Systems Analysis of Industrial Symbiosis

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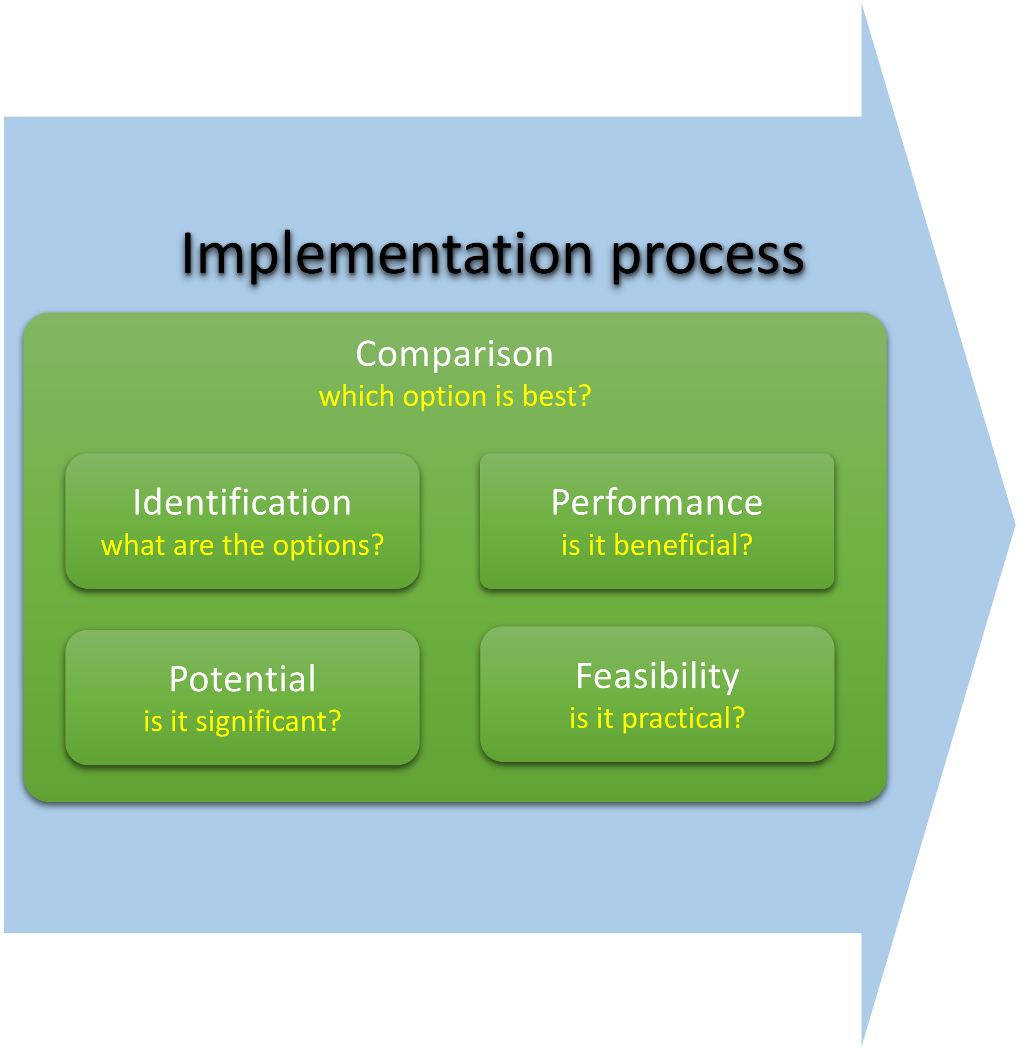
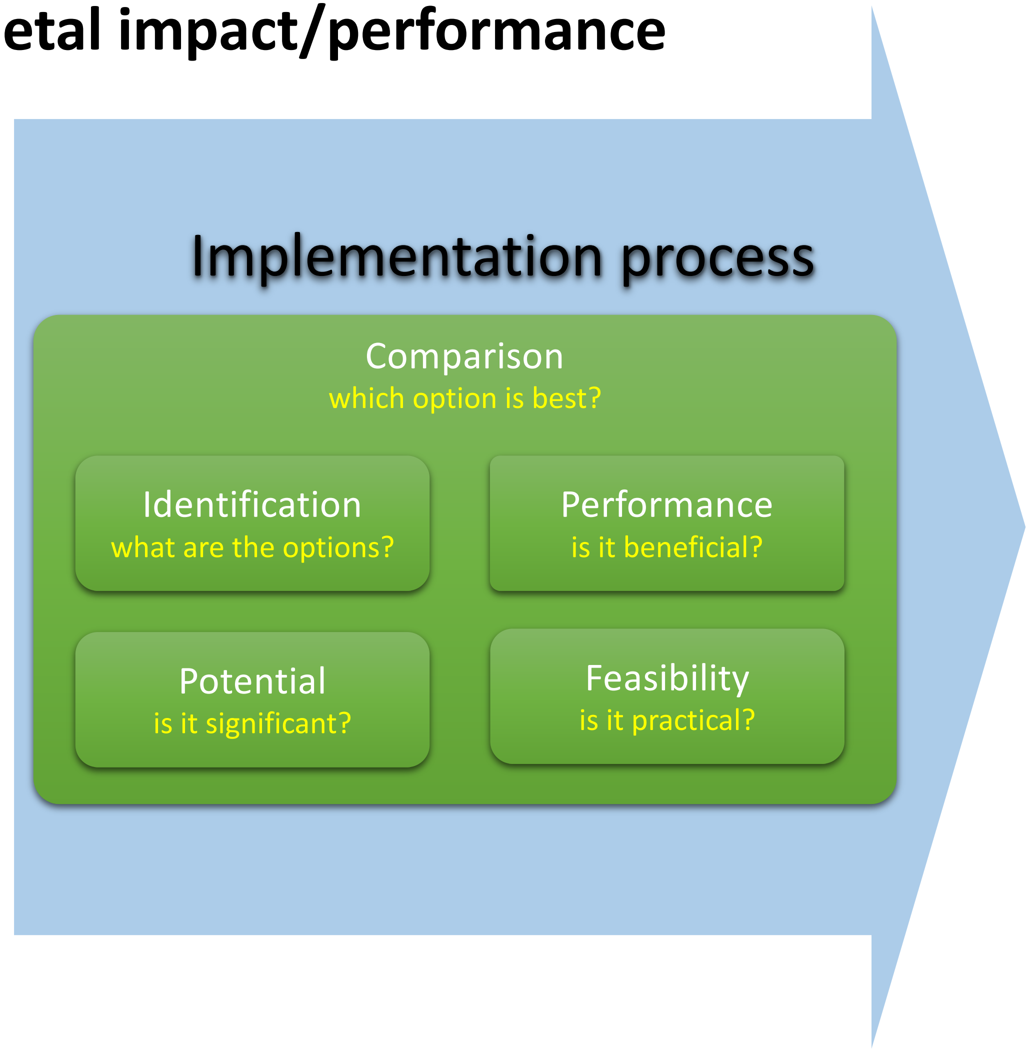
Background

- Our limited resources
  - How to identify high impact areas?
  - How to know which option is more feasible?
  - How to know which choice is better?
  - How to provide credible answer?
- Systems analysis:
  - Is part of implementation process
  - Helps us deliver the right & intended things
    - avoid local improvements at the cost of problem-shifting



Environmental, economic, or societal impact/performance

- Value for decision makers
  - How to compare development path A with B and C?
  - How to assess the impacts on individual actors vis-à-vis the overall IS network?
  - How to assess the business value and socio-economic value of IS?
- Simplified or in-depth assessment?
  - Gain knowledge about the system and development impacts → make better decisions
  - Create systematic and verifiable evidence → make credible public claims
- Feasibility is often relevant
  - Process (feasibility) is as important as the outcome (impact)



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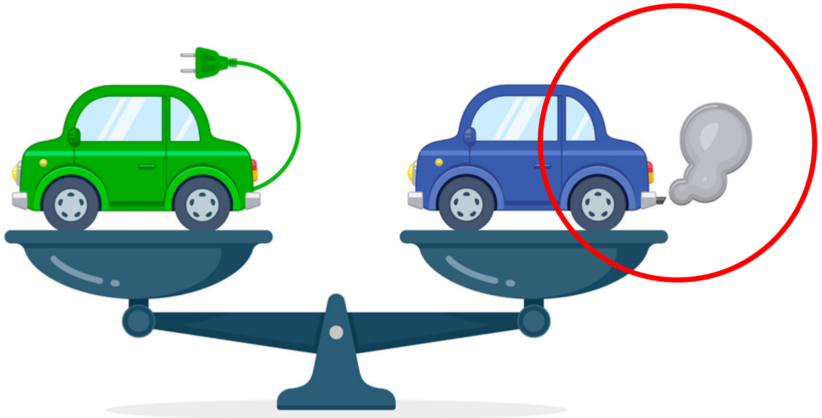
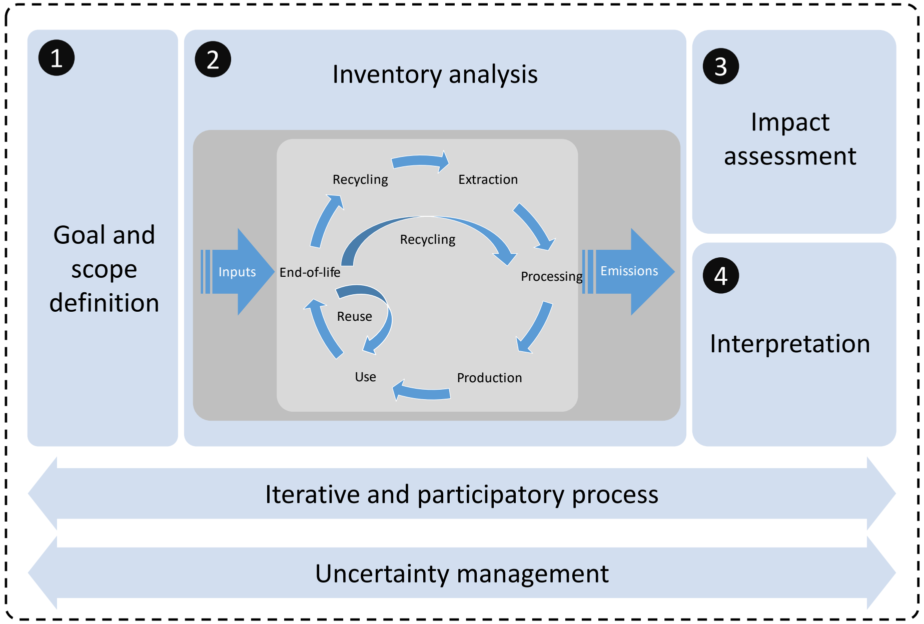
What is systems approach?



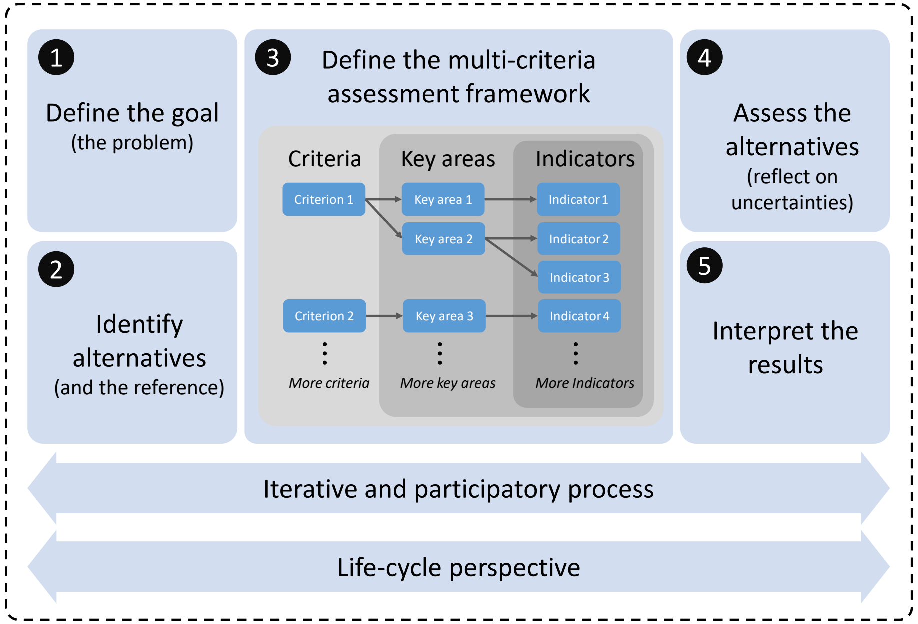
Two important approaches to systems analysis

Life-cycle assessment



Quantitative
Environmental impact
Standardized method
Data intensive

Multi-criteria analysis

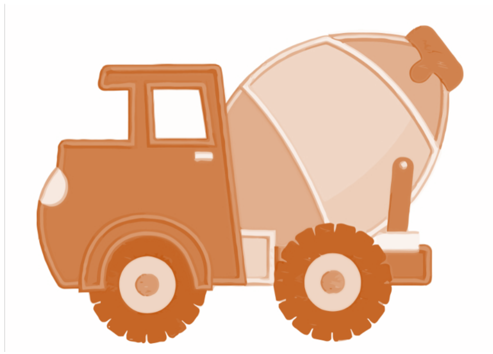


Quantitative and Qualitative
Potential, Impact, Feasibility, Risk, etc.
Can be flexibly designed
Less data intensive

BALTIC INDUSTRIAL SYMBIOSIS

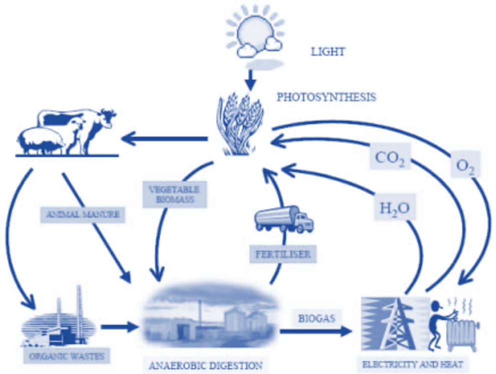
Three different examples

Example 1



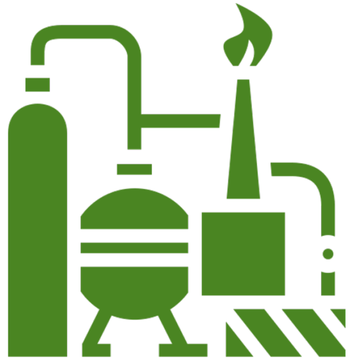
Industrial symbiosis and cement production

Example 2



Industrial symbiosis and enhanced nutrient recovery

Example 3



Industrial symbiosis and biorefinery development

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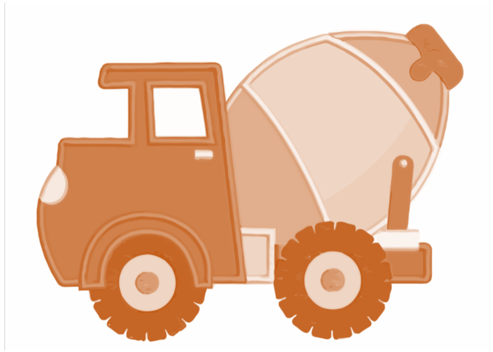
Three examples

Example 1



Industrial symbiosis and cement production

Example 2

Biogas solutions for enhanced nutrient recovery

Example 3

Industrial symbiosis and biorefinery development

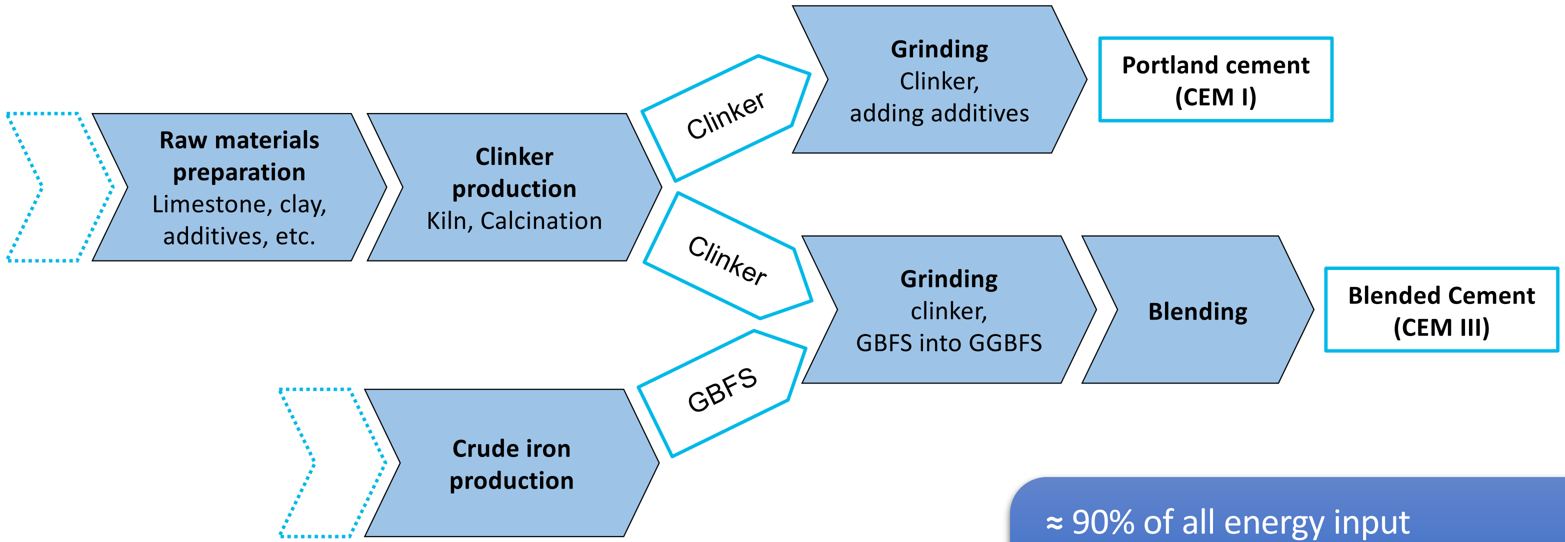
Example 1
IS and Cement

Industrial symbiosis and cement production

Ammenberg, J., Feiz, R., Helgstrand, A., Eklund, M., Baas, L., 2011. Industrial Symbiosis for Improving the CO2-Performance of Cement Production: Final report of the CEMEX-Linköping University Industrial Ecology Project, 2011. Linköping University Electronic Press.

Basics of cement production

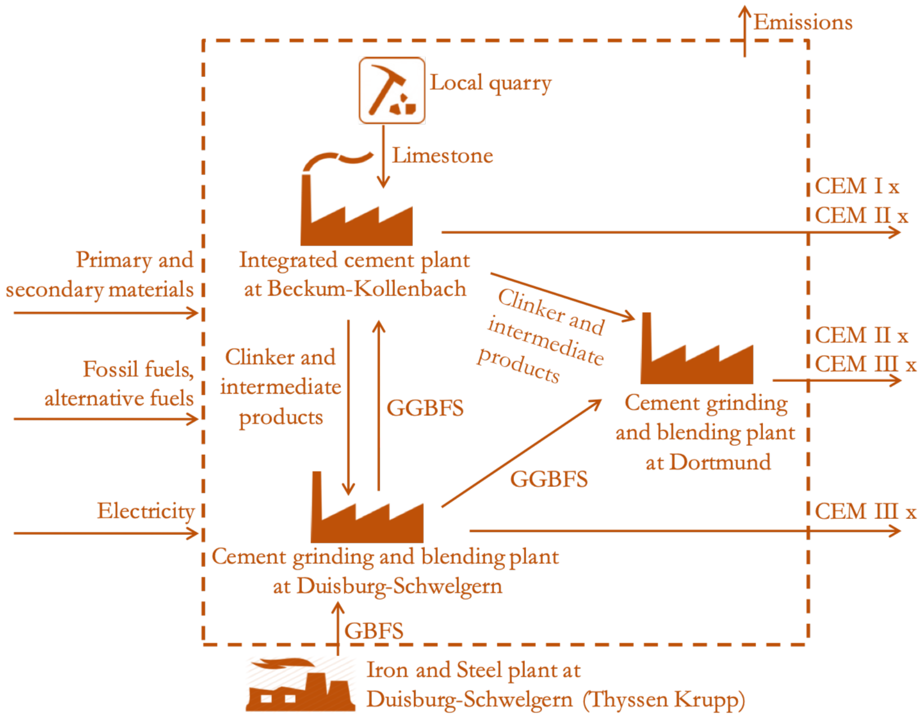
Example 1
IS and Cement



- ≈ 90% of all energy input
- ≈ 100% of the fuels
- ≈ 50% of CO_2 from calcination: $CaCO_3 \rightarrow CaO + CO_2$

CEMEX Cluster West in Germany

Example 1
IS and Cement



In what ways, and how much, industrial ecology and industrial symbiosis can improve the CO_2 performance of a cement production cluster, consist of three facilities?

- Identification
- Feasibility
- Potential
- Performance
- Comparison

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Improvement options: potential and feasibility

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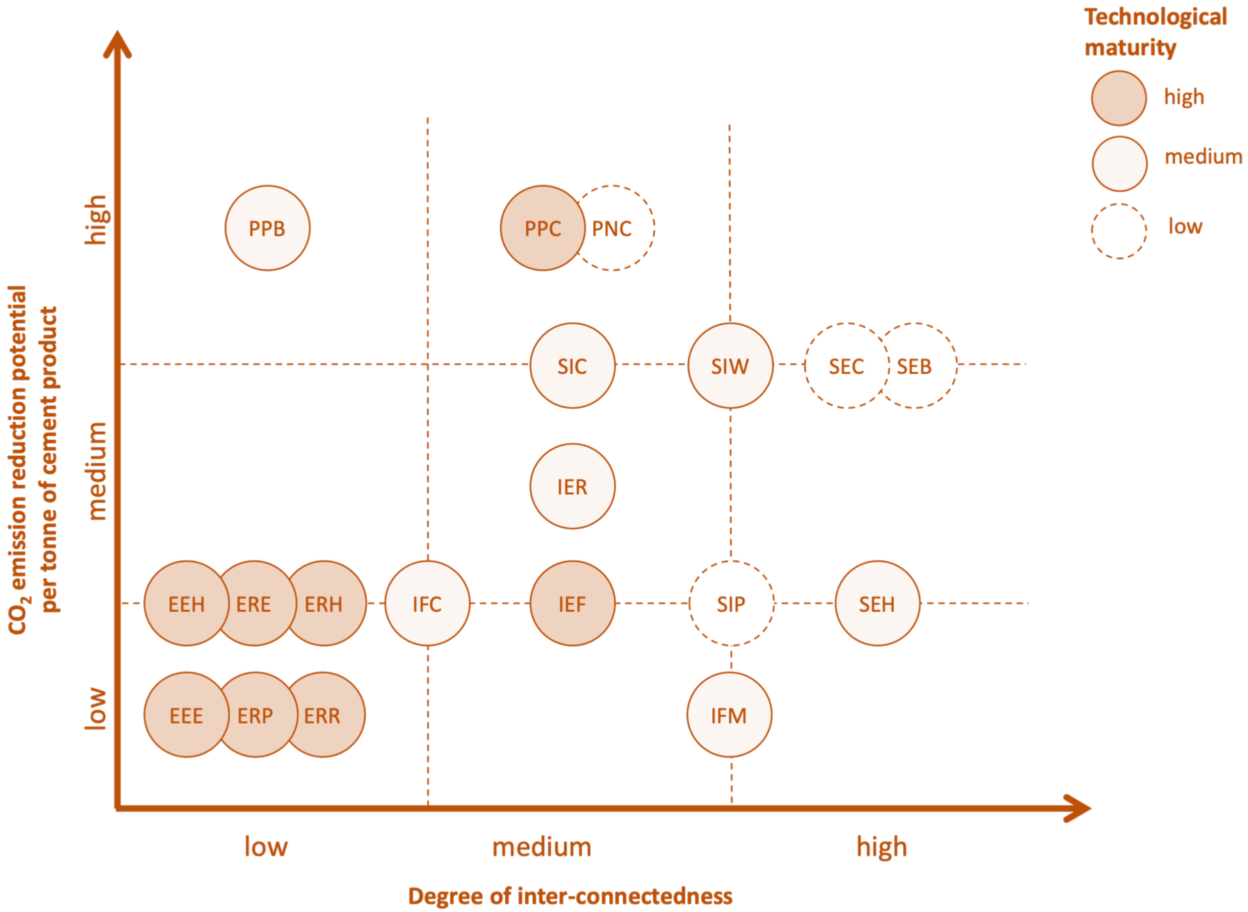
IS and Cement



- Identification
- Potential
- Feasibility
- Comparison

Feiz, R., Ammenberg, J., Baas, L., Eklund, M., Helgstrand, A., Marshall, R., 2015. Improving the CO2 Performance of Cement, Part II: Framework for Assessing CO2 Improvement Measures in Cement Industry. Journal of Cleaner Production.

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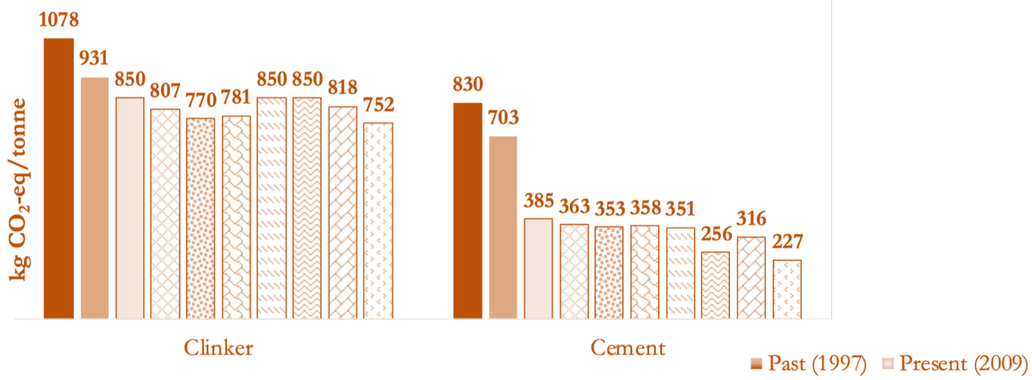
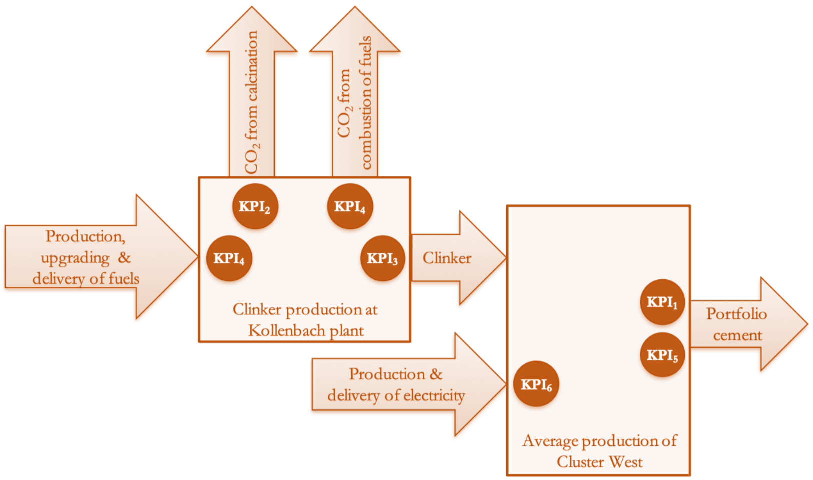
Environmental performance

Example 1
IS and Cement

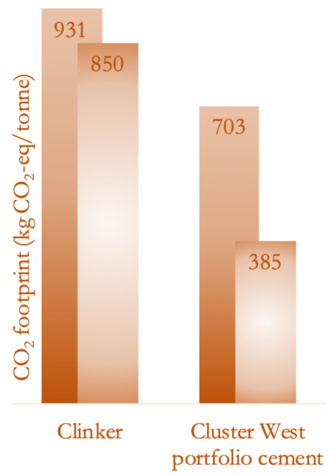
- Life-cycle assessment
  - Reference system and product
  - LCA of selected products
  - LCA of industrial symbiosis
  - Simplified LCA and Key performance indicators (KPIs)
- Comparison
  - different products (without and with IS)
  - past and present (without and with IS)





Performance

Comparison



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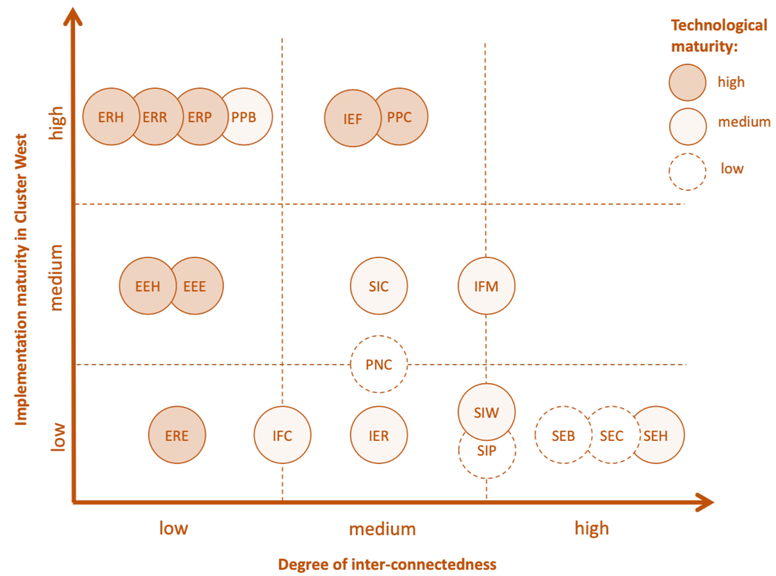
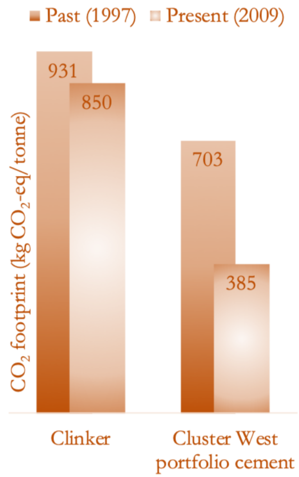
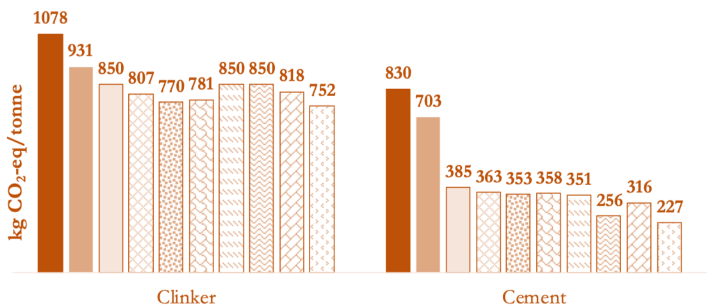
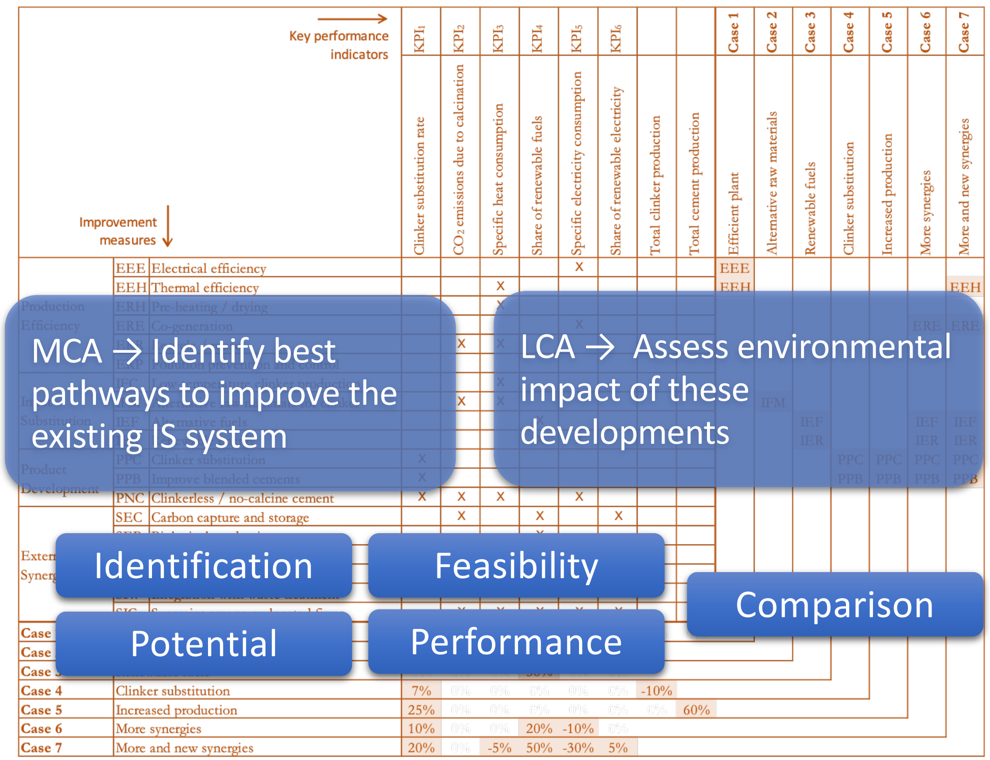
Integrated analysis (MCA + LCA)

Example 1
IS and Cement









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Value for decision-makers

- Industrial symbiosis is strategic for cement producers
  - CEMEX could use the scientifically backed results in many of their plants worldwide
- Simplified & in-depth analysis
  - Identifying possible improvement potential, assess their potential, feasibility, and environmental performance
  - Simplified LCA based on a few Key Performance Indicators (KPIs)
  - Mixed approach: Qualitative and quantitative analysis
- Data requirement
  - Extensive and detailed production data
  - Literature and LCA databases
- Other aspects could have been included
  - e.g. risks of becoming dependent on alternative fuels and raw materials (industrial symbiosis)
  - e.g. economic implications of IS

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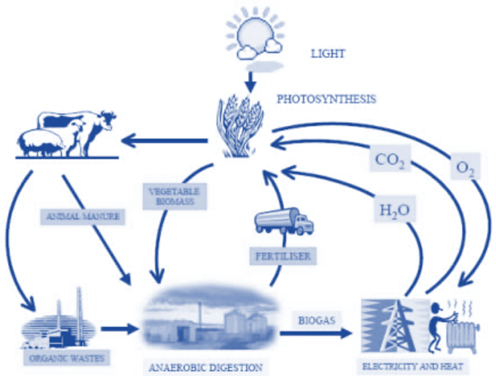
Three examples

Example 1

Industrial symbiosis and cement production

Example 2



Biogas solutions for enhanced nutrient recovery

Example 3

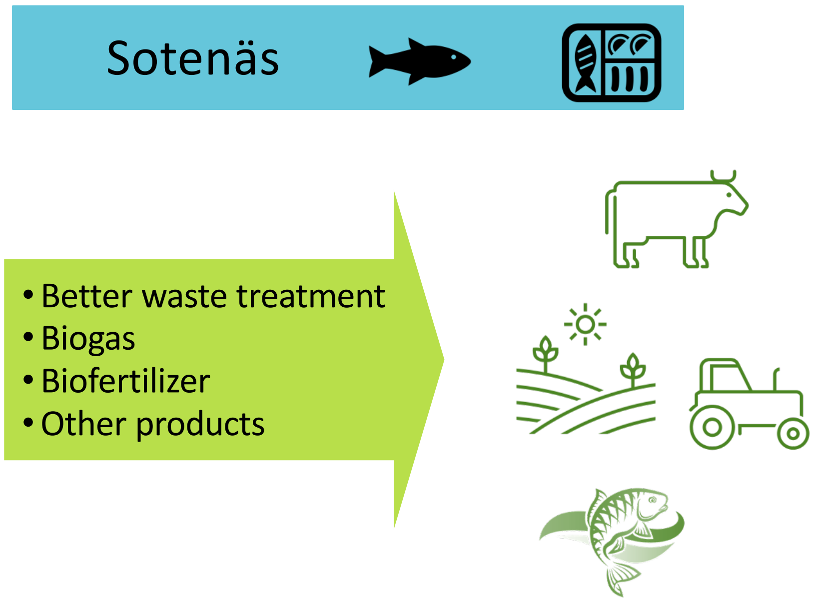
Industrial symbiosis and biorefinery development

Industrial symbiosis and enhanced nutrient recovery

Example 2
IS in Sotenäs

- Industrial symbiosis involving biogas production
- Impact on local nutrient recovery
- Other, non-nutrient related, benefits

- Several sea-food processing plants
- Wastewater treatment in these plants became problematic due to more stringent regulations
- Considered to add:
  - A local biogas plant
  - Land-based salmon production



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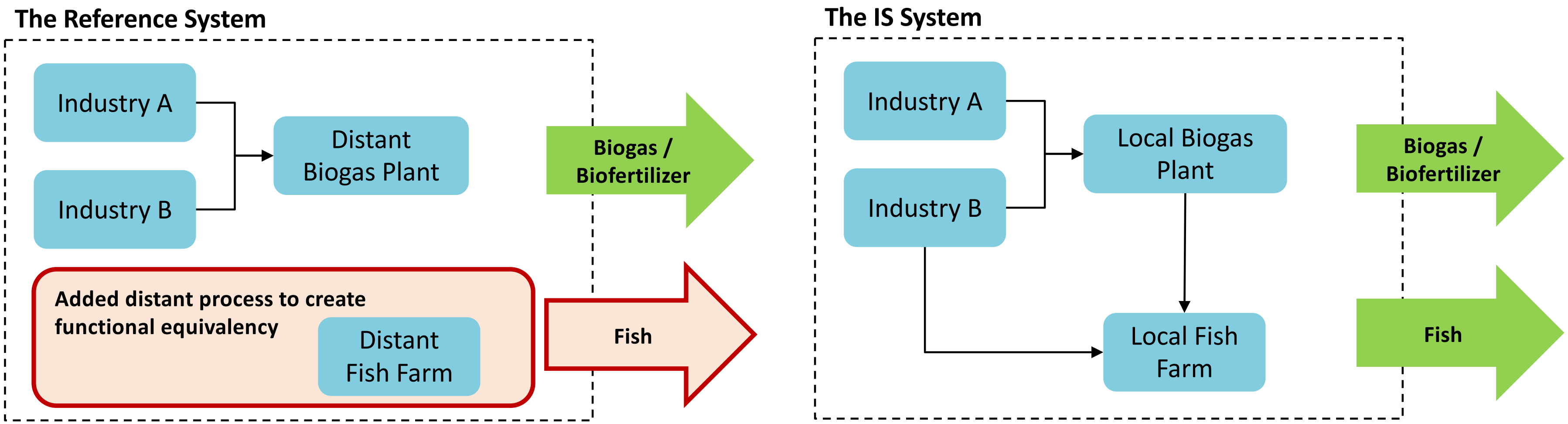
BALTIC INDUSTRIAL SYMBIOSIS

Method

Example 2
IS in Sotenäs

- Defining “reference” (before IS) and “scenario” (after IS) systems
- Nutrient flows (mass balance of N and P)
- Estimate recovery potential
- Estimate some of the other benefits, such as less transportation of organic wastes and recovered nutrients



In each case, both the ”reference”(before IS) and ”scenario” (after IS) should have the same function for comparability.

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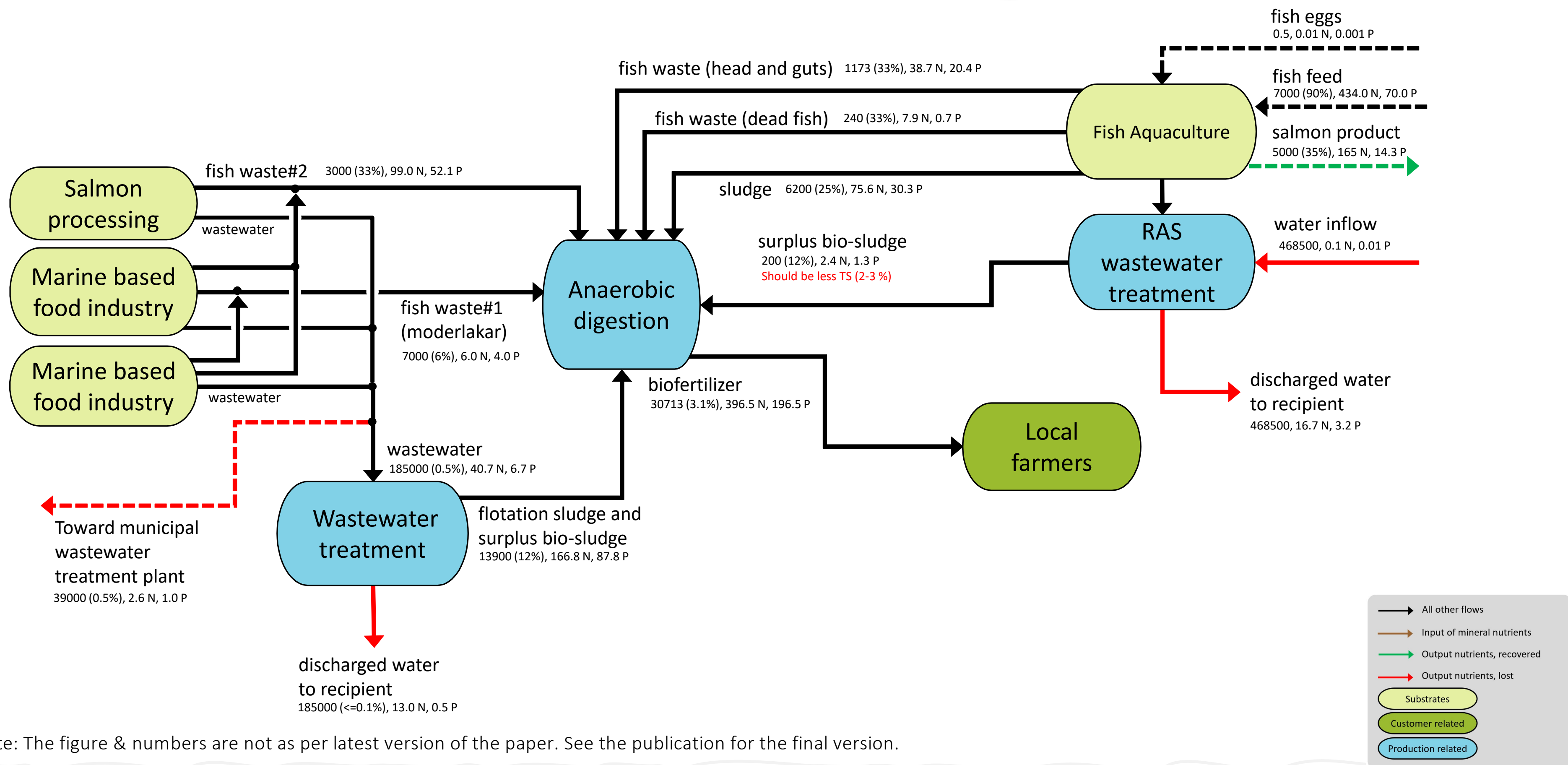
BALTIC INDUSTRIAL SYMBIOSIS

IS case

Example 2
IS in Sotenäs



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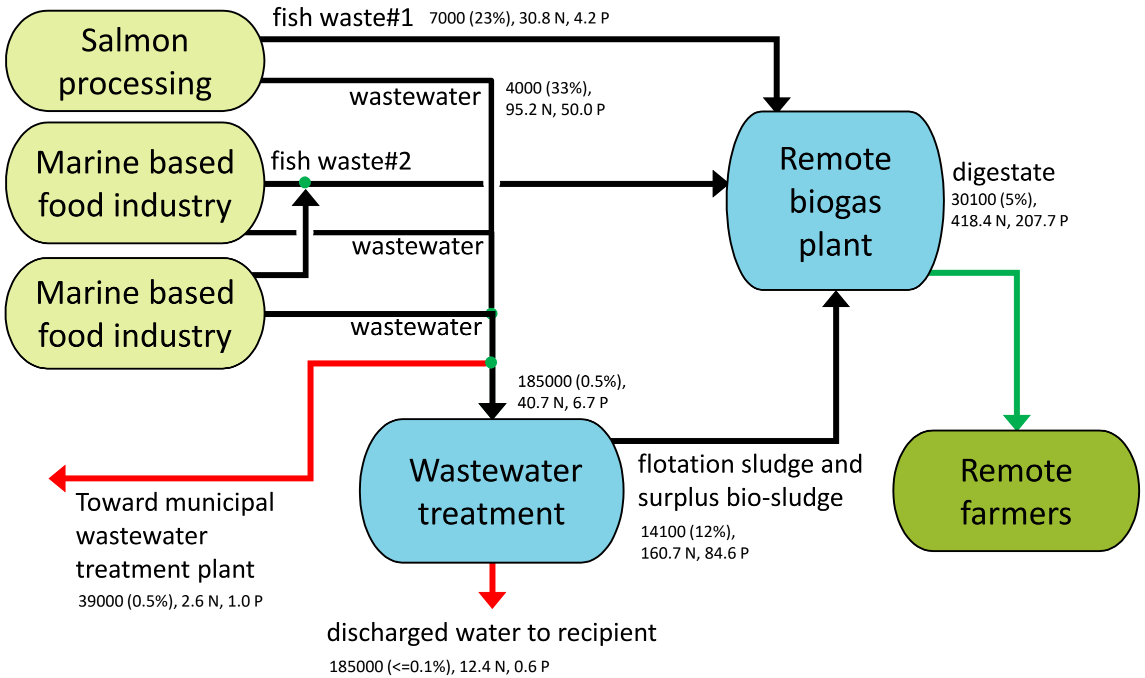
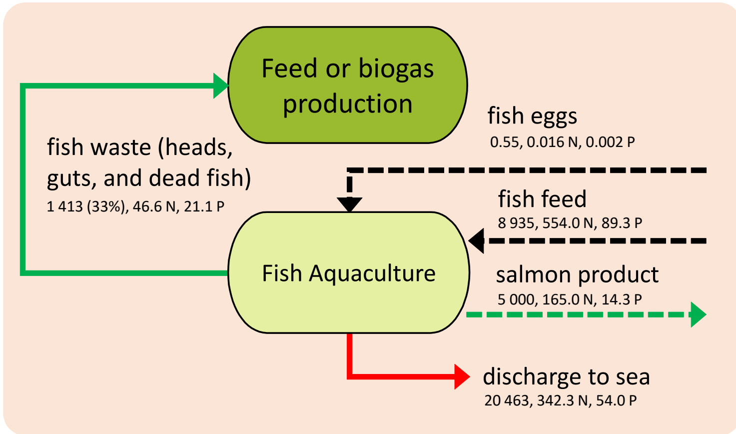
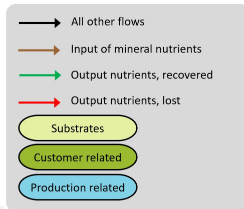
BALTIC INDUSTRIAL SYMBIOSIS

Reference (before IS)

Example 2
IS in Sotenäs







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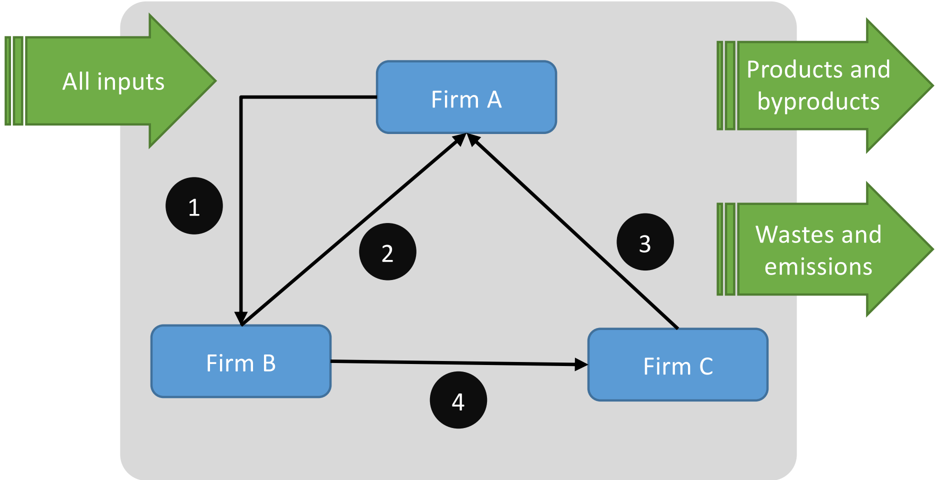
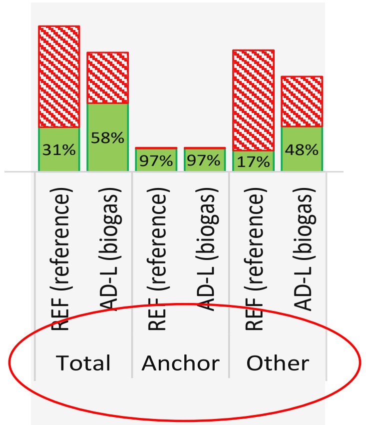
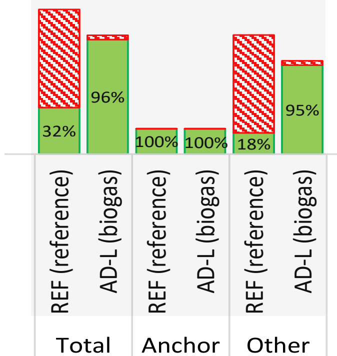
Total vs. firm-level impact assessment of IS

Example 2
IS in Sotenäs

- Total assessment
  - Consider all inputs, outputs, and emissions, and the corresponding life-cycle impacts before and after IS
- Firm-level assessment
  - Assess the impact of each firm (consider each synergistic linkage, and split the benefits among the involved firms)
  - Add up all firm-level impacts to get to total impact of IS







BALTIC INDUSTRIAL SYMBIOSIS

Value for decision makers

Example 2
IS in Sotenäs

- Nutrient recovery is an under-appreciated aspect of biobased industrial symbiosis
  - Systematic and credible evidence on the positive impact of IS on nutrient recovery
  - Quantitative analysis
- Comparability
  - Salmon production using semi-open system were added to the Reference
- Data requirement
  - Filling the mass balance gaps (missing, unmeasured, or contradictory information)
- Other aspects could have been included
  - e.g. how the produced biofertilizer can be used in local farms

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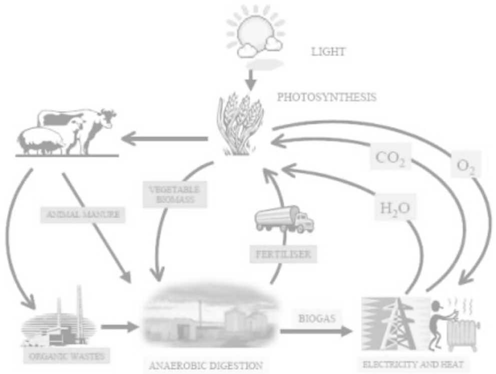
Three examples

Example 1

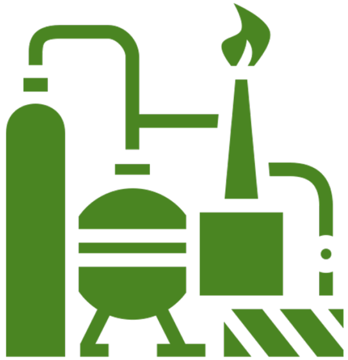
Industrial symbiosis and cement production

Example 2



Biogas solutions for enhanced nutrient recovery

Example 3



Industrial symbiosis and biorefinery development

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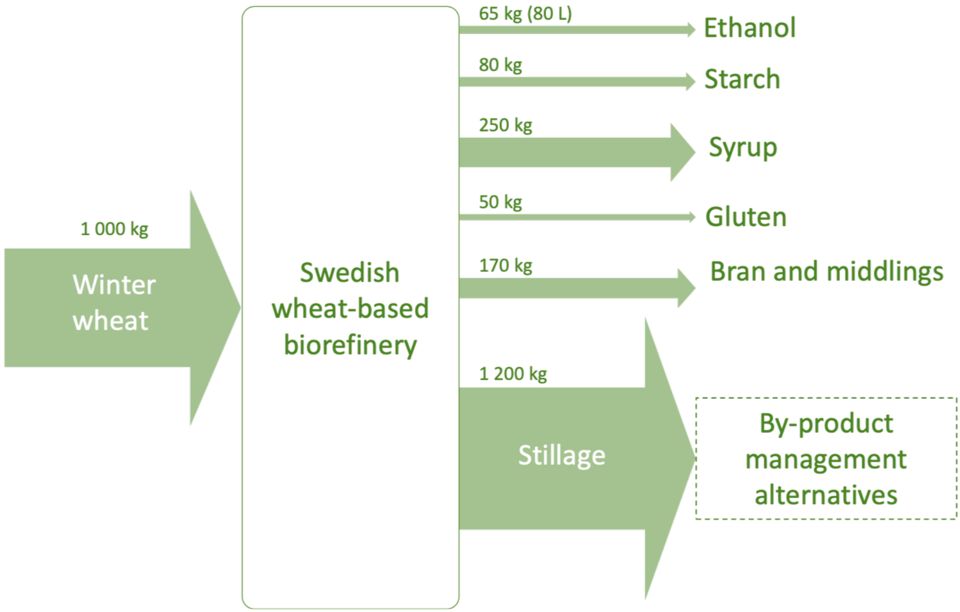
Industrial symbiosis and biorefinery development

Example 3
IS in Lidköping

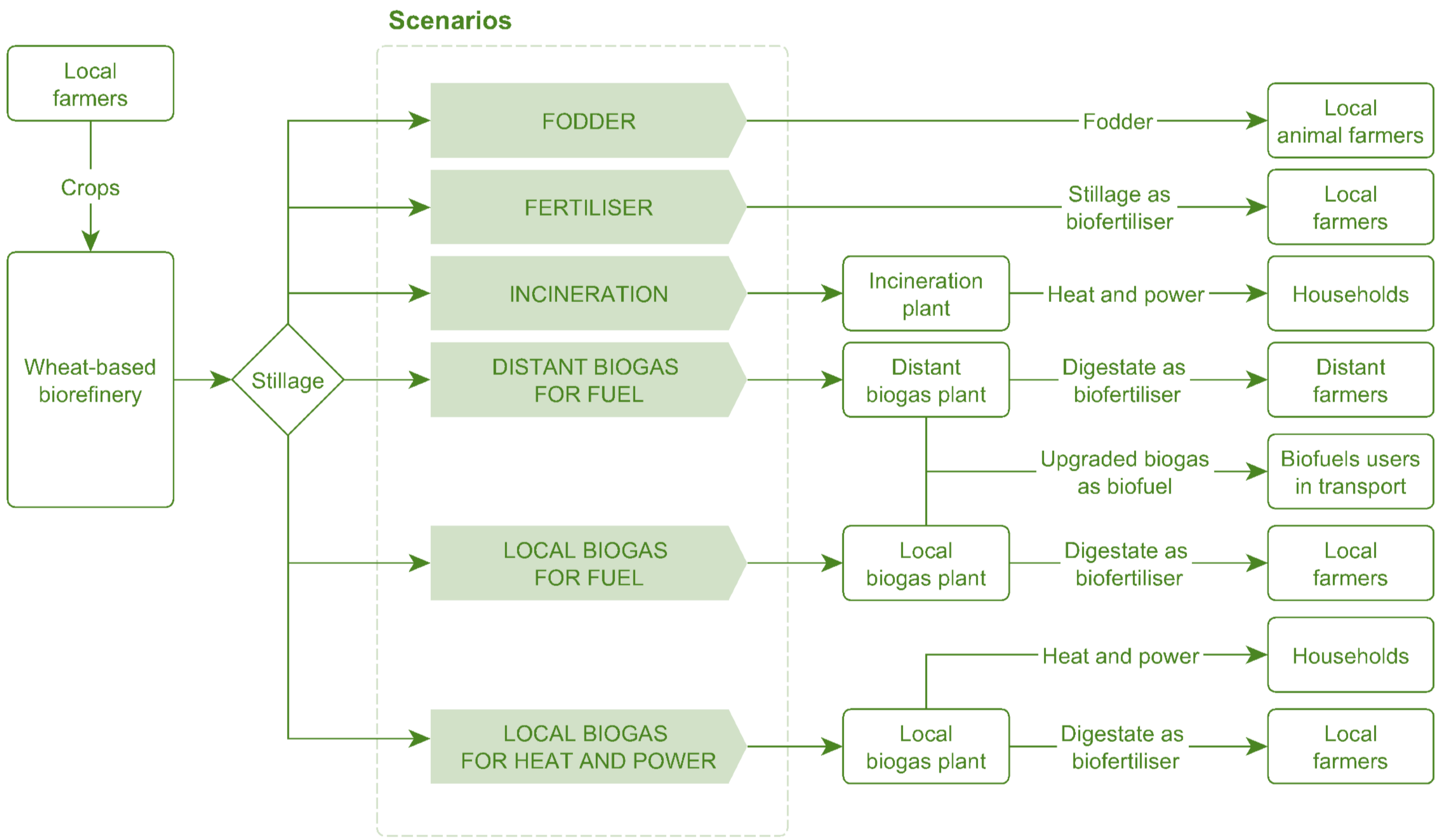
- Lantmännen Reppe wheat-ethanol biorefinery in Lidköping; produces ethanol, gluten, starch and syrup from wheat
- What are the most suitable ways of treating the byproduct, stillage?
  (produce fodder, directly use as biofertilizer, or anaerobically digest and produce biogas and biofertilizer?)
- Comparison of different scenarios using multi-criteria analysis



Hagman, L., Feiz, R., 2021. Advancing the circular economy through organic by-product valorisation—A multi-criteria assessment of a wheat-based biorefinery [article in press]. Waste and Biomass Valorization.

Reference case and scenarios

Example 3
IS in Lidköping



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Biogas role in biorefinery development

Example 3
IS in Lidköping

Key area	Indicator	Fodder	Fertiliser	Incin-eration	Distant biogas for fuel	Local biogas for fuel	Local biogas for heat and power
Energy and environmental performance, nutrients and resource economy (environmental performance)	Nutrient recirculation	Very Good ***	Very Good ***	Very Poor ***	Very Good ***	Very Good ***	Very Good ***
	Primary energy performance†	(Reference)	Very Poor ***	Very Poor ***	Very Good ***	Very Good ***	Very Good ***
	Climate change performance†	(Reference)	Very Poor ***	Very Poor ***	Very Good ***	Very Good ***	Very Good ***
	Local/regional environmental impact	Good **	Fair (Poor) **	Fair **	Good **	Good **	Good **
Economic feasibility (feasibility)	Profitability or cost efficiency†	(Reference)	Very Poor ***	Very Poor ***	Very Poor ***	Fair ***	Very Poor ***
	Transportation efficiency†	(Reference)	Very Good ***	Very Good ***	Very Poor ***	Very Good ***	Very Good ***
	Reduced load on waste systems†	(Reference)	Fair ***	Very Poor ***	Fair ***	Fair ***	Fair ***
Geographical and physical suitability (feasibility)	Geographical and physical suitability	Good ***	Good ***	Poor ***	Poor ***	Good ***	Good ***
Technical feasibility	Technological	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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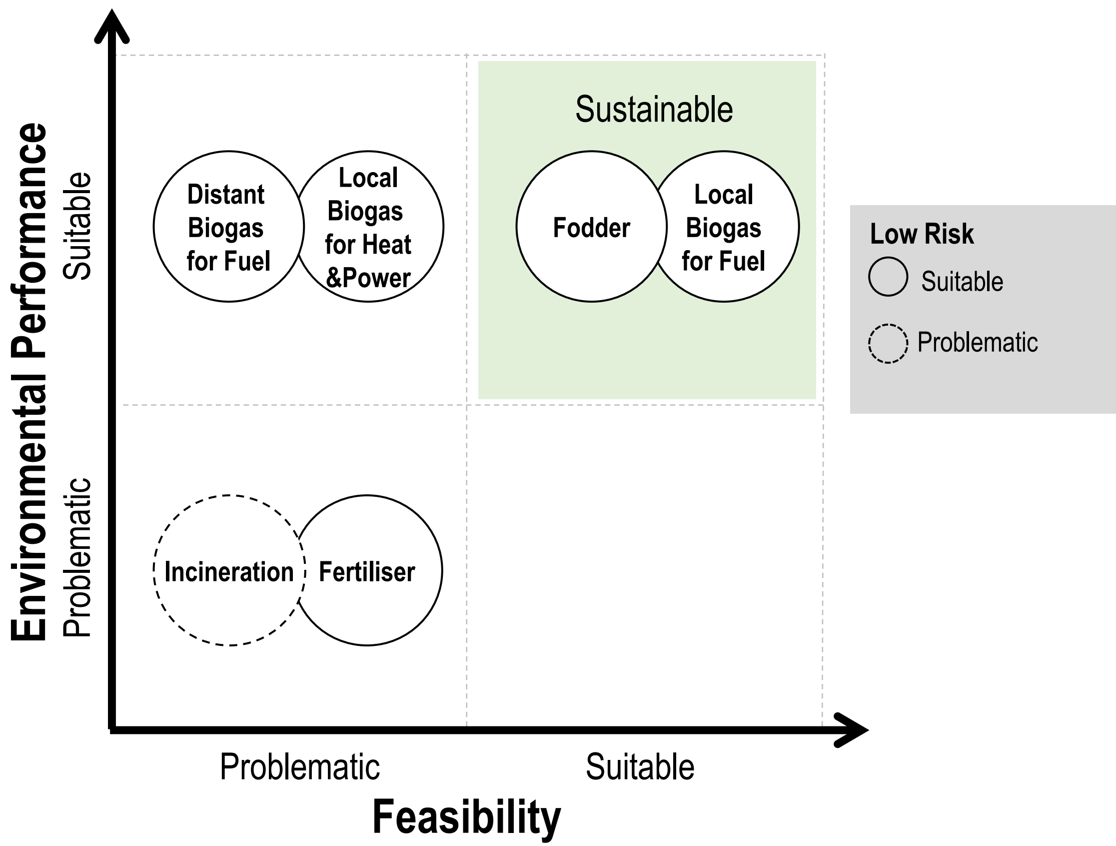
Biogas role in biorefinery development

Example 3
IS in Lidköping



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Value for decision makers

Example 3
IS in Lidköping

- Scope management
  - Assessing the potential, feasibility, risk, and performance of alternatives
  - Quantitative and qualitative analysis
  - Systematic and credible comparison
- Comparability with the reference case
  - The whole production system “before” and “after” IS are compared
- Data requirement
  - Some of the indicators such as GHG emissions required separate LCA studies
  - MCA can be used as the main framework knowledge management.

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Consider:

- Have a clear objective in mind: what is the goal of the study?
  - Who is the audience?
- Learn about the case; its recent history and the involved processes, technologies, and actors
- Have clear and transparent decisions on how you define the boundaries of the studied system and how you make the "before vs after" (or "this vs that") comparable.
- If needed, limit the scope with suitable motivations
  - partial life-cycle
  - focus only on most important aspects or impacts
- Quantitative systems analyses such as LCA cannot answer all questions
  - Use qualitative methods to capture complex, hard to quantify, aspects
- Procedural methods such as MCA are very flexible and can be tailored a lot
  - What type of issues cannot be assessed by quantitative systems analysis?
- Even if you do not want to go for LCA-like methods, you still need to have a system perspective in mind
  - What can happen if you skip systems perspective altogether?

BALTIC INDUSTRIAL SYMBIOSIS

Take away messages

- Systems analysis
  - Helps implementation of industrial symbiosis by allowing resources to **focus on high-impact areas**
  - Adds **transparency** and **credibility** to claims about benefits

- A strategic management tools
  - Are we **moving toward the right direction**?
  - **Simplified** approaches are sometimes enough, but **in-depth comparative analysis** can provide more credible results
  - Life-cycle assessment and multi-criteria analysis can **complement** each other

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Thank you!

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