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

The Waste Hierarchy

- 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.

Turning waste into a resource
Extraction and recycling
INDUSTRIAL ECOLOGY & CIRCULAR ECONOMY

Biological nutrient cycle

Production and Consumption

Technological nutrient cycle

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 plants

Remaining at sludge-based biogas plants

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

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

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

3. Only healthy ecosystems sustain 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
The alternative scenario shows a decrease in loss of phosphorous, which substitutes mineral fertilizer.
## ENERGY PRODUCTION AND BIOWASTE PATHWAYS

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**Energy production - system level**

- Net Electricity production: 97237 [MWh] (Reference), 134762 [MWh] (Alternative)
- Net thermal energy production: 282322 [MWh] (Reference), 258372 [MWh] (Alternative)
- Avoided use of fossil electricity: -37525 [MWh]
- Supply of fossil thermal energy: -23950 [MWh]

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 CO₂ emission reduction of 29.6 kg CO₂ eq. per ton of dry weight biowaste treated corresponding to a 9% reduction in CO₂ 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.

LIFE CYCLE IMPACT ASSESSMENT - TRADE OFFS

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- Human Toxicity, HT
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- Freshwater eutrophication, FE
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Cd accumulation in topsoil

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<tr>
<th>Years</th>
<th>BAU</th>
<th>Sludge T3</th>
<th>Sludge T6 (BioP)</th>
<th>Pig manure</th>
<th>Struvite</th>
<th>Sludge T3 (non wheat)</th>
<th>Sludge T6 (BioP) (non wheat)</th>
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Ecotoxicity limit

- BAU
- Sludge T3
- Sludge T6 (BioP)
- Pig manure
- Struvite
- Sludge T3 (non wheat)
- Sludge T6 (BioP) (non wheat)
HOW TO DEAL WITH THE CHALLENGES OF MOVING UP THE WASTE HIERARCHY?

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
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

Regional/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