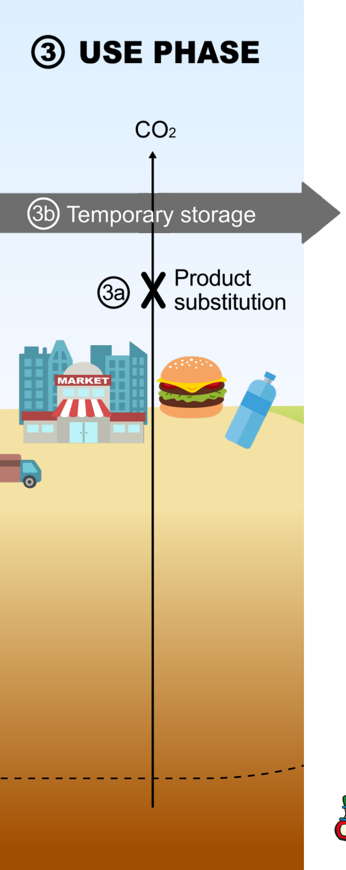
- Are low-impact products **additions to** rather than **transitions from** high-impact products? [4-6]
    - Does the production of a seaweed product mean the production of something else is being stopped?

Recommended reading

4. York, R. 2021. **Poultry and fish and aquatic invertebrates have not displaced other meat sources**. Nat. Sustain., 4 (9), pp. 766-768, 10.1038/s41893-021-00714-6

5. York and Bell, 2019. **Energy transitions or additions? why a transition from fossil fuels requires more than the growth of renewable energy**. Energy Res. Social Sci., 51, pp. 40-43, 10.1016/j.erss.2019.01.008

6. Longo S.B., B. Clark, R. York, A.K. Jorgenson. 2019. **Aquaculture and the displacement of fisheries captures**. Conserv. Biol., 33 (4) (2019), pp. 832-841, 10.1111/cobi.13295



TEMPORARILY STORED BIOGENIC CARBON

- Also challenging to account, with no single approach or standard. EC 2010 (ILCD Handbook) suggests:

$$\textit{Credit for temporary carbon storage} = \frac{\Sigma \text{ stored carbon (tons)} \,.\, \text{Storage duration (in years)}}{100 \text{ years (or other time horizon)}}$$

Example:

1000 tons wet weight of S. latissima (assuming 17% dry matter of which ≈32% is carbon)

contains ≈ 200 tons CO_2 eq (54.5 tons C)

Assuming biogenic carbon is stored 0.5 years on average across whole value chain:

$$\textit{Credit for temporary carbon storage} = \frac{200 \text{ tons } CO_2 \text{ eq} \,.\, 0.5 \text{ years}}{100 \text{ years}} = \mathbf{1 \text{ ton } CO_2 \text{ eq}}$$

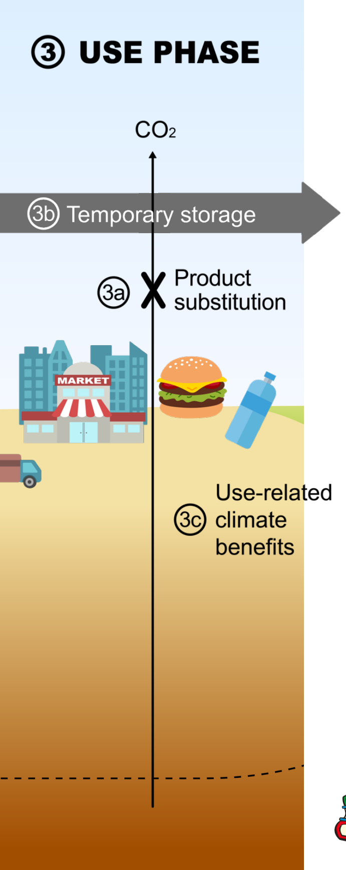
- Short-term GHG reductions in the atmosphere may help to “buy us some time” to avoid critical tipping points

Recommended reading

Brandão M., A. Levasseur, M.U.F. Kirschbaum, B.P. Weidema, A.L. Cowie, S.V. Jørgensen, M.Z. Hauschild, D.W. Pennington, K. Chomkhamsri. **Key issues and options in accounting for carbon sequestration and temporary storage in life cycle assessment and carbon footprinting**. Int. J. Life Cycle Assess., 18 (1) (2013), pp. 230-240, 10.1007/s11367-012-0451-6

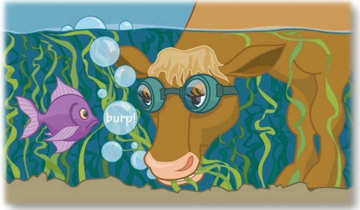
Jørgensen S.V. , M.Z. Hauschild, P.H. Nielsen. **The potential contribution to climate change mitigation from temporary carbon storage in biomaterials.** Int. J. Life Cycle Assess., 20 (4) (2015), pp. 451-462, 10.1007/s11367-015-0845-3

EC. International Reference Life Cycle Data System (ILCD) Handbook - General Guide for Life Cycle Assessment - Detailed Guidance. First edition (2010) March 2010. EUR 24708 EN

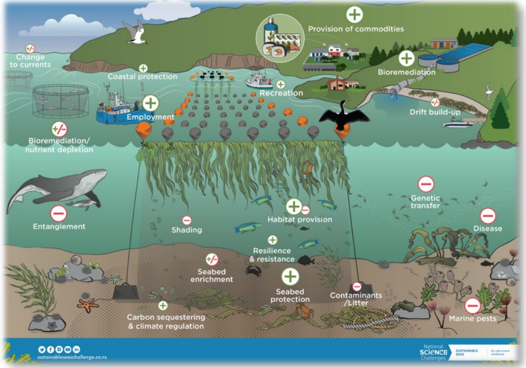


OTHER USE-RELATED BENEFITS

- Specific benefits for increases in efficiency or other rebound effects
- Adding *asparagopsis* to cattle feed can lower methane emissions [1,2]
- Other *in situ* climate adaptation benefits:
  - Coastal protection[3]
  - Mitigation of ocean acidification[4]

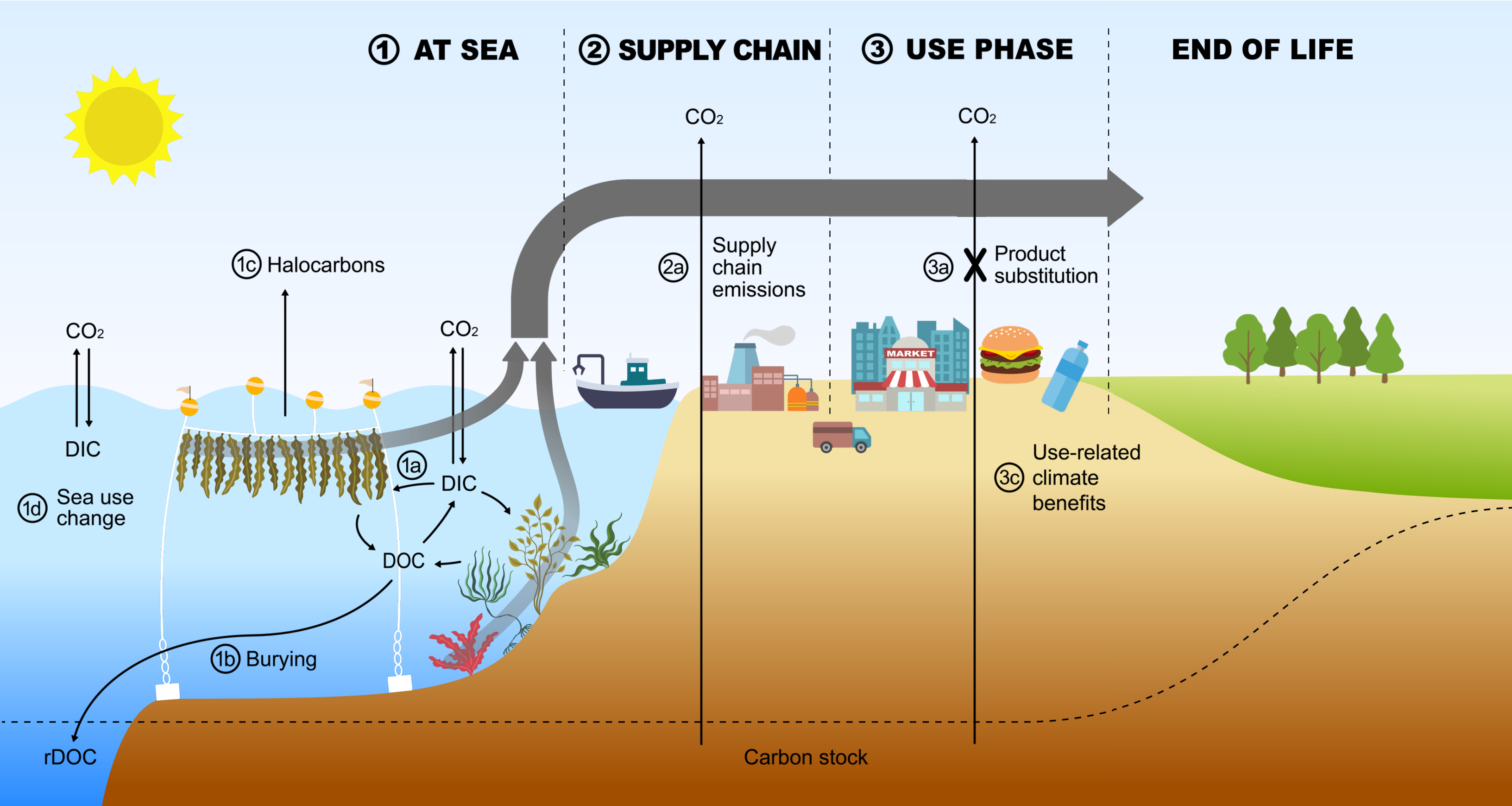


https://teen.wng.org/comment/42948



Recommended reading

1. **Roque** B.M., M. Venegas, R.D. Kinley, R. de Nys, T.L. Duarte, et al. **Red seaweed (Asparagopsis taxiformis) supplementation reduces enteric methane by over 80 percent in beef steers.** PLoS ONE, 16 (3) (2021), Article e0247820, 10.1371/journal.pone.0247820
2. **Nilsson**, J and **Martin**, M. **Exploratory environmental assessment of large-scale cultivation of seaweed used to reduce enteric methane emissions.** 2022. Sust Prod and Cons 30, pp. 413-423 doi.org/10.1016/j.spc.2021.12.006
3. **Mork** M. **Wave attenuation due to bottom vegetation** J. Grue, B. Gjevik, J.E. Weber (Eds.), Waves and Nonlinear Processes in Hydrodynamics, Springer Netherlands (1996), pp. 371-382, 10.1007/978-94-009-0253-4_30
4. **Krause-Jensen** D., C.M. Duarte, I.E. Hendriks, L. Meire, M.E. Blicher, N. Marbà, M.K. Sejr. **Macroalgae contribute to nested mosaics of pH variability in a subarctic fjord.** Biogeosciences, 12 (16) (2015), pp. 4895-4911, 10.5194/bg-12-4895-2015



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DOC
3c Use-related climate benefits
1b Burying
rDOC
Carbon stock

TO CARBON STOCK OR BACK TO THE ADMOSPHERE

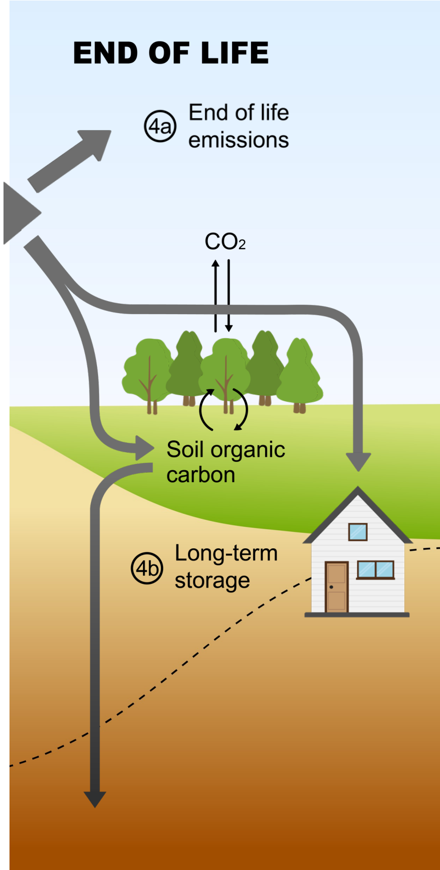
- The emissions from this final stage are referred to in LCA as end-of-life emissions
- Where do the material inputs of the system (e.g. longline ropes) and the biogenic carbon end-up?
    - Waste management choices (e.g. landfill, recycling, composting, incineration)
    - … affect the destinies of residual materials (sewage sludge, ashes, etc.)
    - … and eventual sinks (e.g. water, air) and gas composition (CO_2, CH_4, etc.)
- Products with a longer life (e.g. construction materials), including carbon capture (e.g. BECCS) or that contribute to soil organic carbon (e.g. biochar) can lead to long term (> 100 years) carbon storage, can claim climate benefits

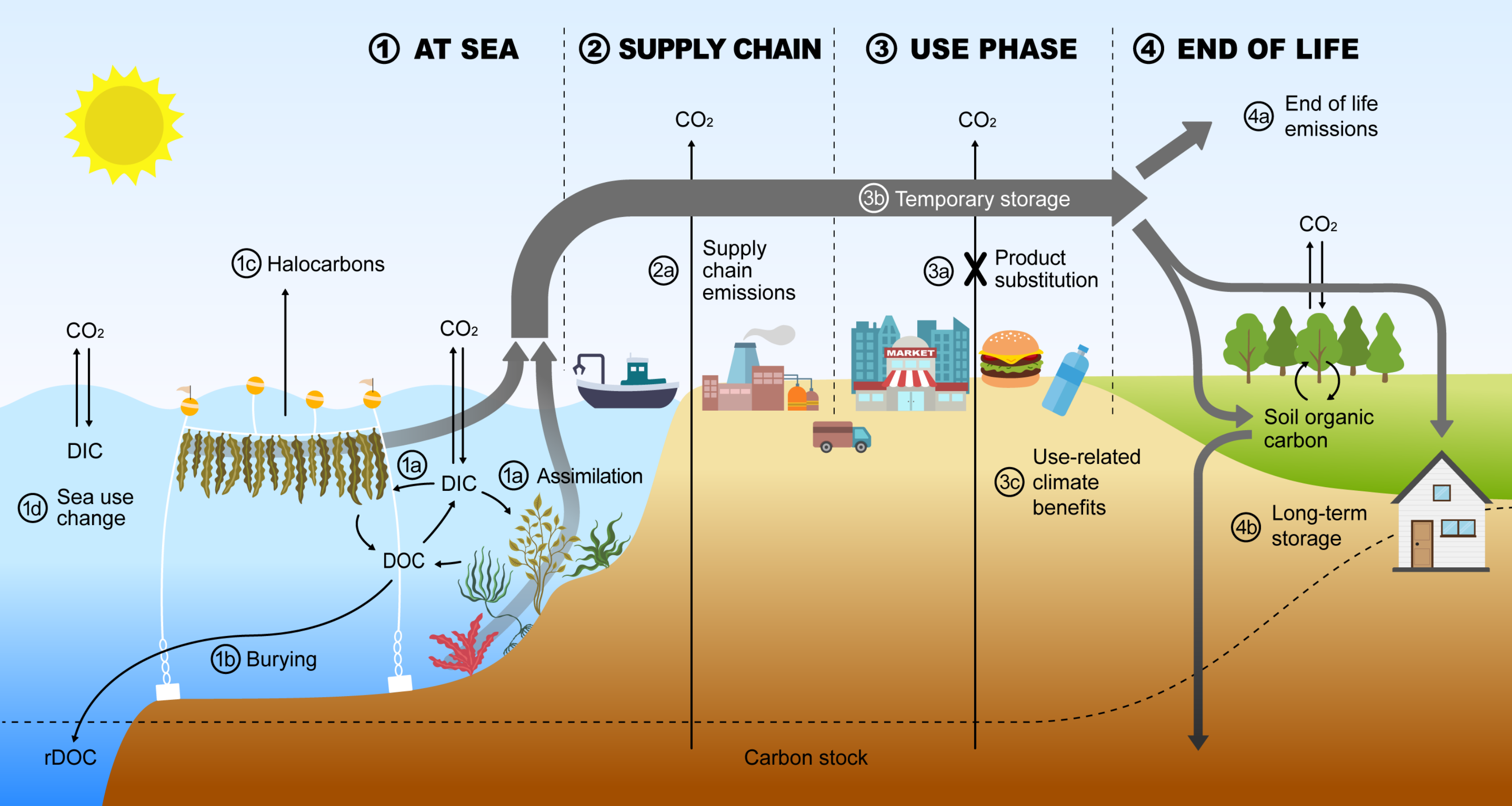
$$\textit{Credit for temporary carbon storage} = \frac{\Sigma\ \textit{stored carbon (tons)}\ .\ \textbf{\textit{Storage duration (in years)}}}{100\ \textit{years (or other time horizon)}}$$

Recommended reading

Laurent A., I. Bakas, J. Clavreul, A. Bernstad, M. Niero, E. Gentil, M.Z. Hauschild, T.H. Christensen. **Review of LCA studies of solid waste management systems – Part I: lessons learned and perspectives**. Waste Manag., 34 (3) (2014), pp. 573-588, 10.1016/j.wasman.2013.10.045

Hou P., Y. Xu, M. Taiebat, C. Lastoskie, S.A. Miller, M. Xu. **Life cycle assessment of end-of-life treatments for plastic film waste.** J. Clean. Prod., 201 (2018), pp. 1052-1060, 10.1016/j.jclepro.2018.07.278

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1a
DIC
1a Assimilation
DOC
1b Burying
rDOC
CO2
2a Supply chain emissions
3b Temporary storage
CO2
3a Product substitution
MARKET
3c Use-related climate benefits
4a End of life emissions
CO2
Soil organic carbon
4b Long-term storage
Carbon stock

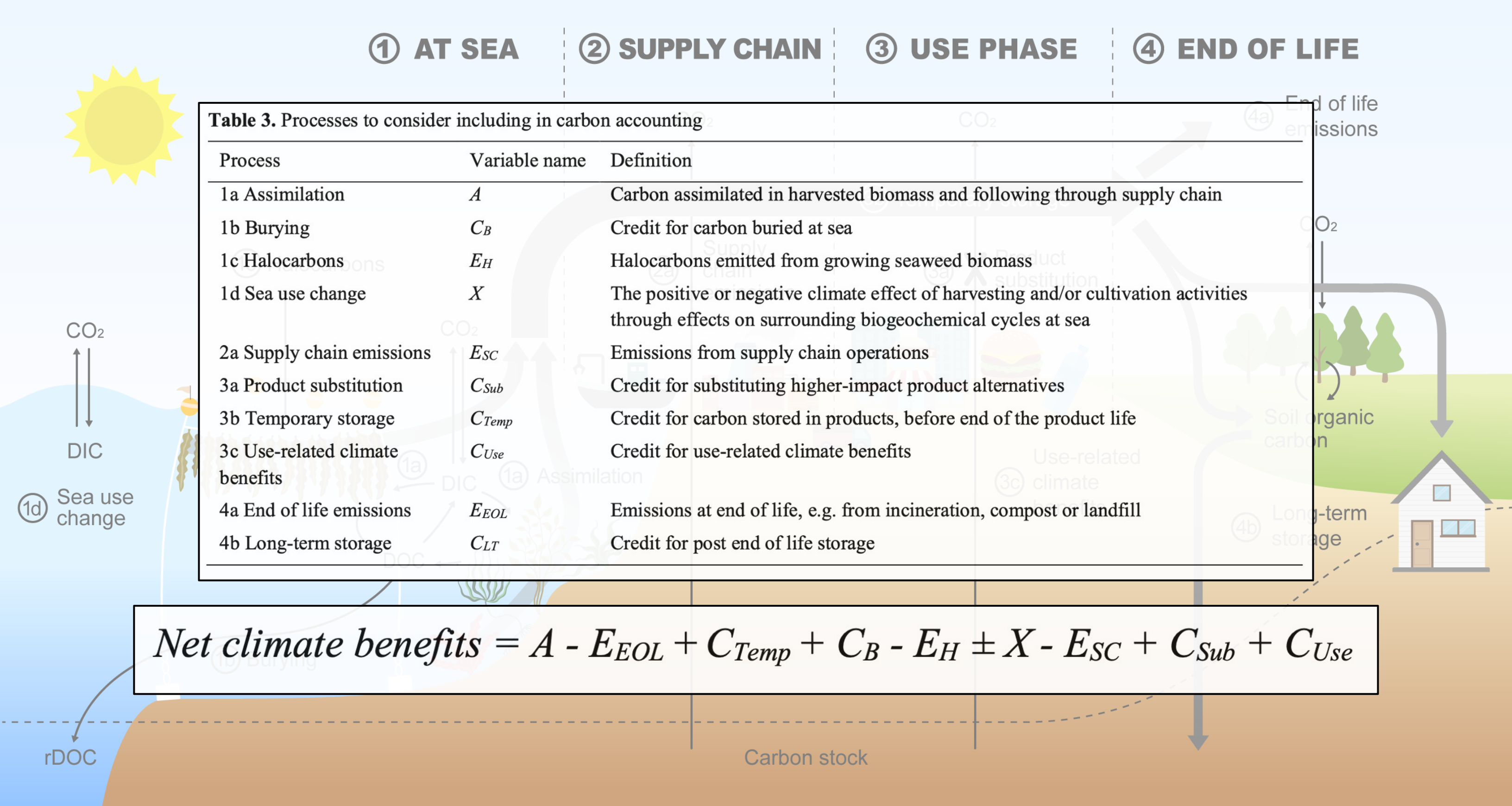

Table 3. Processes to consider including in carbon accounting

Process	Variable name	Definition
1a Assimilation	A	Carbon assimilated in harvested biomass and following through supply chain
1b Burying	C_B	Credit for carbon buried at sea
1c Halocarbons	E_H	Halocarbons emitted from growing seaweed biomass
1d Sea use change	X	The positive or negative climate effect of harvesting and/or cultivation activities through effects on surrounding biogeochemical cycles at sea
2a Supply chain emissions	E_{SC}	Emissions from supply chain operations
3a Product substitution	C_{Sub}	Credit for substituting higher-impact product alternatives
3b Temporary storage	C_{Temp}	Credit for carbon stored in products, before end of the product life
3c Use-related climate benefits	C_{Use}	Credit for use-related climate benefits
4a End of life emissions	E_{EOL}	Emissions at end of life, e.g. from incineration, compost or landfill
4b Long-term storage	C_{LT}	Credit for post end of life storage

$$\textit{Net climate benefits} = A - E_{EOL} + C_{Temp} + C_B - E_H \pm X - E_{SC} + C_{Sub} + C_{Use}$$

The role of algae in a sustainable food system - environment and nutrition

The future supply and consumption of algae is expected to increase both in Sweden and globally, with great commercial potential. The project will meet the need for **increased knowledge about algae's environmental impact, nutritional quality and health effects.** The results will be useful as a guide to sustainable production and consumption of algae.

Research Institutes of Sweden

CHALMERS
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FORMAS


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Elinor Hallström
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Nutritional quality
Health effects
Environmental effects
(focus on climate)
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Chalmers
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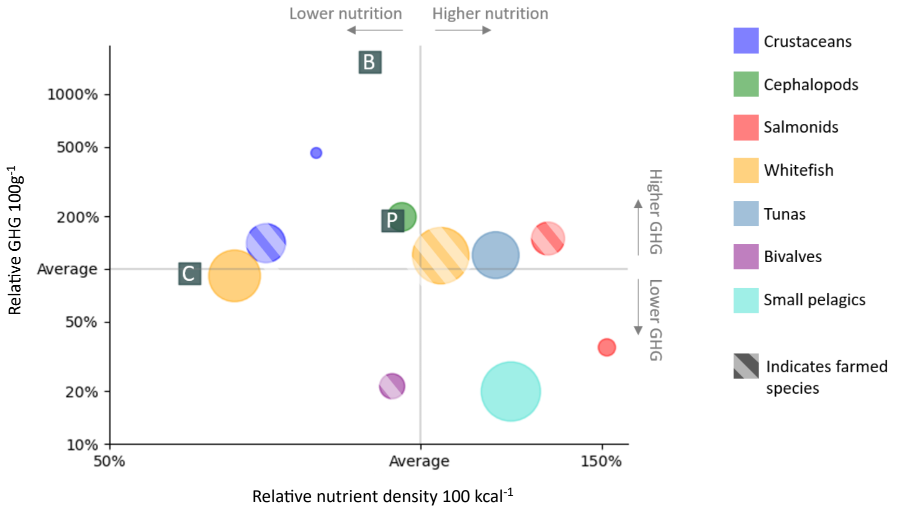
Environmental & nutritional performance

Previous research

- Show large variation in climate impact and nutritional quality between seafood species
- Results for algae are lacking

Remaining questions

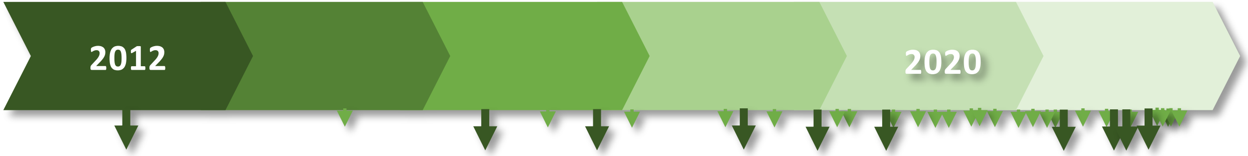
- Performance of algae in relation to other foods?
- Variation between algae species?



Recommended reading

Bianchi, M., Hallström, E., Parker, R.W.R. et al. **Assessing seafood nutritional diversity together with climate impacts informs more comprehensive dietary advice**. Commun Earth Environ 3, 188 (2022). https://doi.org/10.1038/s43247-022-00516-4

Hallström E, Bergman K, Mifflin K, Parker R, Tyedmers P, Troell M, Ziegler F. 2019. **Combined climate and nutritional performance of seafoods**. J Clean Prod. 230:402–411. doi:10.1016/j.jclepro.2019.04.229



- Around 20+ LCAs in 2020 that met search criteria and of which **6 matched our inclusion criteria**
- Because of methodological differences**, numerical results cannot be compared** meaningfully
- Review of inventory data: collect inventories and recalculate impacts **using one harmonized approach**

Report	Year	Location	Seaweed species	Functional unit
Langlois et al.	2012	Europe	*Saccharina latissima*	1 km trip with a gas-powered car
Aitken et al.	2014	Chile	*Macrocystis pyrifera*	1 MJ of energy
Taelman et al.	2015	Ireland & France	*Saccharina latissima*	1 MJ exergy seaweed
Seghetta et al.	2017	Denmark	*Saccharina latissima*	1 ha of sea under cultivation
Thomas et al.	2020	Sweden	*Saccharina latissima*	1 ton fresh weight biomass

Algren et al. (in prep)

Environmental impacts of kelp aquaculture through harmonized recalculation of life cycle inventory data

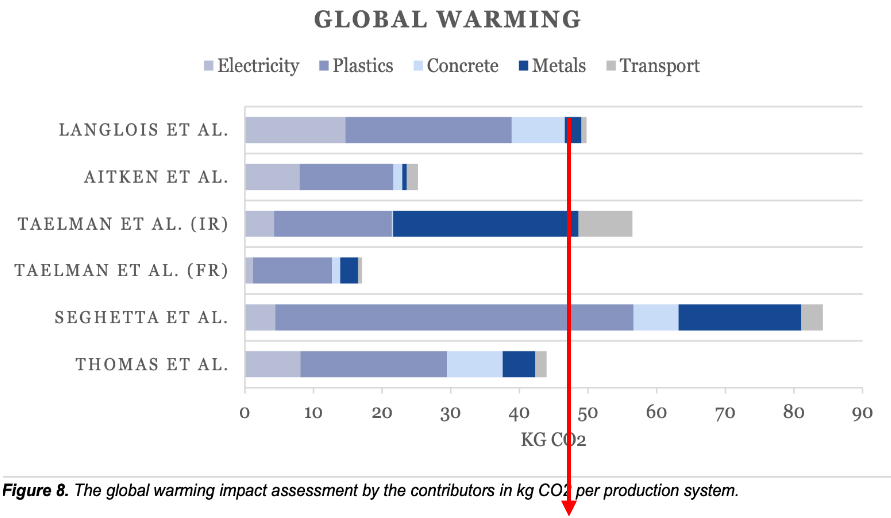
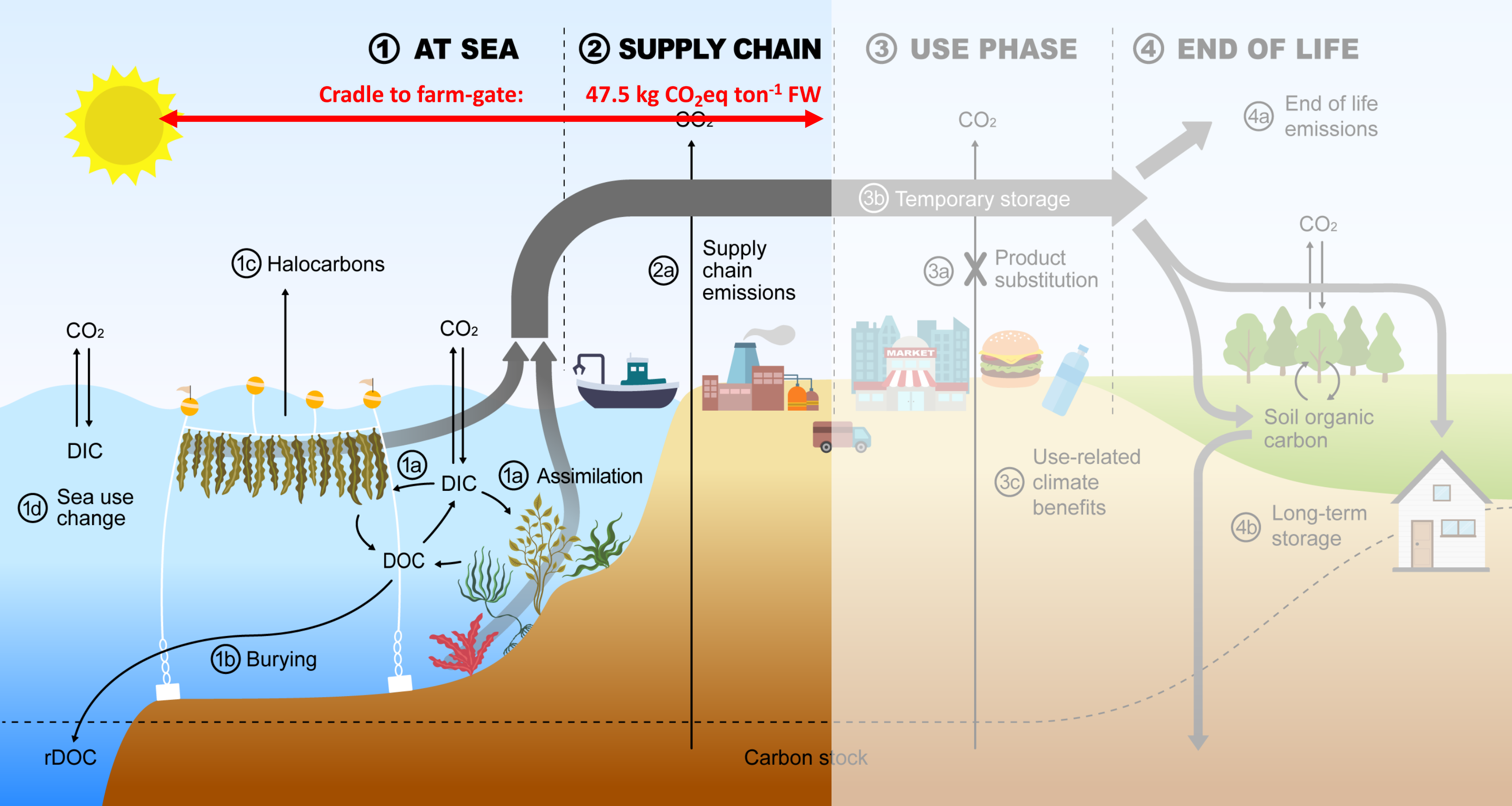


Figure 8. *The global warming impact assessment by the contributors in kg CO2 per production system.*

Mean ≈ **47.5 kg** CO_2 eq per ton FW (longline + raft production of *Saccharina* & *Macrocystis*)

Still under development and not yet peer-reviewed.
Please do not re-use.



① AT SEA
② SUPPLY CHAIN
③ USE PHASE
④ END OF LIFE
Cradle to farm-gate:
47.5 kg CO_2eq ton^{-1} FW
CO_2
CO_2
4a End of life emissions
3b Temporary storage
CO_2
1c Halocarbons
2a Supply chain emissions
3a Product substitution
CO_2
CO_2
DIC
MARKET
Soil organic carbon
1a
DIC
1a Assimilation
Use-related climate benefits
3c
1d Sea use change
DOC
4b Long-term storage
1b Burying
rDOC
Carbon stock

Method
Literature review

- Three aspects:
  - Nutrition
  - Toxicity
  - Bioavailability
- Dried, non-processed algae, from areas without known contamination
- 114 original articles (2011 – 2021)
- 1 research institute (CEVA database)

Maria Jacobsen
RISE/SLU

Method
Nutritional assessments

- **Nutritional contribution**
  - % of recommended intake of nutrients, per portion (5 gram dry weight)

- **Nutrition claims**
  (according to EU Regulation 1924/2006)

- **Nutrient density score;** Nutrient Rich Food (NRF)
  - NRF11.3 and NRF21.3

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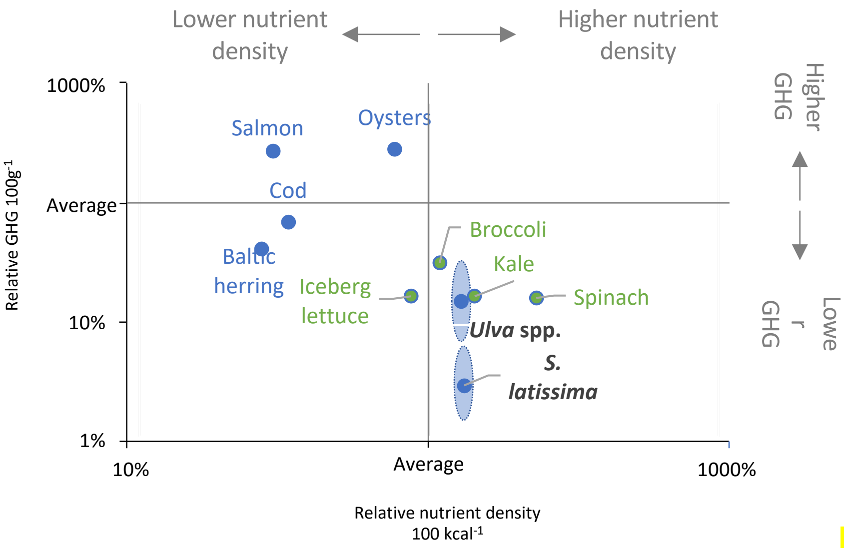
RISE/SLU

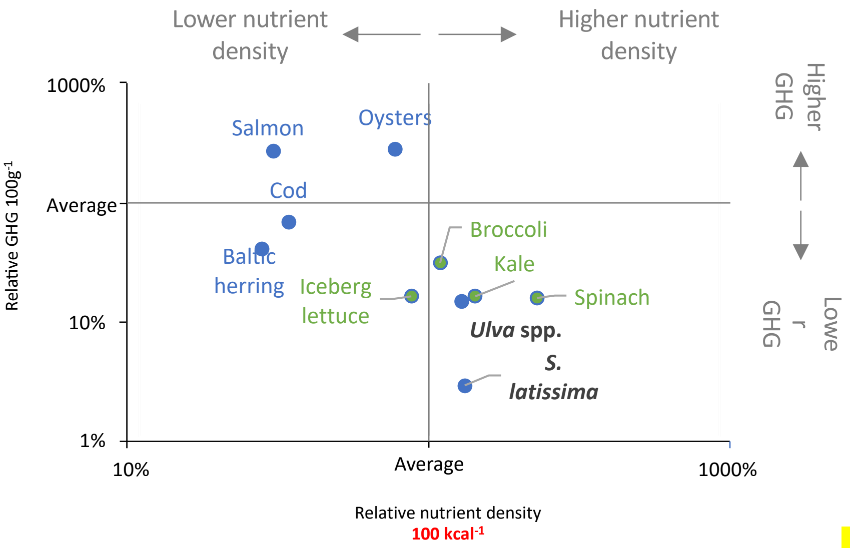
Combined climate & nutritional performance of *S. latissima* and *Ulva* spp.



- ***Low climate impact per nutritional value*** in relation to selected reference foods
- BUT results depend largely on assumptions and methods used

Still under development and not yet peer-reviewed. Please do not re-use.

Combined climate & nutritional performance of *S. latissima* and *Ulva* spp.



Method aspects to consider

- Differences in portion size!
- 100 kcal=

    0.4 portions of raw salmon
    14 portions of fresh spinach
    7-8 portions of dried algae

- Representative comparisons?

Still under development and not yet peer-reviewed.
Please do not re-use.

Knowledge gaps

Need for more **randomized controlled interventional trials (RCTs)** on effects of seaweed consumption on human health

Need for better understanding of **vitamin content and bioavailability** (notably B12)

Need for studies focusing on **other species** and effects of **real-life processing & cooking**

Need for LCAs of **scaled-up** production of **more species**, **cultivated** and **wild-harvested**, from a **cradle-to-plate perspective**

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Seaweed and climate impacts
A systems perspective and comparison with other foods

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Questions about nutritional aspects

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Questions about health effects

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