SUSTAINABILITY ASSESSMENT OF BIORESOURCE MANAGEMENT SYSTEMS (BMS) - A DANISH CASE STUDY

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POLICY STRATEGIES AND ACTION PLANS

Organic waste combustion with energy production

- For the last decades, 80% of organic fraction of household waste has been combusted

Biogasification with energy and natural fertilizer production

- Today around 7% of the manure and 35% of the sludge is biogasified

Goal of the Resource action plan for waste management

- 20% reduction in the amount of organic waste going to combustion in 2018

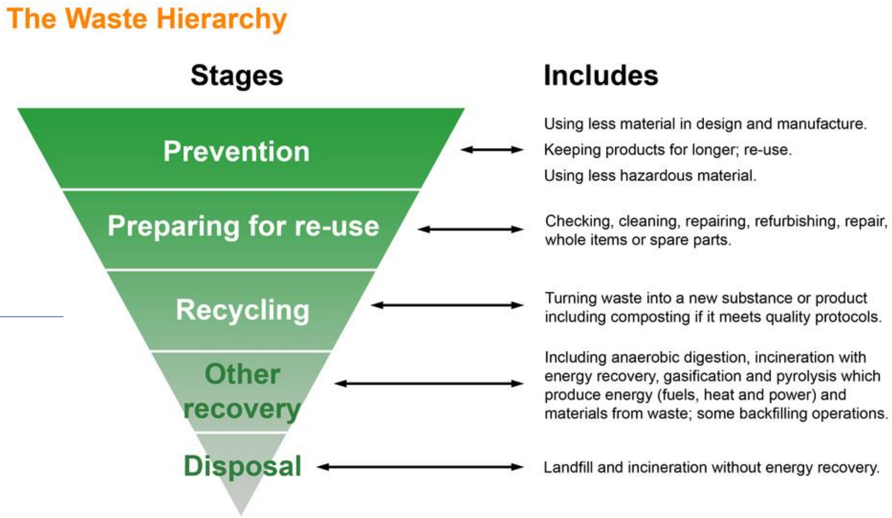
Goals of the Green Growth Plan

- 45% increase in the amount of biogasified manure ,prior to spreading on agricultural soils in 2020
- Financial support scheme for heat and power from biogas to support the 2020 goal
- No financial support on the use of energy crops above 12% , no restriction on biowaste in 2020

-MOVING UP IN THE WASTE HIERARCHY

Turning waste into a resource

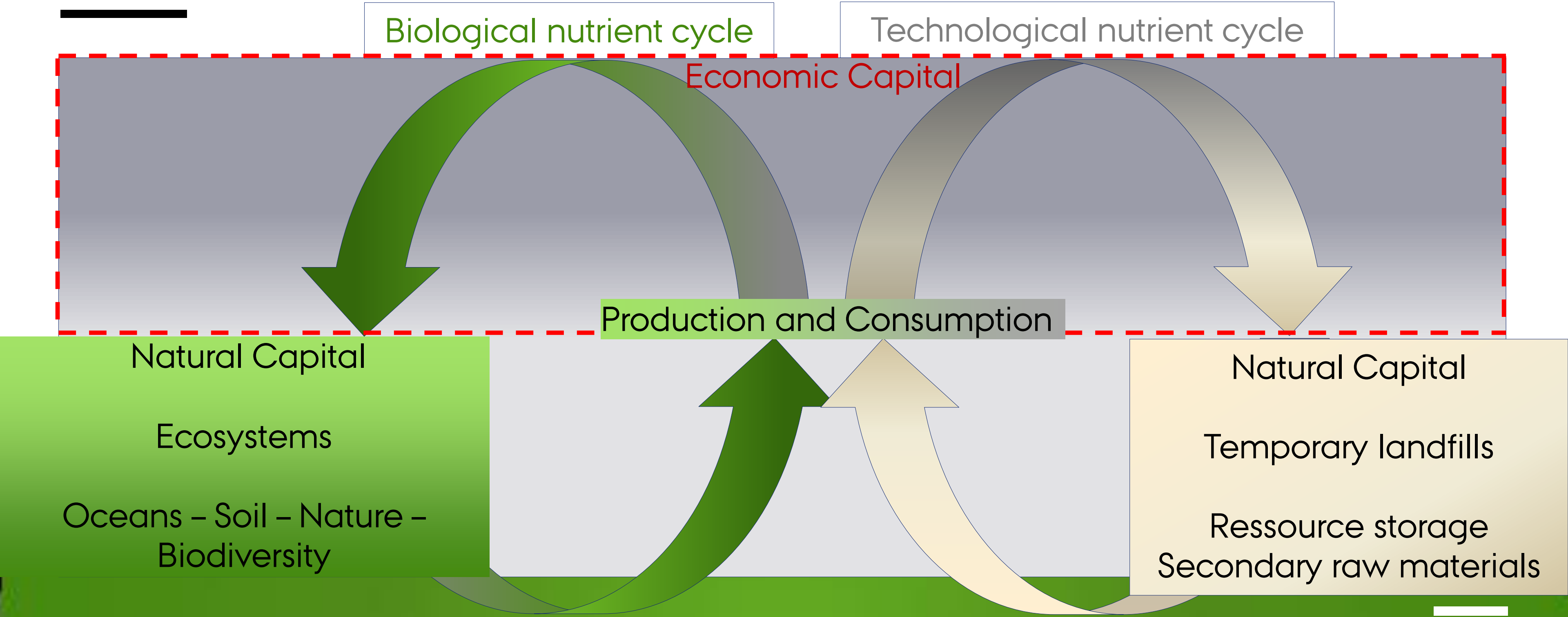
Extraction and recycling



The Waste Hierarchy

Stages	Includes
Prevention	Using less material in design and manufacture. Keeping products for longer; re-use. Using less hazardous material.
Preparing for re-use	Checking, cleaning, repairing, refurbishing, repair, whole items or spare parts.
Recycling	Turning waste into a new substance or product including composting if it meets quality protocols.
Other recovery	Including anaerobic digestion, incineration with energy recovery, gasification and pyrolysis which produce energy (fuels, heat and power) and materials from waste; some backfilling operations.
Disposal	Landfill and incineration without energy recovery.

INDUSTRIAL ECOLOGY & CIRCULAR ECONOMY



Biological nutrient cycle

Technological nutrient cycle

Economic Capital

Production and Consumption

Natural Capital

Ecosystems

Oceans – Soil – Nature – Biodiversity

Natural Capital

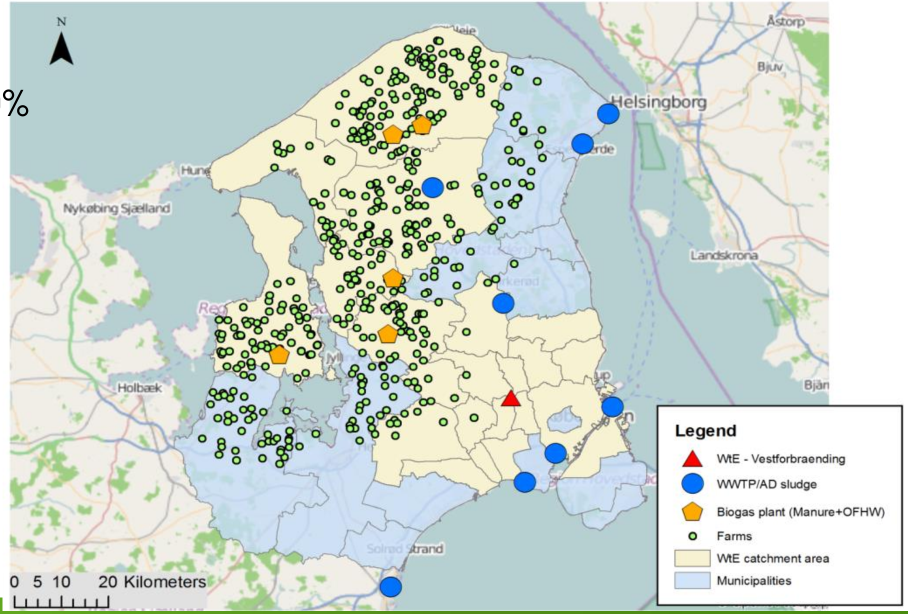
Temporary landfills

Ressource storage
Secondary raw materials

REORGANISATION OF THE BIOWASTE FLOWS AND MANAGEMENT IN DK

SYSTEM DESCRIPTION

Reallocation of 20% of the organic household waste incinerated to co-digestion at sludge and manure-based biogas plants



Increase the amount of manure biogasified from 5 to 50%

Codigestion of organic household;

- 25% dw at manure-based biogas plante

Remaining at sludge-based biogas plants

- 1WtE plant
- 5 manure-based biogas plants
- 8 sludge-based biogas plants
- farmers

Sustainable Ressource Flows

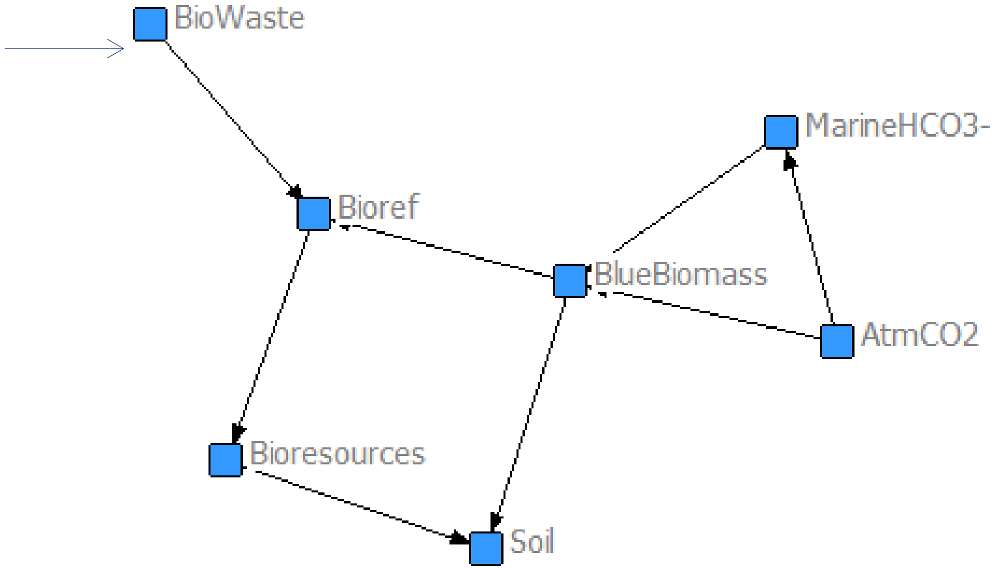
1. Environmental restoration may be obtained by **ecoindustrial ressource flows**; i.e. Human-Environment system exchange of naturally occurring compounds , materials and energy flows mimicking the natural biogeochemical cycles, dimensions and scales

2. Antropogenic compounds should be recycled inside the technophere and reabsorbed in equals rates to their dispersion; exchanged at levels below any observable adverse impact.

3. Only healthy ecosystems sustains services

CIRCULAR RESOURCE MANAGEMENT

- From linear to circular Carbon flows



- For Ecosystem Health and Service Preservation

ECOINDUSTRIAL SYSTEM ANALYSIS

Methodological approaches:

Life cycle assessment at system level – cradle to cradle

Ecological network analysis

LCA OF TECHNOLOGY SYSTEMS FOR MANAGING RESOURCES IN ORGANIC WASTE

Goal and scope

To evaluate

- the resource efficiency of alternative biowaste management systems
- the effectiveness in producing climate change mitigation
- reducing? the impacts on the environment and human health

Impact categories:

climate change,

fossil depletion,

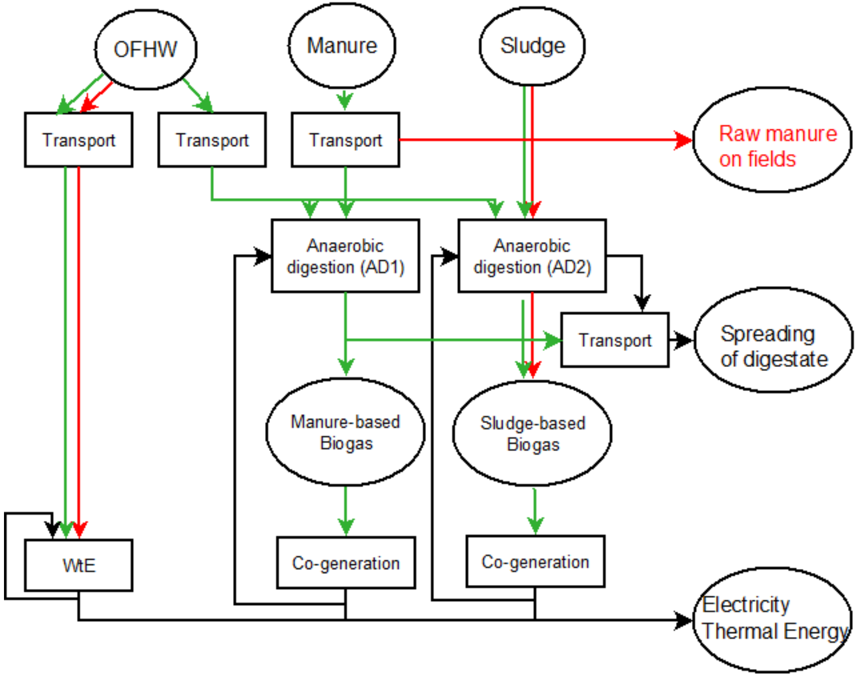
terrestrial ecotoxicity,

human toxicity,

freshwater and marine eutrophication

BIOWASTE STOCKS AND PATHWAYS

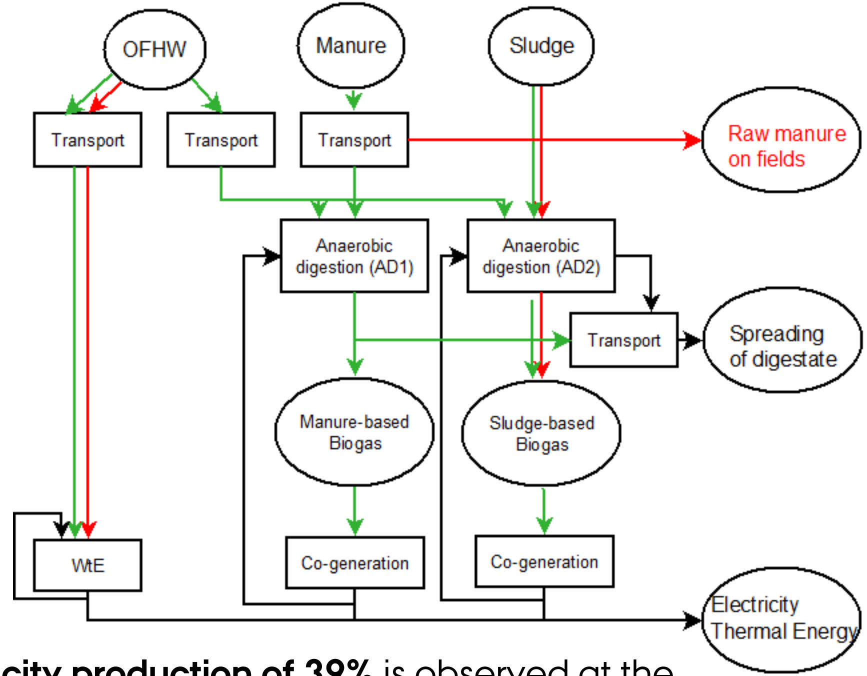
Biowaste Technology	**Reference Scenario** Resource stocks [Mg dw]	**Alternative Scenario** Resource stocks [Mg dw]
Incineration (WtE) - OFHW	69.970	46.910
Direct spread - Manure	20.573	-
Anaerobic Digestion (AD1) - Manure	-	20.573
Codigestion (AD1) - OFHW	-	5.144
Anaerobic Digestion (AD2) - Sludge	57.629	57.629
Codigestion (AD2) - OFHW	-	17.916
AD1 Digestate	-	15.032
AD2 Digestate	32.856	32.987
Direct spread - Manure - P fertilizer	79	-
AD1 - P fertilizer	-	**84**
AD2- P fertilizer	329	**347**
Substituted mineral P fertilizer	-	**23**



The alternative scenario shows a **decrease in loss of phosphorous**, which substitutes mineral fertilizer

ENERGY PRODUCTION AND BIOWASTE PATHWAYS

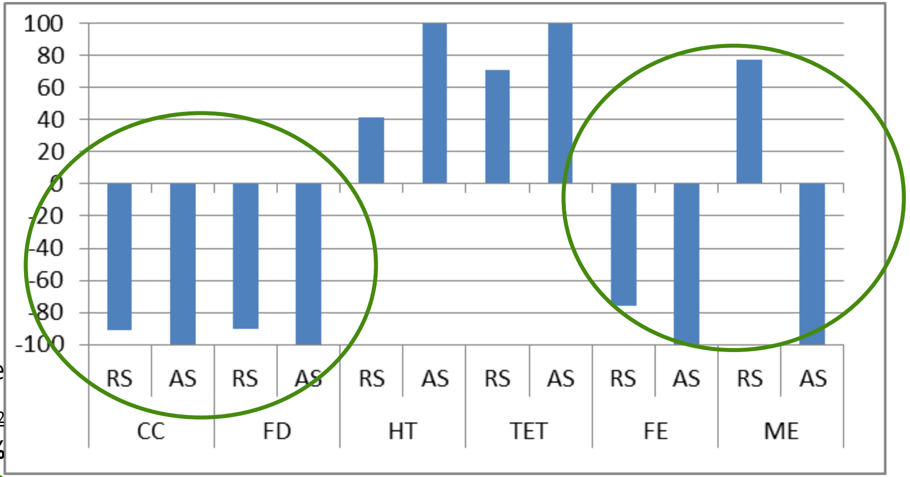
Biowaste Technology	Reference Scenario Energy production [MWh]	Alternative Scenario Energy production [MWh]
Incineration (WtE) - Net electricity	43304	29032
Incineration (WtE) - Net thermal ene	223505	149843
AD1 - Net electricity	-	19908
AD1 - Net thermal energy	-	15402
AD2 - Net electricity	53933	85822
AD2 - Net thermal energy	58817	93127
Energy production -system level		
Net Electricity production	97237	134762
Net thermal energy production	282322	258372
Avoided use of fossil electricity	-	**37525**
Supply of fossil thermal energy	-	**23950**



For the analyzed system a **net increase in green electricity production of 39%** is observed at the expense of a decrease in the net heat production of 9%.

LIFE CYCLE IMPACT ASSESSMENT - BENEFITS

Impact categories:
Climate Change, CC
Fossil Depletion, FD
Human Toxicity, HT
Terrestrial Ecotoxicity, TET
Freshwater eutrophication, FE
Marine eutrophication, ME



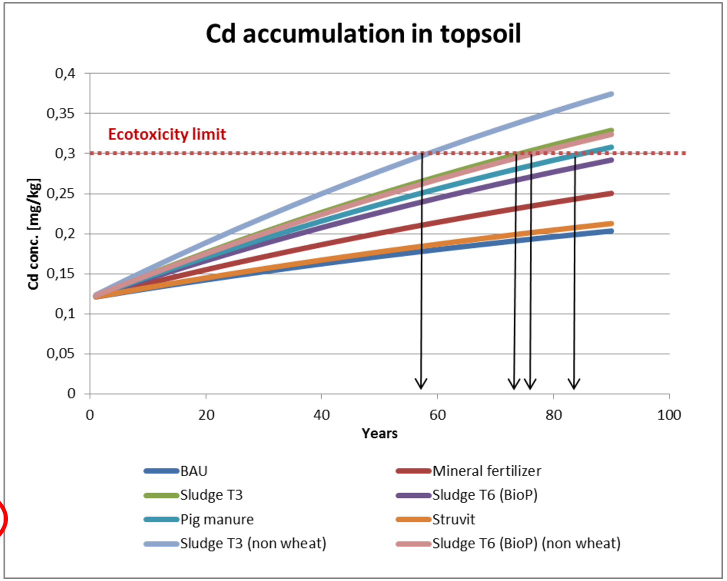
For the analyzed system a net increase in green electricity production of 39% is observed at the expense of a decrease in the net heat production of 9%. The Life Cycle Assessment reveals a net CO_2 emission reduction of 29.6 kg CO_2 eq. per ton of dry weight biowaste treated **corresponding to a 9% reduction in CO_2 emission. The latter accompanied by a net reduction in depletion of fossil resources of 11% and a reduction in the impact on Freshwater and Marine Eutrophication of 31% and 229%** respectively. The model estimates a decrease in the environmental performance regarding the impact categories human toxicity and terrestrial ecotoxicity which increases 142% and 40% respectively.

Source: Thomsen, M., Seghetta, M., Mikkelsen, M.H., Gyldenkærne, S., Becker, T. and Frederiksen, P., 2015. Comparative Life Cycle Assessment of existing and future biowaste management systems - A Danish Case study, Journal of Cleaner Production, *to be submitted*

LIFE CYCLE IMPACT ASSESSMENT - TRADE OFFS

Impact categories:
Climate Change, CC
Fossil Depletion, FD
Human Toxicity, HT
Terrestrial Ecotoxicity, TET
Freshwater eutrophication, FE
Marine eutrophication, ME

For the analyzed system a net increase in green electricity production of 39% is observed at the expense of a decrease in the net heat production of 9%. The Life Cycle Assessment reveals a net CO_2 emission reduction of 29.6 kg CO_2 eq. per ton of dry weight biowaste treated corresponding to a 9% reduction in CO_2 emission. The latter accompanied by a net reduction in depletion of fossil resources of 11% and a reduction in the impact on Freshwater and Marine Eutrophication of 31% and 22% respectively. **The model estimates a decrease in the environmental performance regarding the impact categories human toxicity and terrestrial ecotoxicity which increases 142% and 40% respectively.**



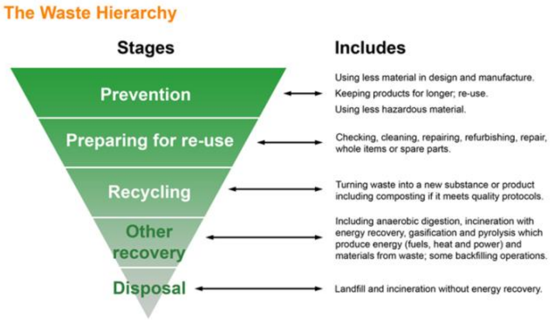
Human health Damage Costs analysed in depht in Pizzol, M., Smart, J.C.R., Thomsen, M., 2014. External costs of cadmium emissions to soil: a drawback of phosphorus fertilizers. Journal of Cleaner Production 84, 475–483. *Presented in the European Commission News Letter Science for Environmental Policy* http://ec.europa.eu/environment/integration/research/newsalert/pdf/371na2_en.pdf

HOW TO DEAL WITH THE CHALLENGES OF MOVING UP THE WASTE HIERACHY?

Benefits and trade offs ?

Where are the critical flows?

Solutions?



Ecological Network Analysis:

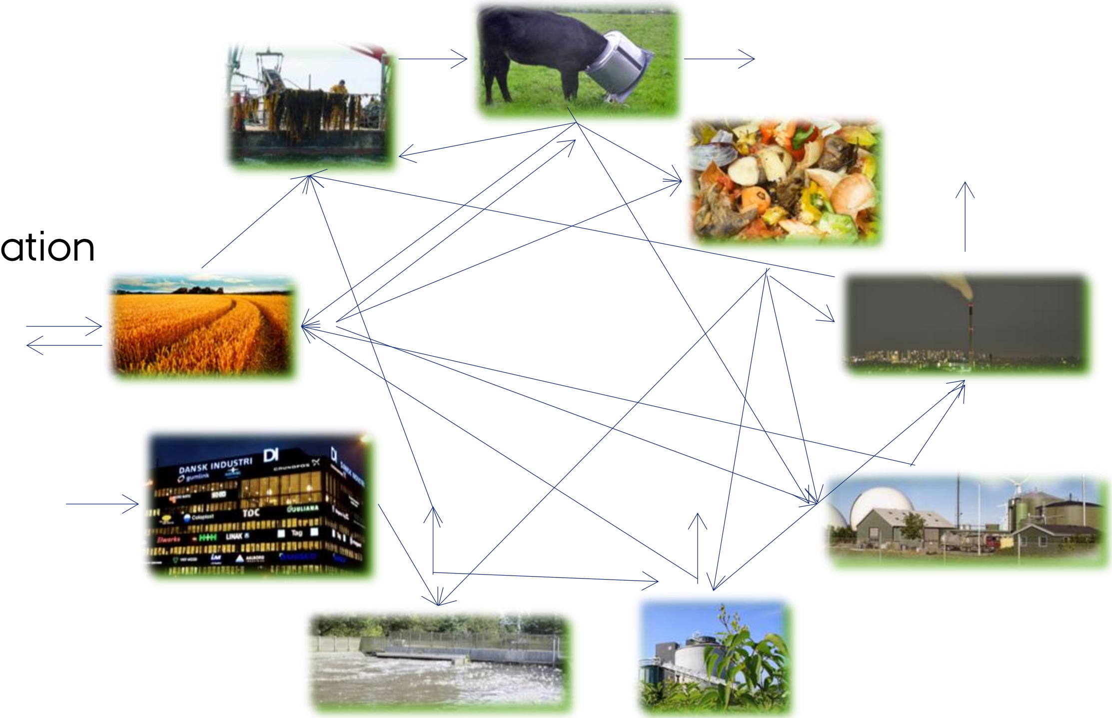
- ENA allows quantifying the sustainability (using natural systems as a reference - strong sustainability)
- Multi-layer networks (C, N, P, Cd) - ENA for assessing the sustainability of Bioresource Management Systems (Zealand Region)

NETWORK ANALYSIS

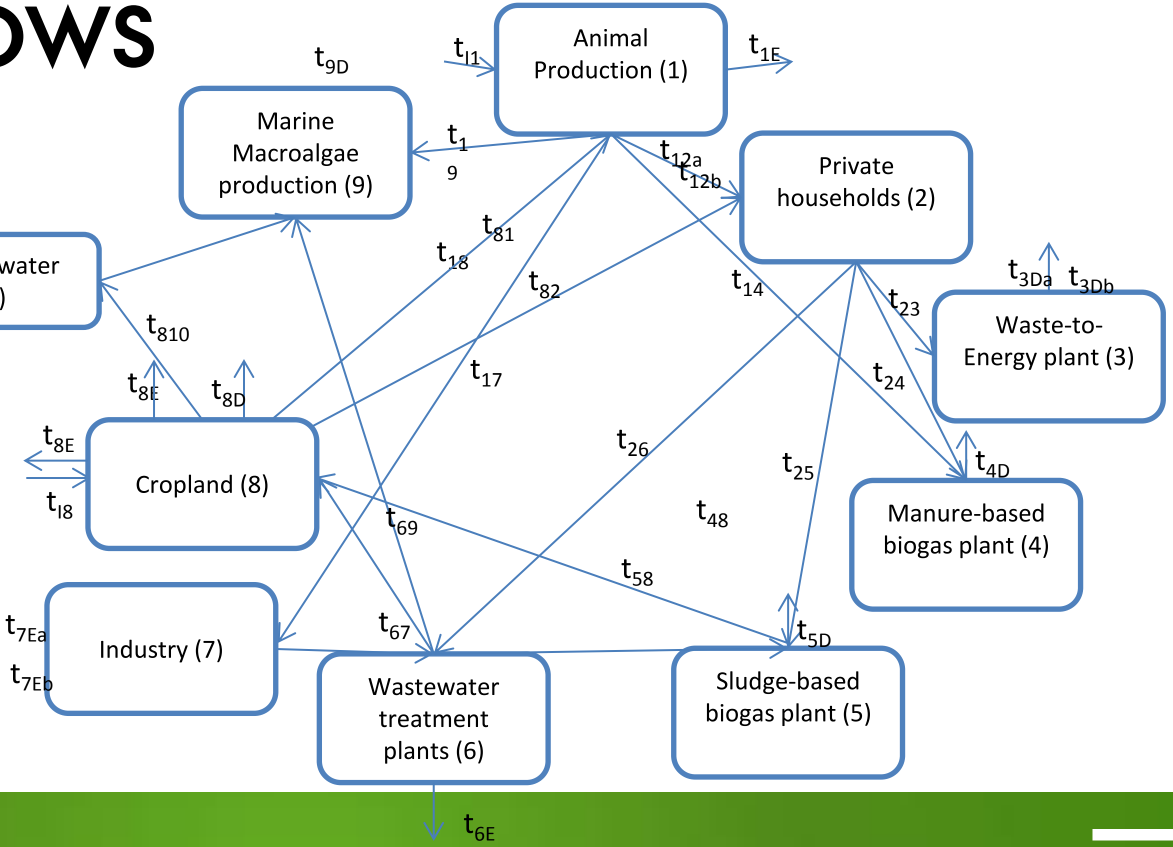
Including natural capital

C, N, P and Cd

Circularity = self-supply = self-preservation
Local clean and circular currents



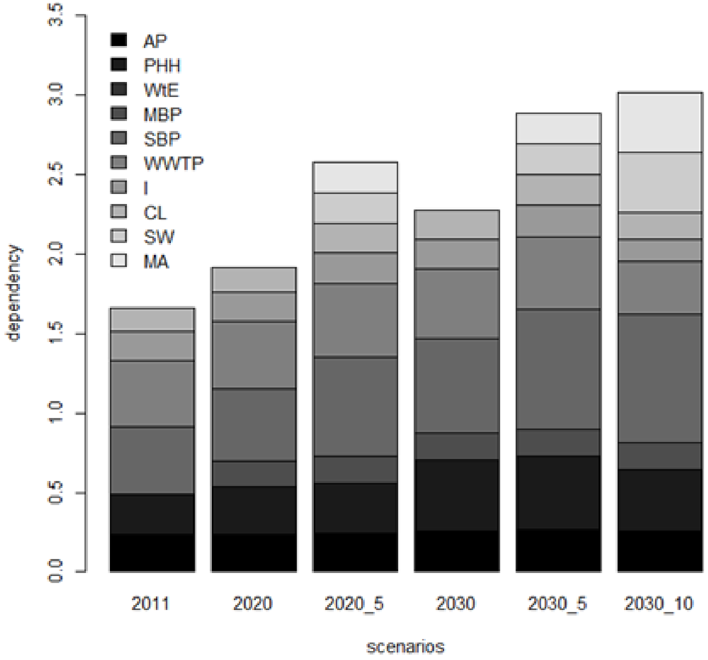
NODES AND FLOWS



CROPLAND
- PHOSPHOROUS DEPENDENCY MATRIX

The more compartment we include in the network, the more recycling of phosphorous we achieve

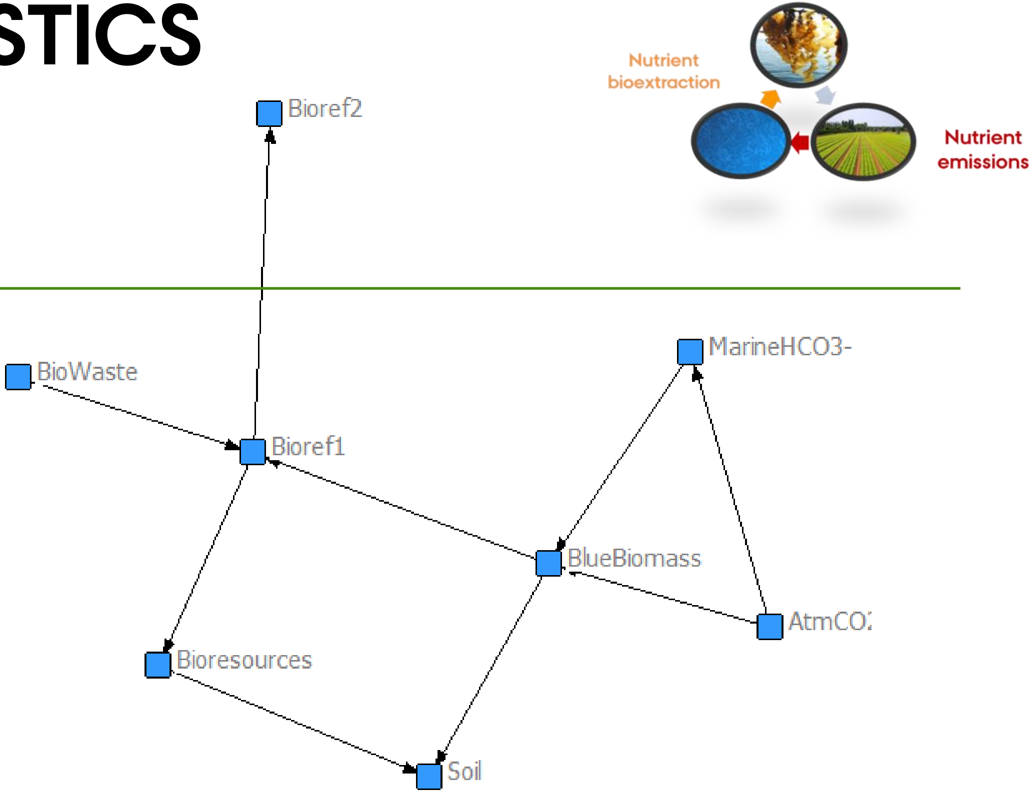
- the higher the column
- the maximum width of each compartment is one



SCALES AND LOGISTICS

Regioal/Global scale

Local community driven



Circular biogenic **carbon flow**
-an instrument for climate change mitigation

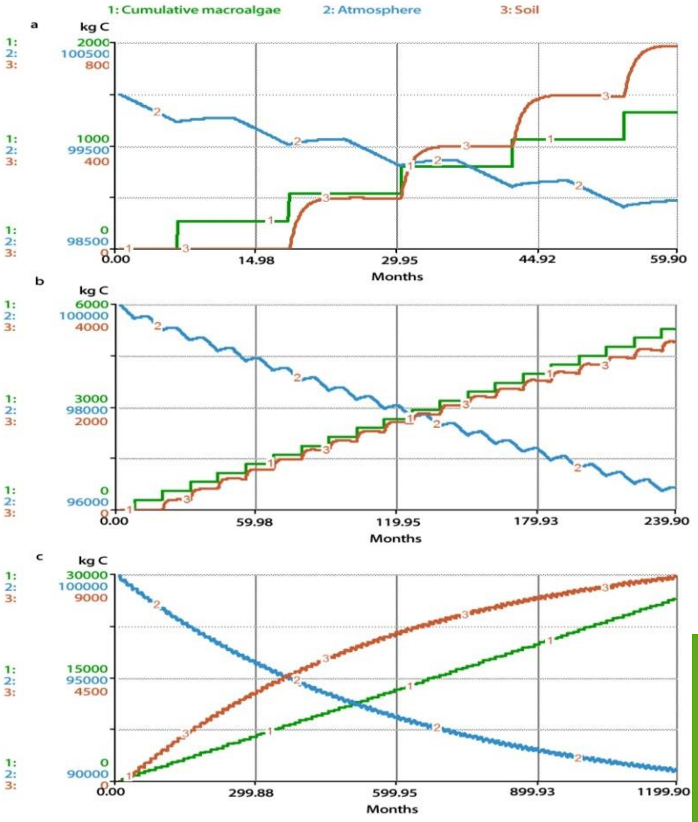
1 ha cultivated **every year** evaluated in 100 yr

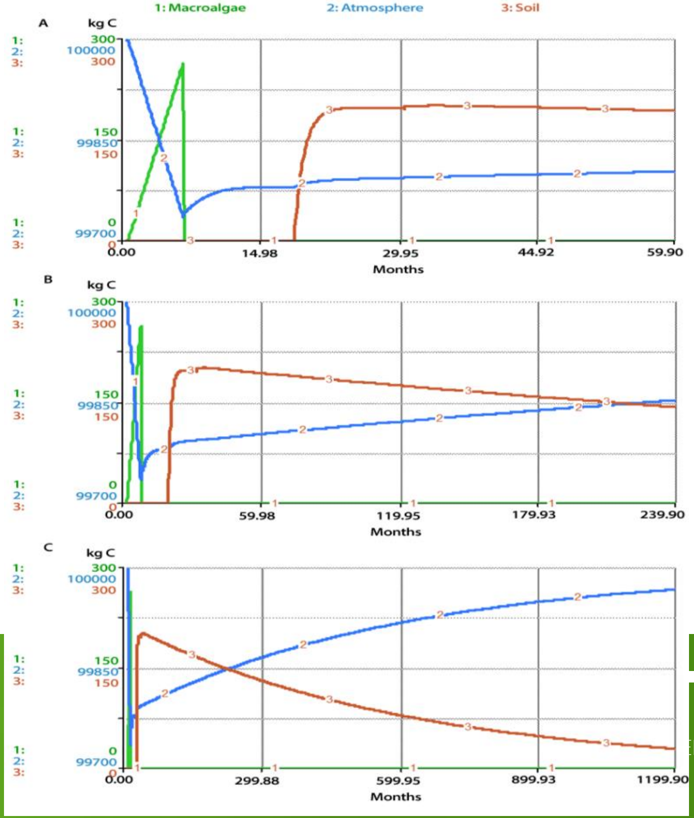
1 ha cultivated **1 year** evaluated in 100 yr

5 yr

20 yr

100 yr





TRANSFORMATION OF CO_2 INTO C IN SOIL

Fig. 1 - Reduction of 30 kg of C from atmosphere over 100 year is achieved, when only 1 macroalgae production cycle (1 Mg dw) is considered.

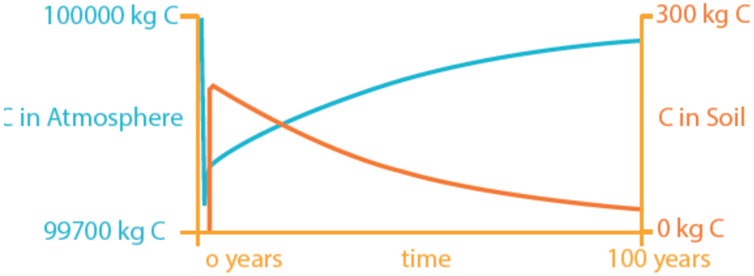
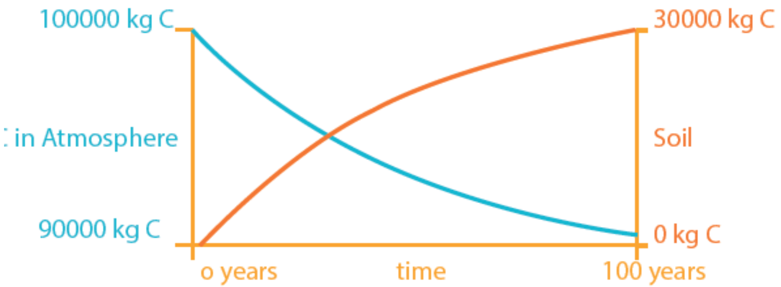


Fig. 2 - Reduction of 9200 kg of C from atmosphere over 100 year is achieved, when a continuous macroalgae production is performed (100 Mg dw).



CONCLUSIONS

- Circular bioresource management systems are able to contribute to
  - Increased self-supply/recycling and decreased loss of resources
  - mitigation of climate change mitigation and marine and freshwater eutrophication
- Including offshore macroalgae production and biorefinery improves the system level contribution mitigation of eutrophication and climate change
  - By re-assimilation of air emissions and land-based effluents
- When considering the whole system from cradle to cradle it is possible to quantify an accumulating carbon in agricultural soil
- Upcycling (innovative green/clean) technologies are needed to avoid trade-off from carry over effects from recycling of contaminants

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