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

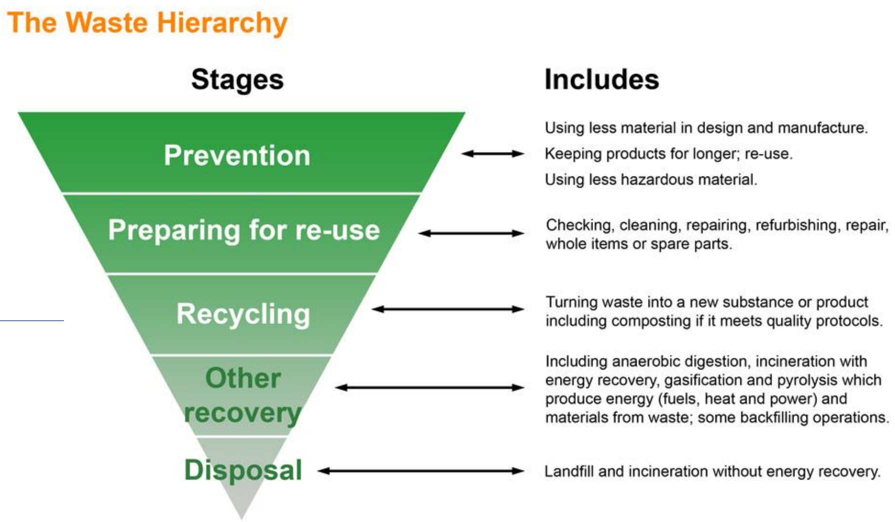
Goals of the Green Growth Plan

- 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

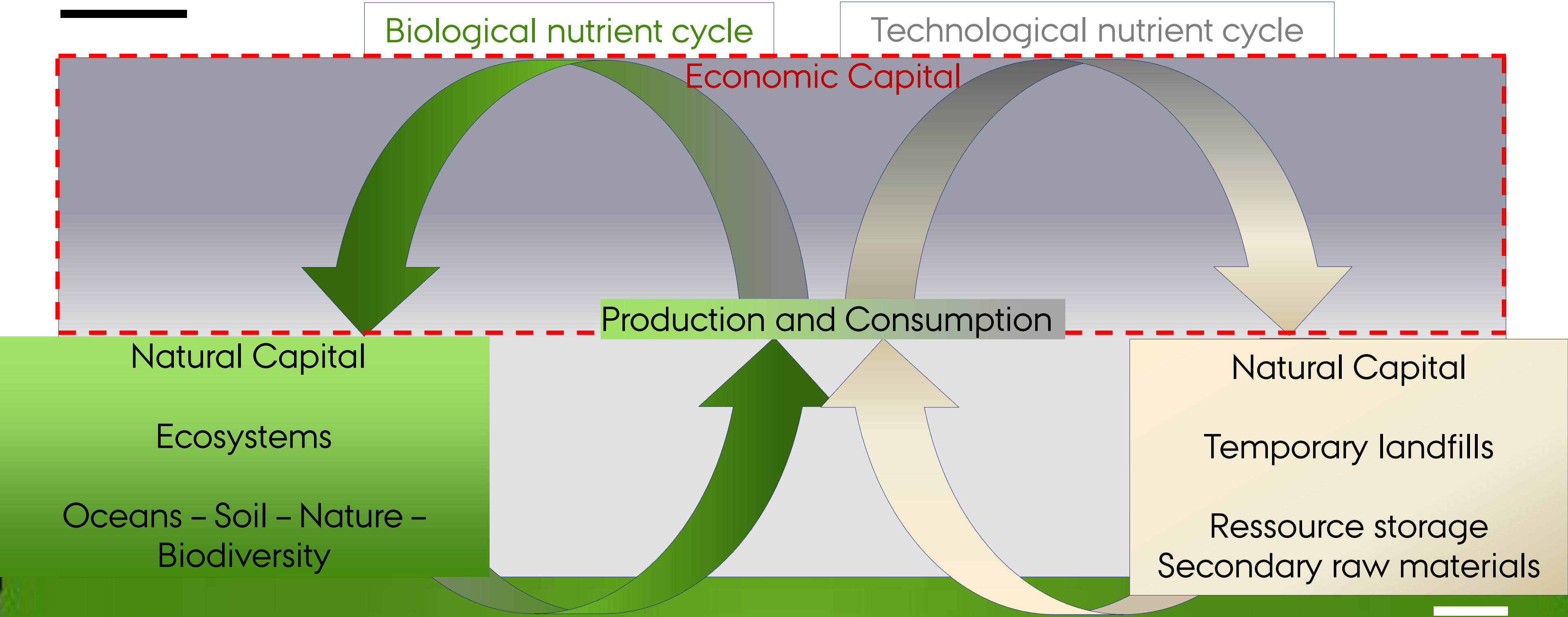
-MOVING UP IN THE WASTE HIERARCHY

Turning waste into a resource

Extraction and recycling



INDUSTRIAL ECOLOGY & CIRCULAR ECONOMY



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

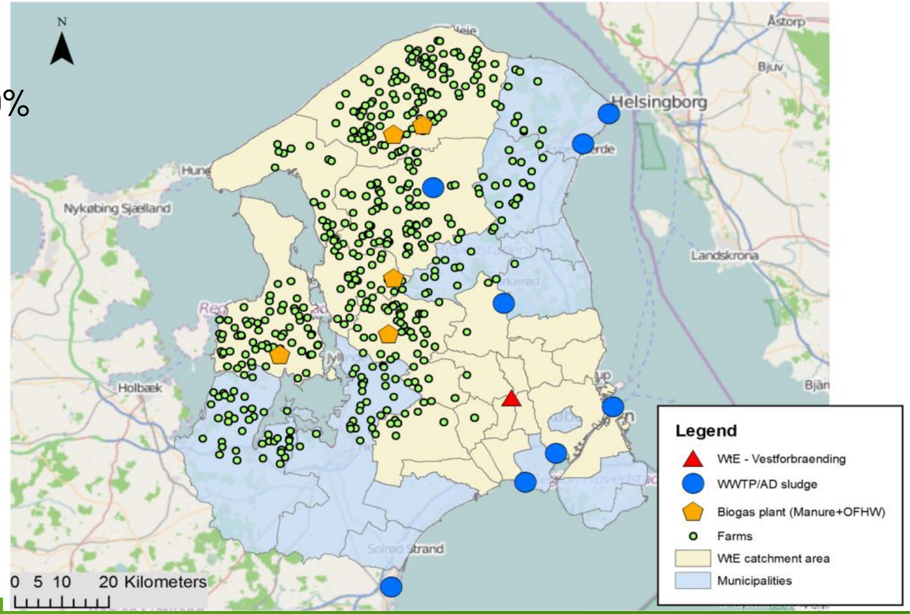
Increase the amount of manure biogasified from 5 to 50%

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

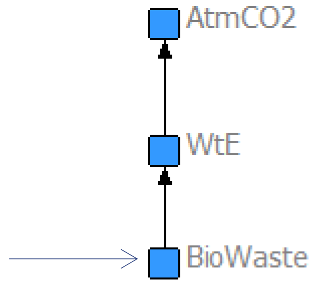
1. Environmental restoration may be obtained by **ecoindustrial ressource flows**; i.e. Human-Environment system exchange of naturally occurring compounds , materials and energy flows mimicking the natural biogeochemical cycles, dimensions and scales

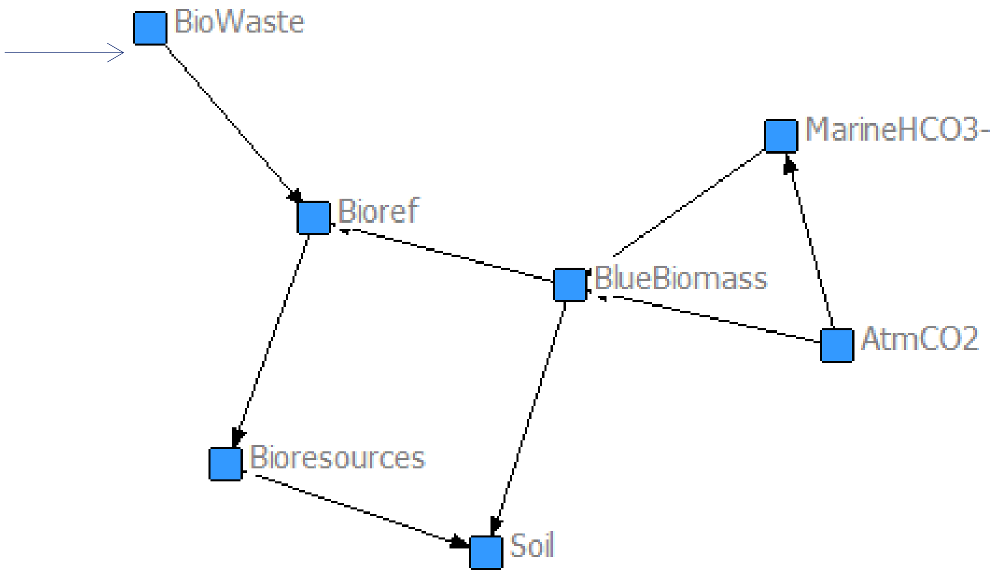
2. Antropogenic compounds should be recycled inside the technophere and reabsorbed in equals rates to their dispersion; exchanged at levels below any observable adverse impact.

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,

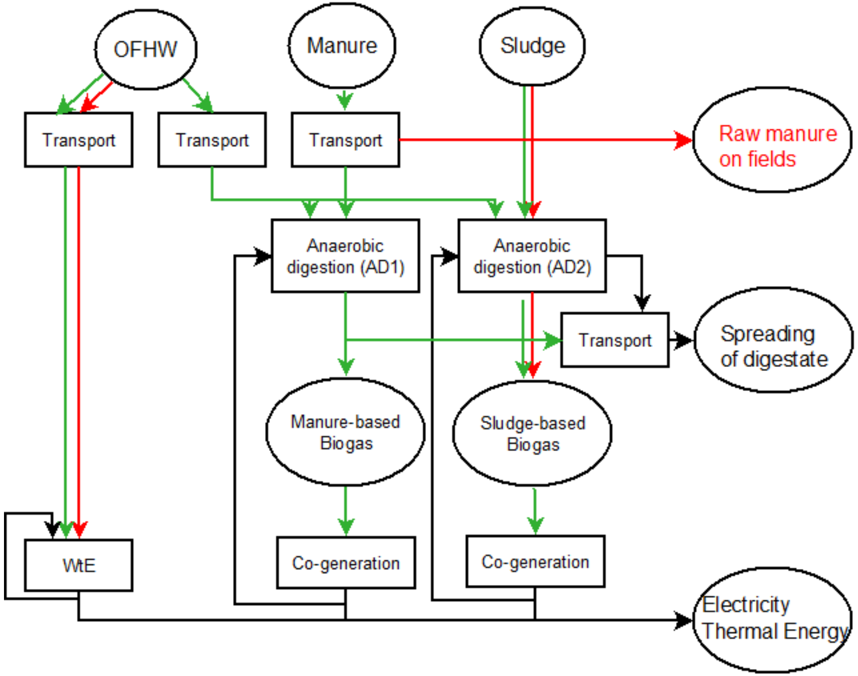
terrestrial ecotoxicity,

human toxicity,

freshwater and marine eutrophication

BIOWASTE STOCKS AND PATHWAYS

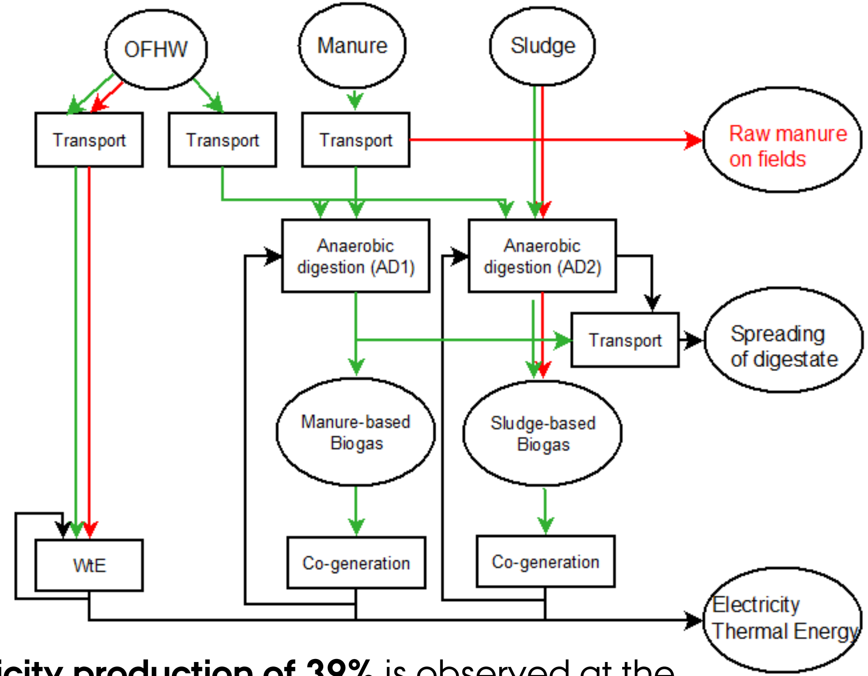
Biowaste Technology	Reference Scenario Resource stocks [Mg dw]	Alternative Scenario Resource stocks [Mg dw]
Incineration (WtE) - OFHW	69.970	46.910
Direct spread - Manure	20.573	-
Anaerobic Digestion (AD1) - Manure	-	20.573
Codigestion (AD1) - OFHW	-	5.144
Anaerobic Digestion (AD2) - Sludge	57.629	57.629
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

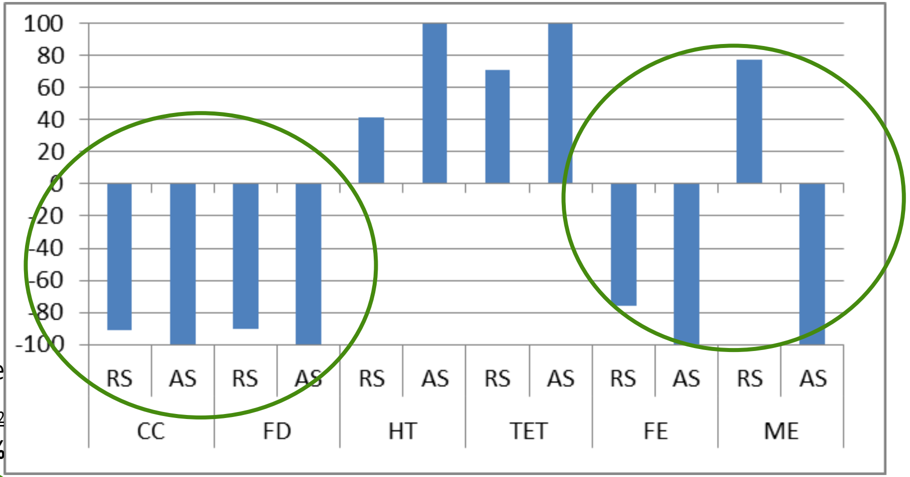
Biowaste Technology	Reference Scenario Energy production [MWh]	Alternative Scenario Energy production [MWh]
Incineration (WtE) - Net electricity	43304	29032
Incineration (WtE) - Net thermal ene	223505	149843
AD1 - Net electricity	-	19908
AD1 - Net thermal energy	-	15402
AD2 - Net electricity	53933	85822
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



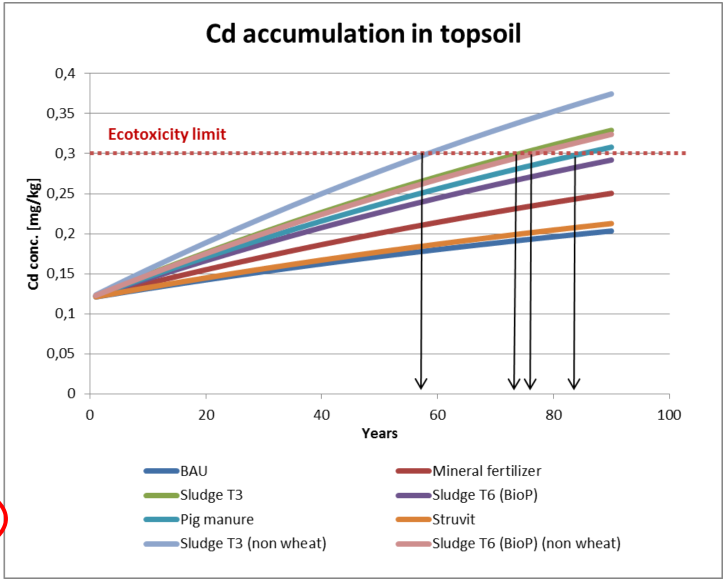
For the analyzed system a net increase in green electricity production of 39% is observed at the expense of a decrease in the net heat production of 9%. The Life Cycle Assessment reveals a net CO_2 emission reduction of 29.6 kg CO_2 eq. per ton of dry weight biowaste treated **corresponding to a 9% reduction 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 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.**



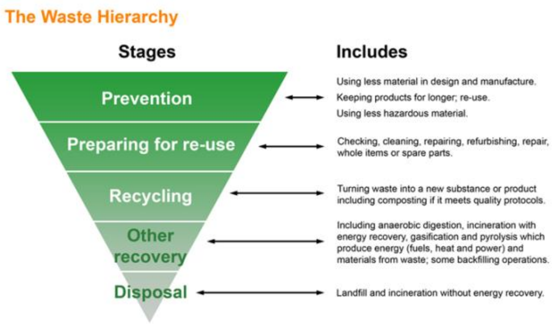
Human health Damage Costs analysed in depht in Pizzol, M., Smart, J.C.R., Thomsen, M., 2014. External costs of cadmium emissions to soil: a drawback of phosphorus fertilizers. Journal of Cleaner Production 84, 475–483. *Presented in the European Commission News Letter Science for Environmental Policy* 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:

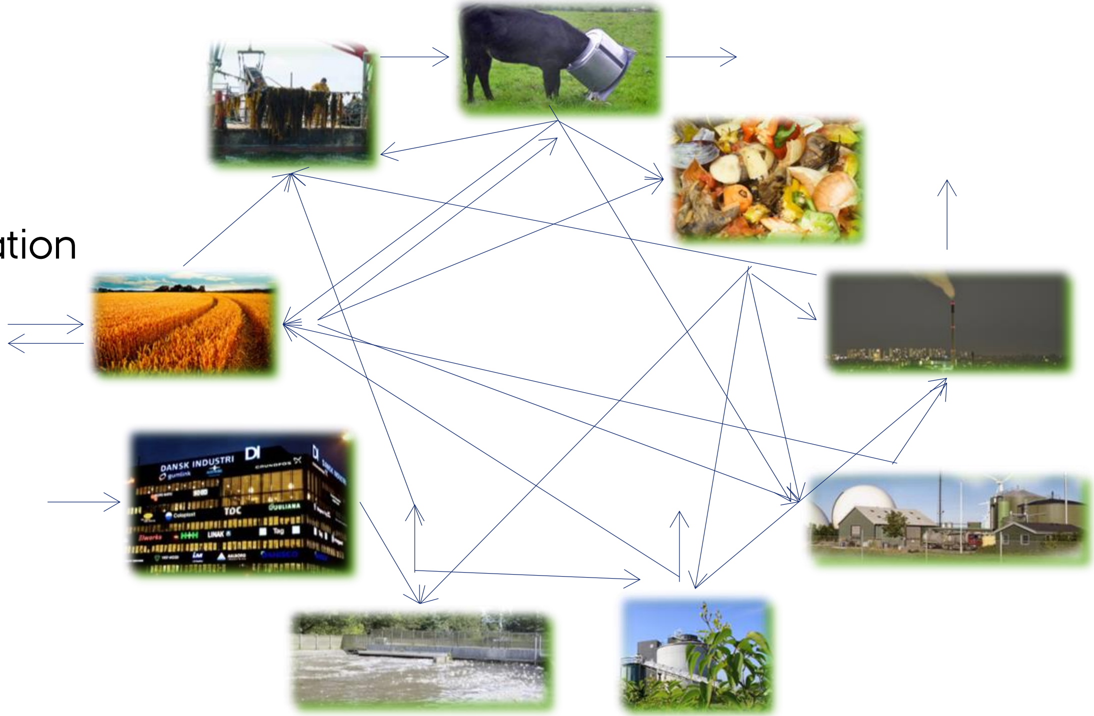
- ENA allows quantifying the sustainability (using natural systems as a reference - strong sustainability)
- Multi-layer networks (C, N, P, Cd) - ENA for assessing the sustainability of Bioresource Management Systems (Zealand Region)

NETWORK ANALYSIS

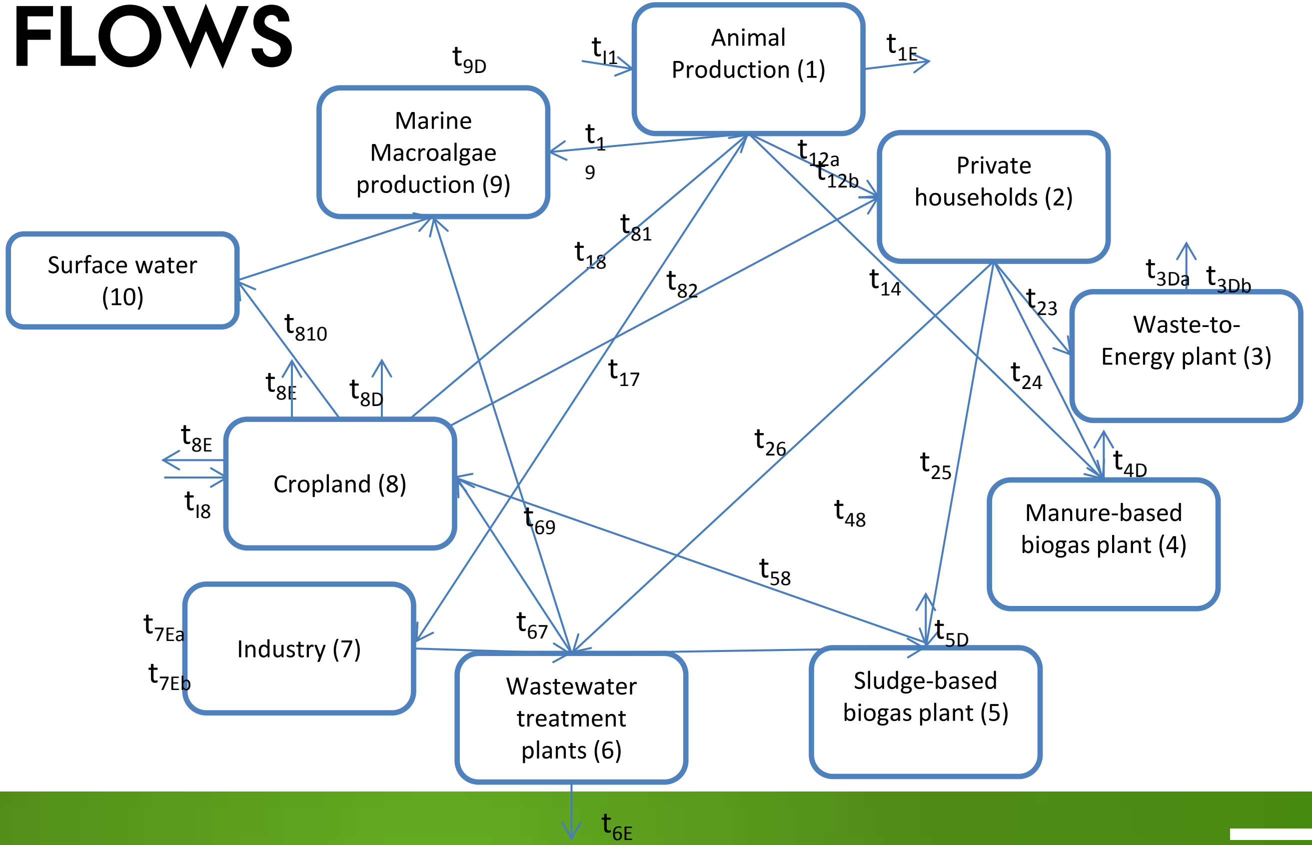
Including natural capital

C, N, P and Cd

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



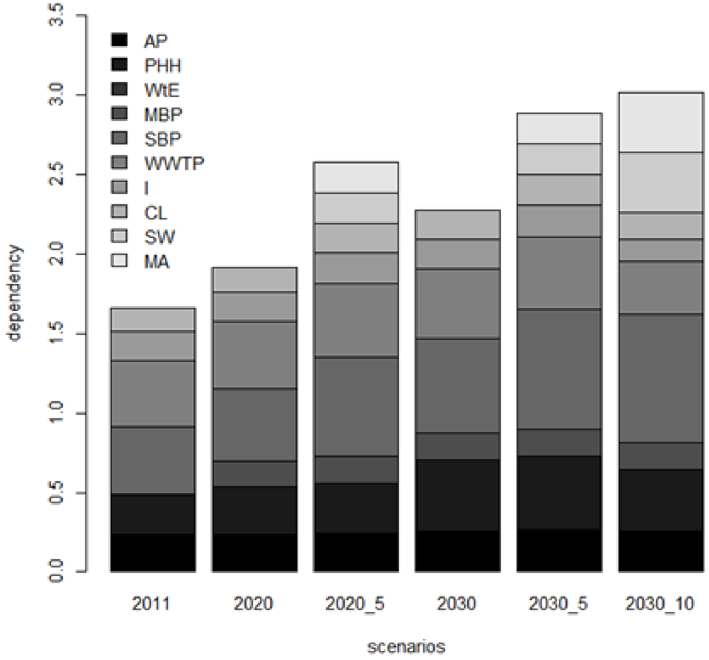
NODES AND FLOWS



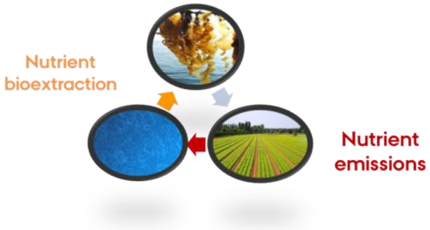
CROPLAND
- PHOSPHOROUS DEPENDENCY MATRIX

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

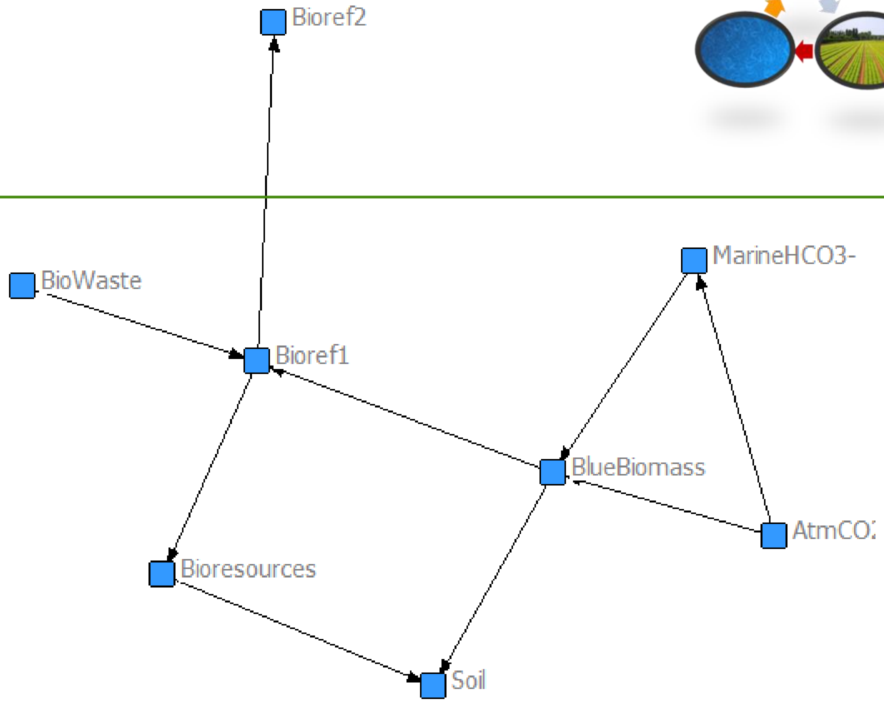


SCALES AND LOGISTICS



Regioal/Global scale

Local community driven



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

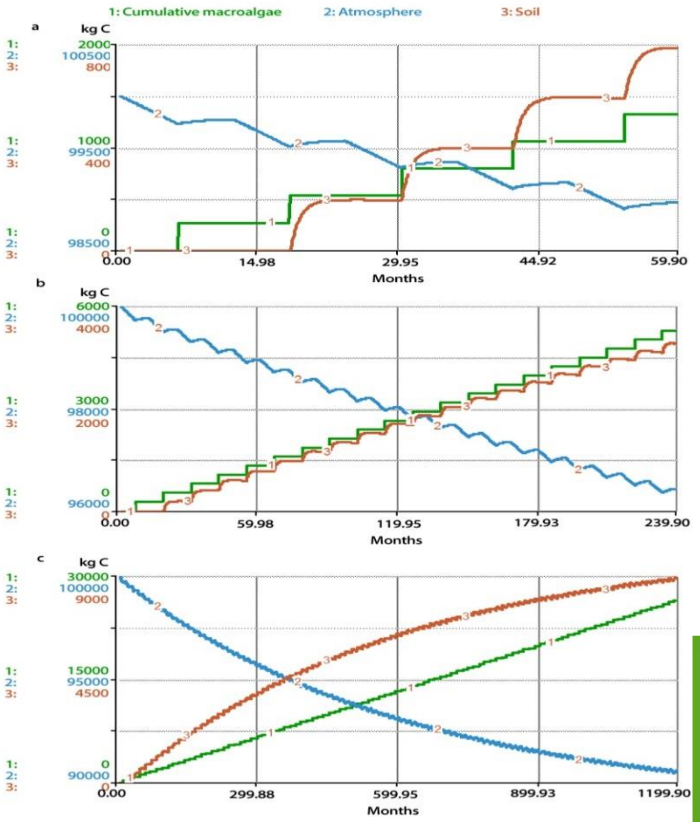
1 ha cultivated **every year** evaluated in 100 yr

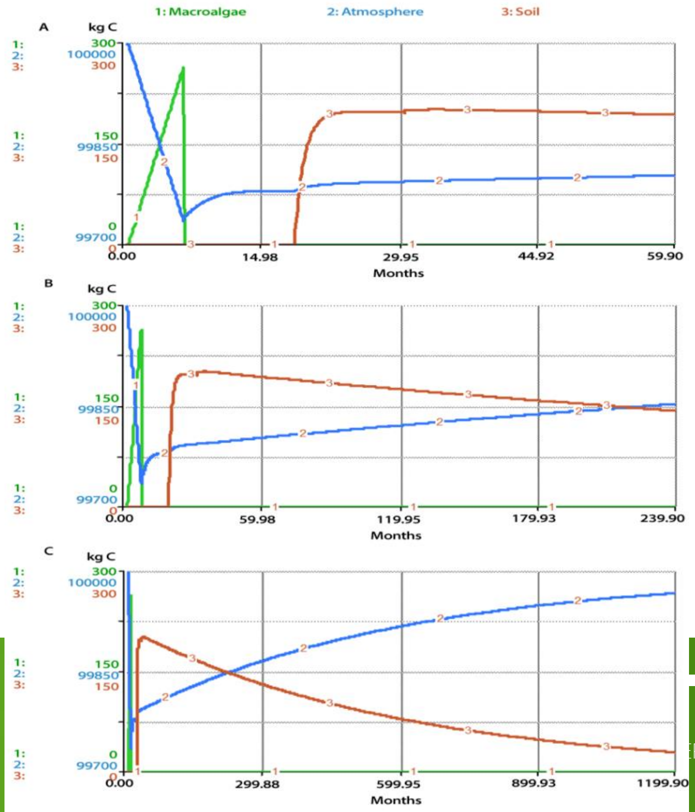
1 ha cultivated **1 year** evaluated in 100 yr

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.

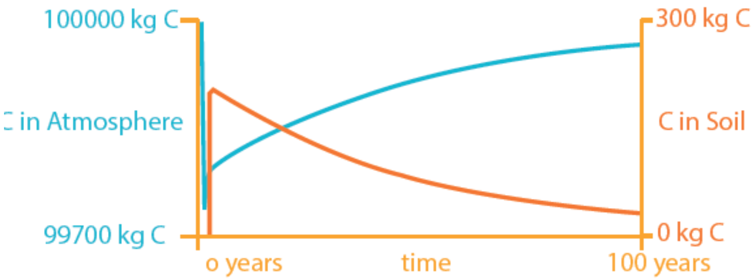
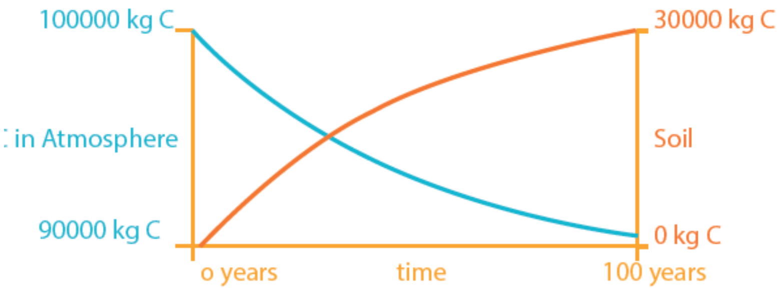


Fig. 2 - Reduction of 9200 kg of C from atmosphere over 100 year is achieved, when a continuous macroalgae production is performed (100 Mg dw).



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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