UNIVERSITY OF Southampton

Anaerobic digestion system

Life cycle assessment

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VALORGAS

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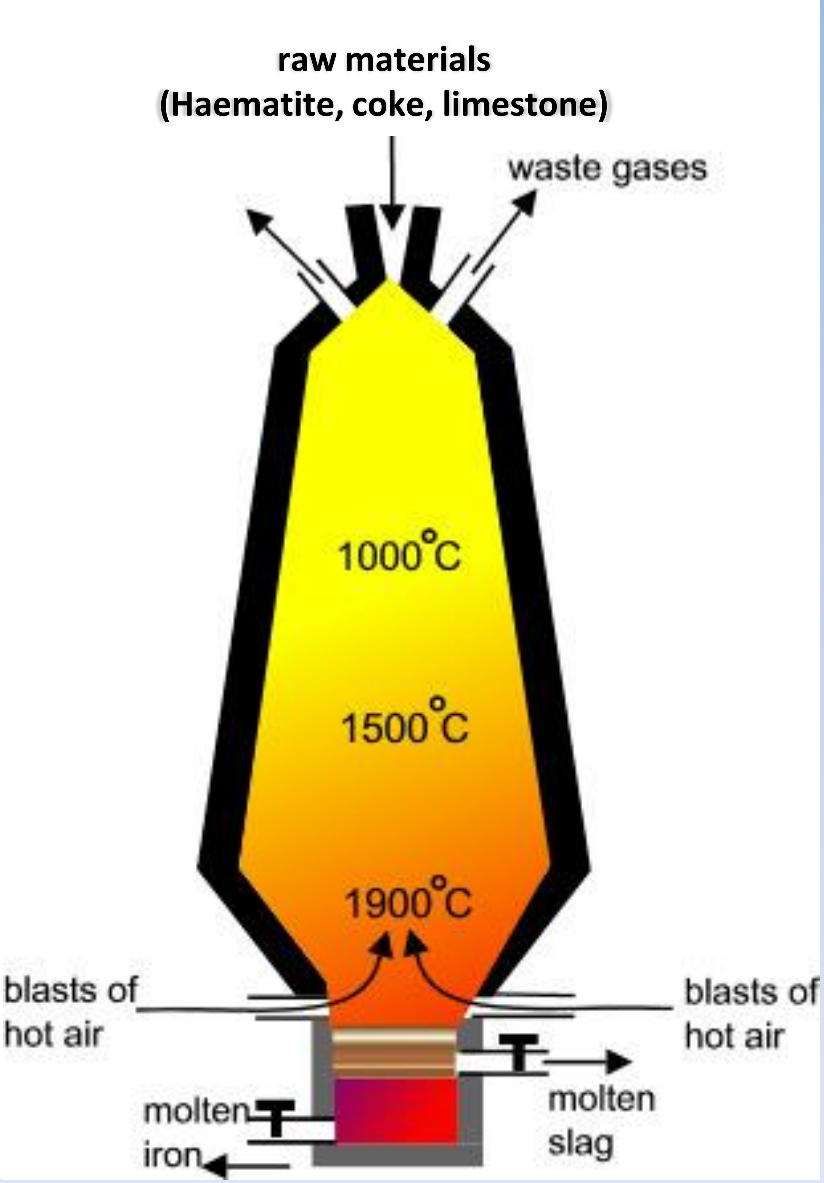
- An AD case study on integrated farming systems
- Further LCA development

Sustainable development

Iron – the blast furnace



Source: http://sciencepark.etacude.com/lzone/reactivity/blast_furnace.php

$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$
$CO_2\ (g) + C\ (s) \rightarrow 2\ CO\ (g)$
$Fe_2O_3\ (s) + 3CO\ (g) \rightarrow 2\ Fe\ (l) + 3CO_2\ (g)$

Iron mine

Source: www.quarryplant.net

Coal mine

Source: vninvestment.wordpress.com

Cement manufacturing

- CO_2
- Particulate matter
- NO_x
- SO_2
- Heavy metals
- etc

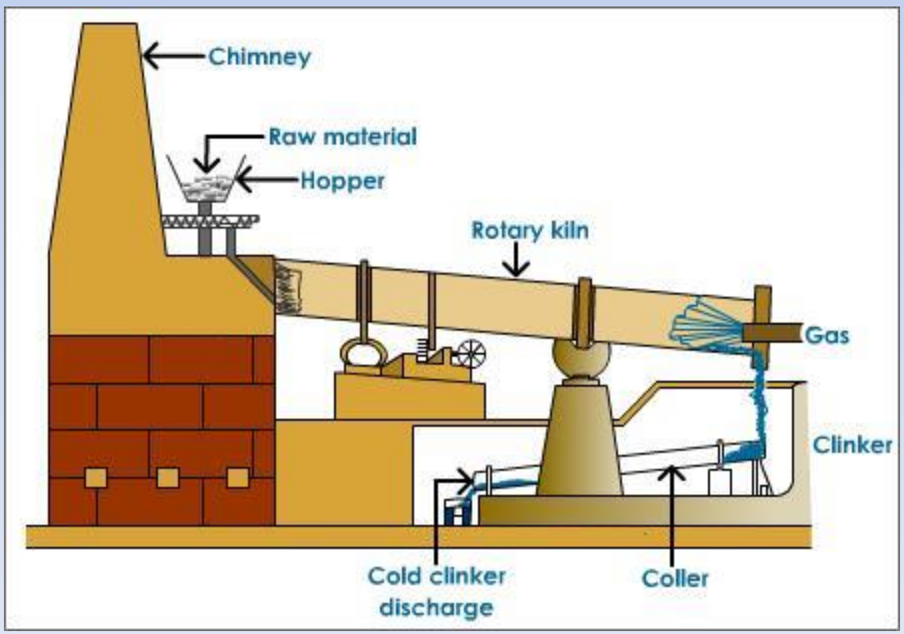
Energy-related: C (s) + O_2 (g) ➔ CO_2 (g)
Raw material-related: $CaCO_3$ ➔ CaO (s) + CO_2 (g)

Limestone quarry

Source: Lcommons.wikimedia.org

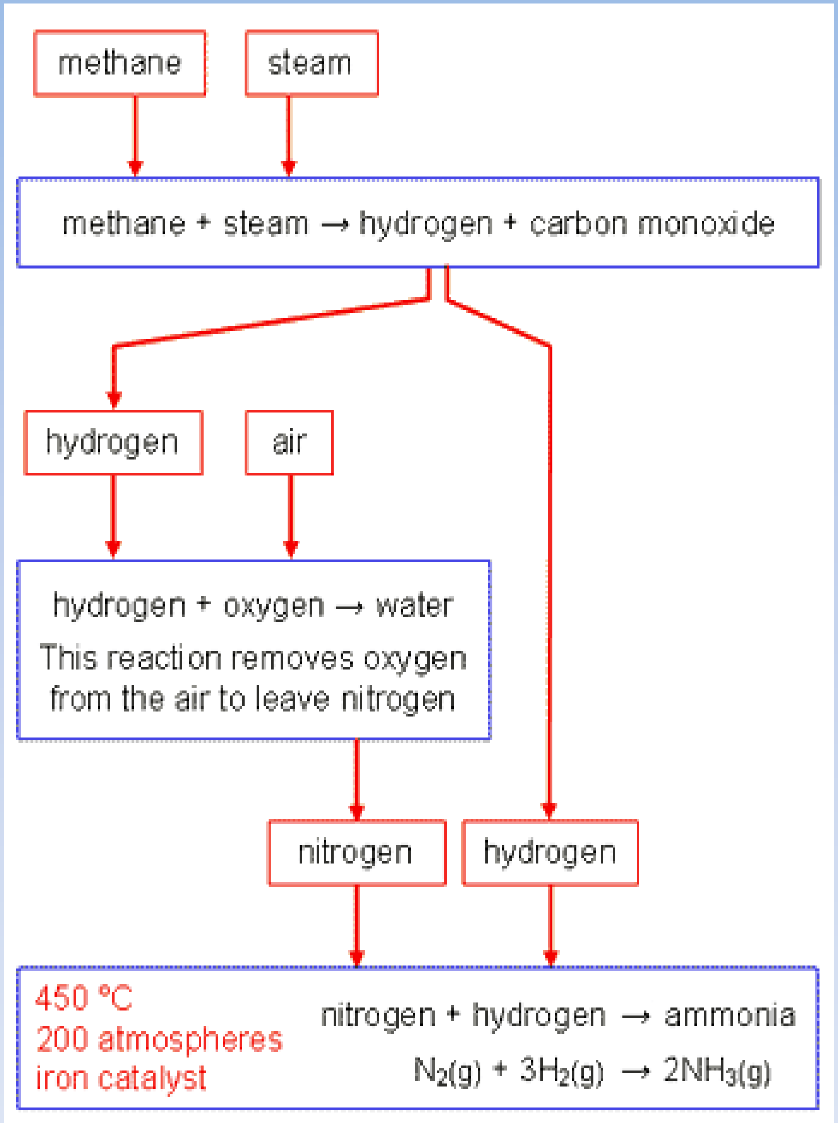
Clay mine

Source: commons.wikimedia.org



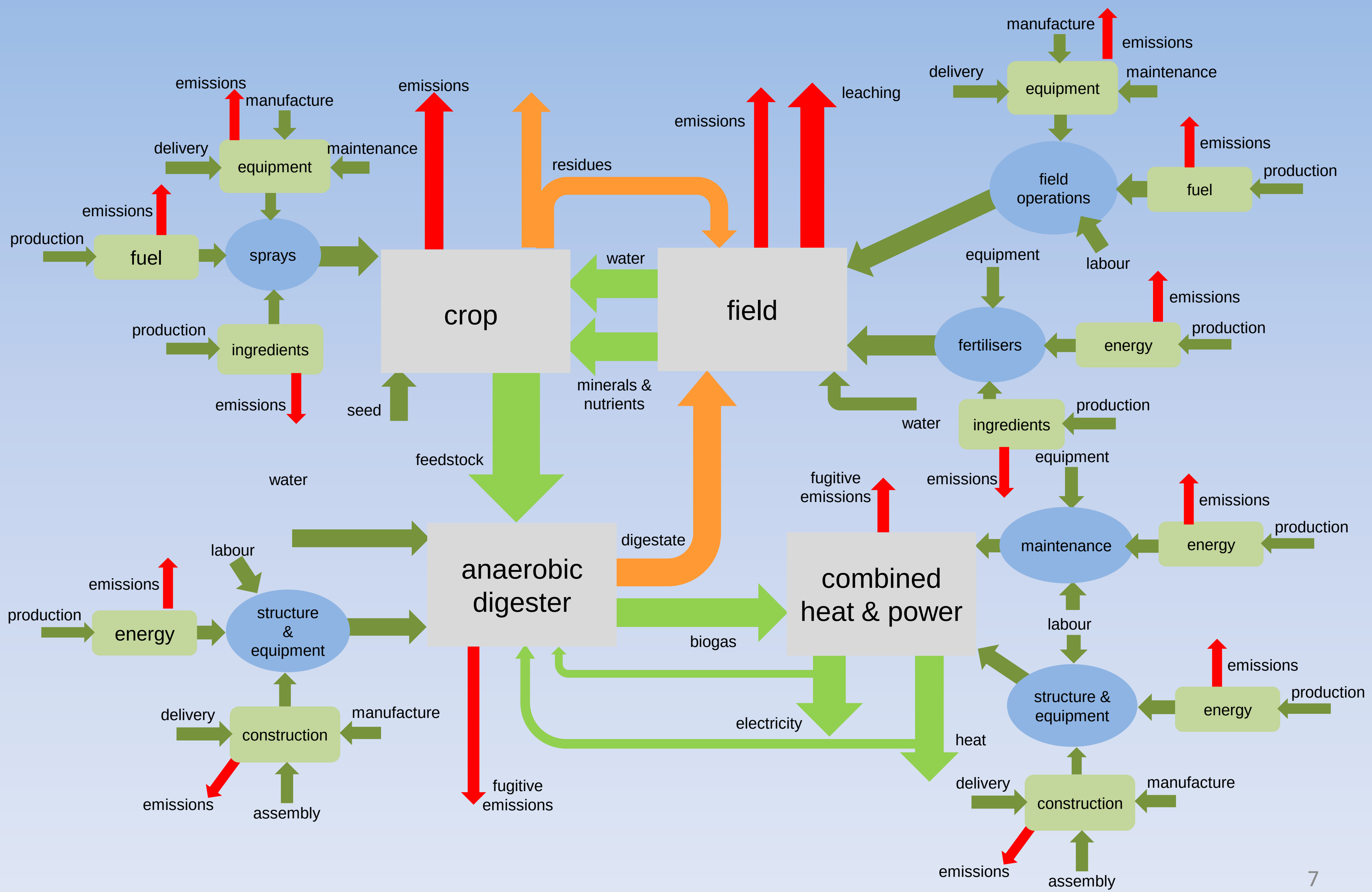
Source: http://www.ustudy.in/node/2565

Ammonia and the Haber process

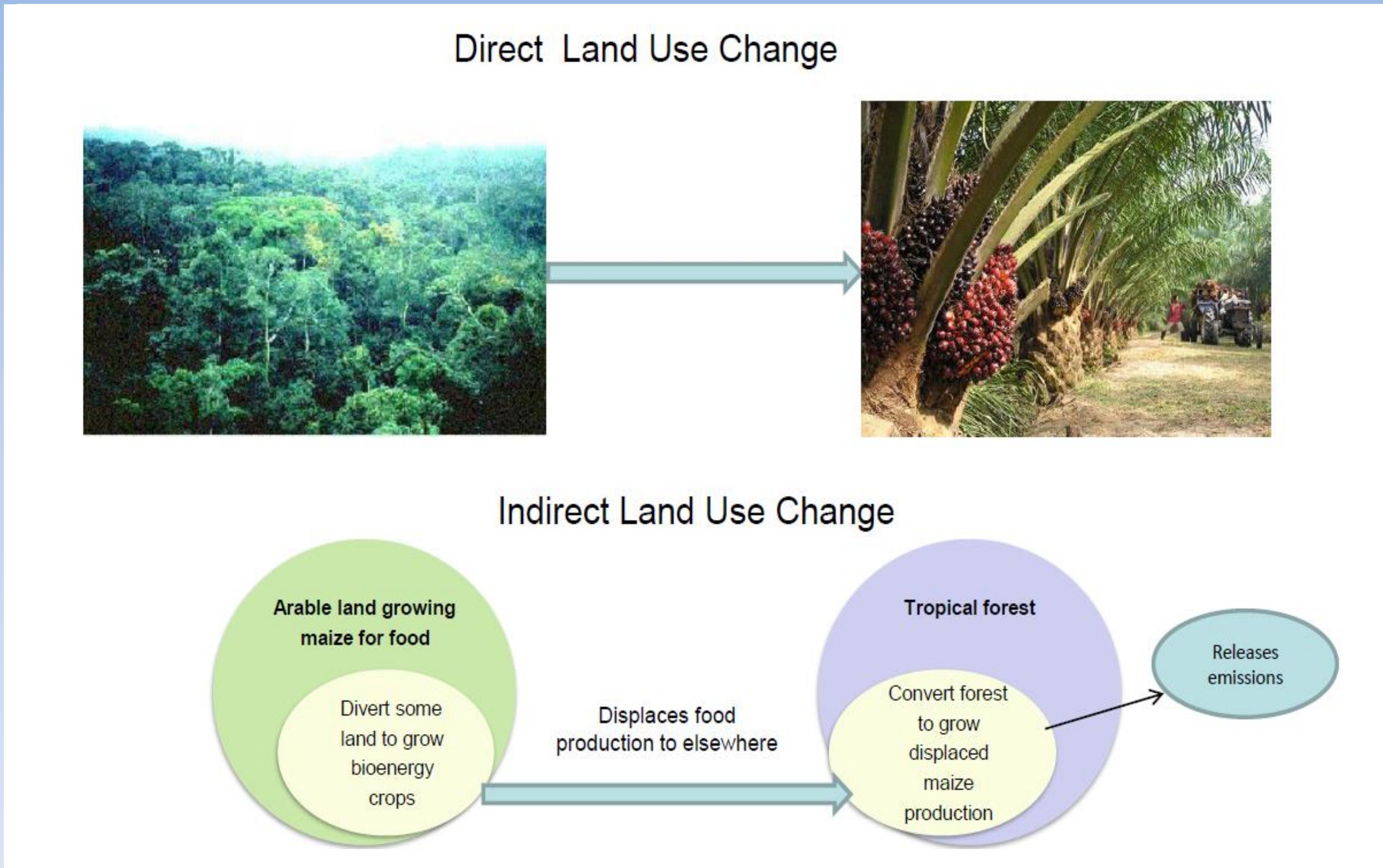


Source: www.bbc.co.uk

Sources of GHG emissions in farm AD



Land use change emissions



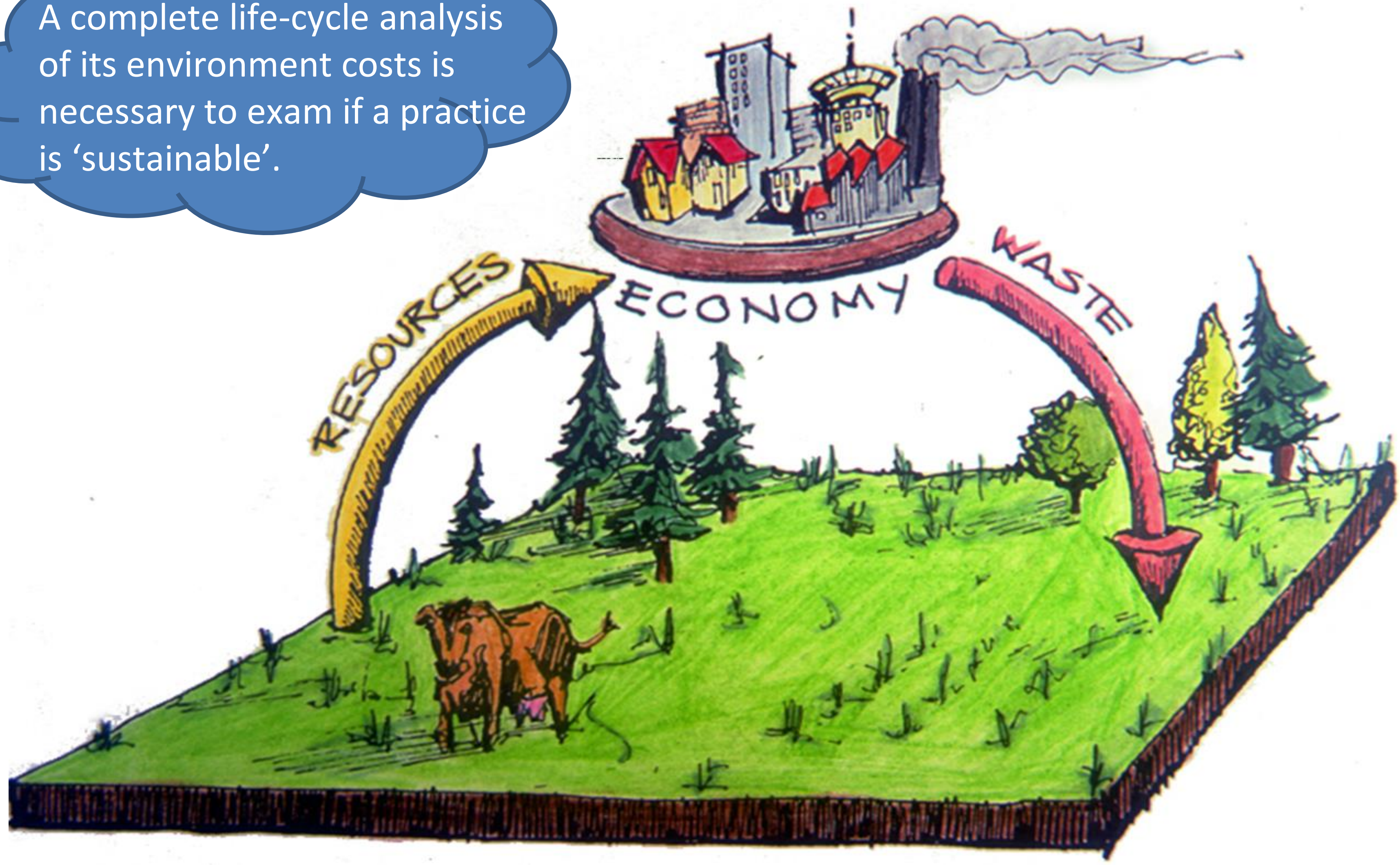
Source: www.theccc.org.uk

Sustainable development

- Our Common Future, the world commission on environment and development (1987):
  - Sustainable development - 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.
- A better quality of life - strategy for sustainable development for the UK (1999):
  - Social process which recognises the needs of everyone
  - Effective protection of the environment
  - Prudent use of natural resources
  - Maintenance of high and stable levels of economic growth and employment
- It has transformed into an environmental term because the economy is a wholly owned subsidiary of the biosphere

Sustainable development

A complete life-cycle analysis of its environment costs is necessary to exam if a practice is 'sustainable'.



Source: www.dgl.salemstate.edu

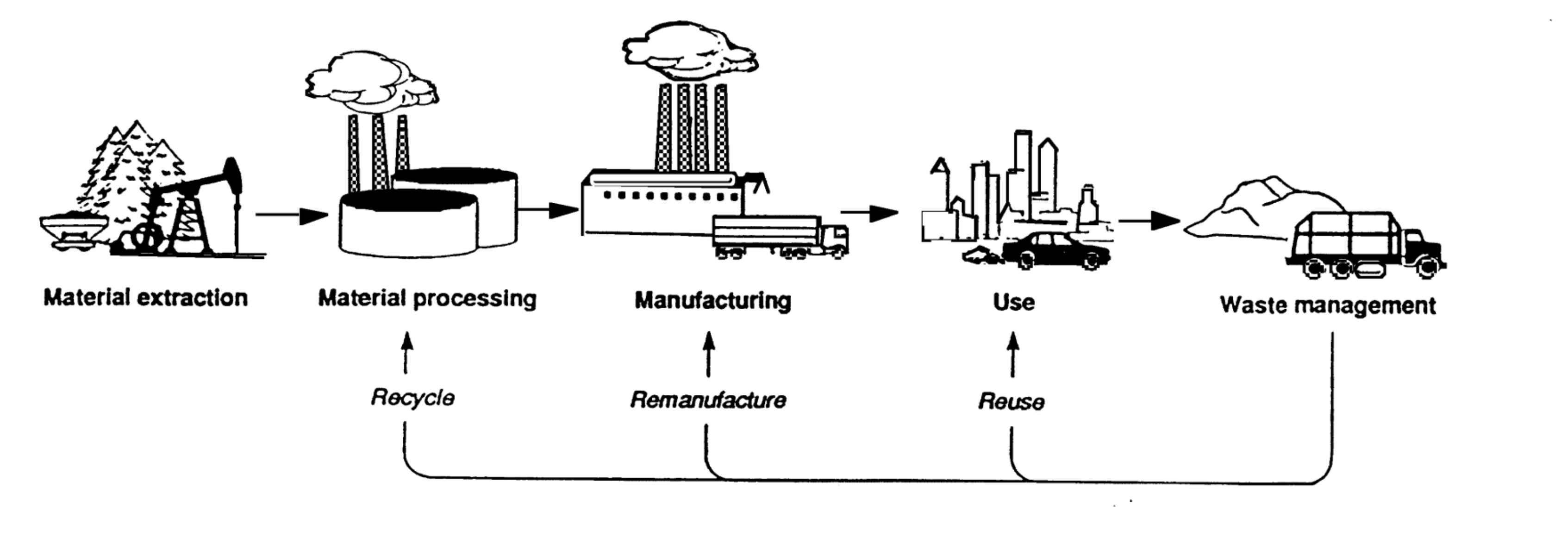
Sustainable development

- If it takes more energy to produce than it does produce then it is not sustainable
- If it leads to an increase in GHG emissions or negative environmental impact, it is not sustainable
- Electric cars are clean, but where does the electricity come from? Where do the materials in the batteries come from?
- Need to look at the full life cycle
- The impact on sustainability should be measured

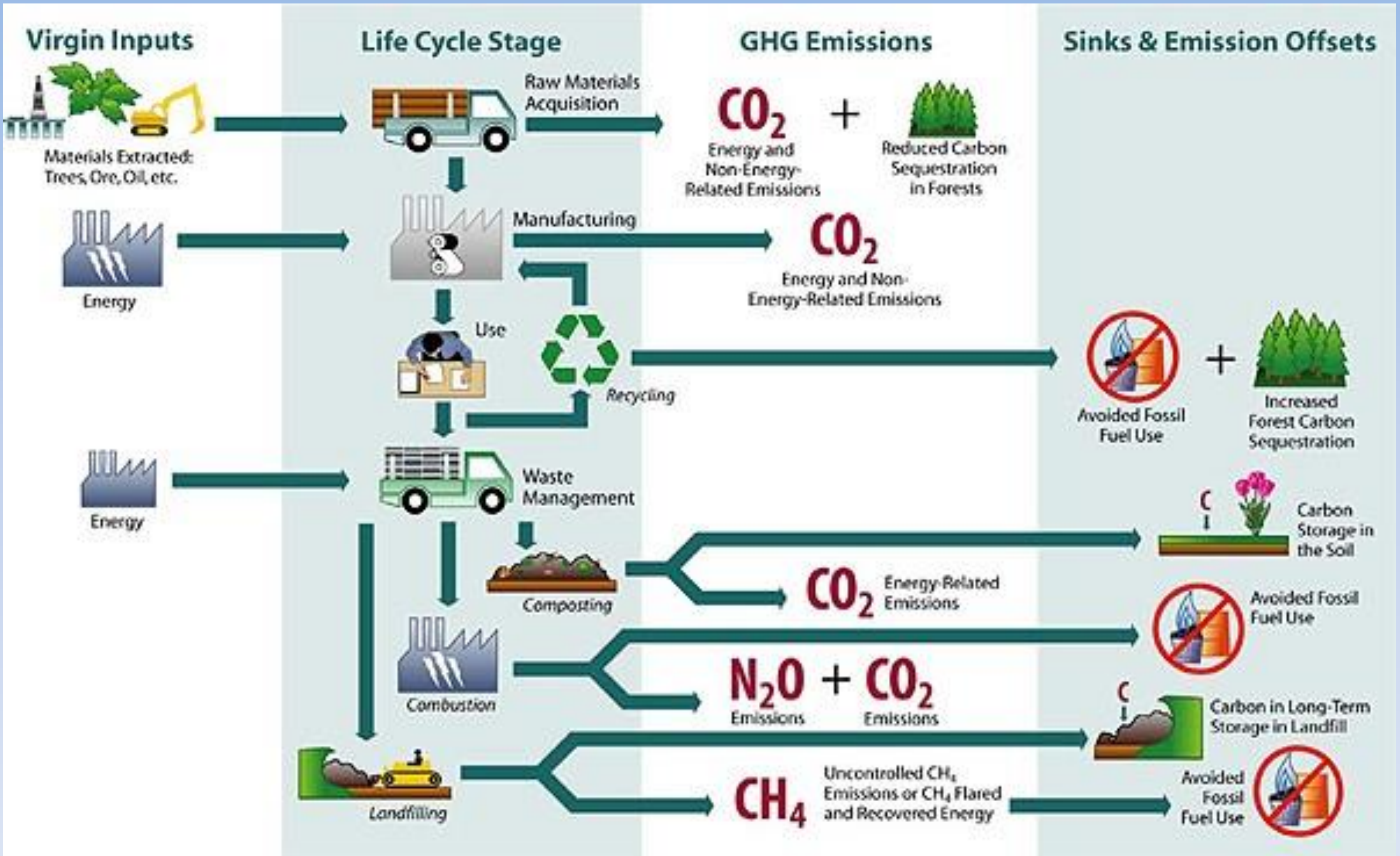
Life cycle assessment

Life cycle assessment

- Life cycle assessment (LCA) currently is a tool to identify environmental burdens and evaluate the environmental consequences of a product, process or service over its life cycle from cradle to grave (i.e. from extraction of resources through to the disposal of unwanted residues).



How LCA works



http://www.epa.gov/climatechange/waste/lifecycle.html

Life cycle assessment (LCA)

- LCA has developed into a major tool for sustainability decision support
- Its relevance has been continuously judged and improved in terms of the quality of the support it provides:
  - Does it give the information as required?
  - Could it do a better job?
  - This depends on the questions to be answered
- Example on anaerobic digestion
  - Small-step improvement options for a give AD process
  - Comparison between different fuels/biofuels, including biomethane
  - Evaluation of a global shift towards a more biobased energy system

LCA framework

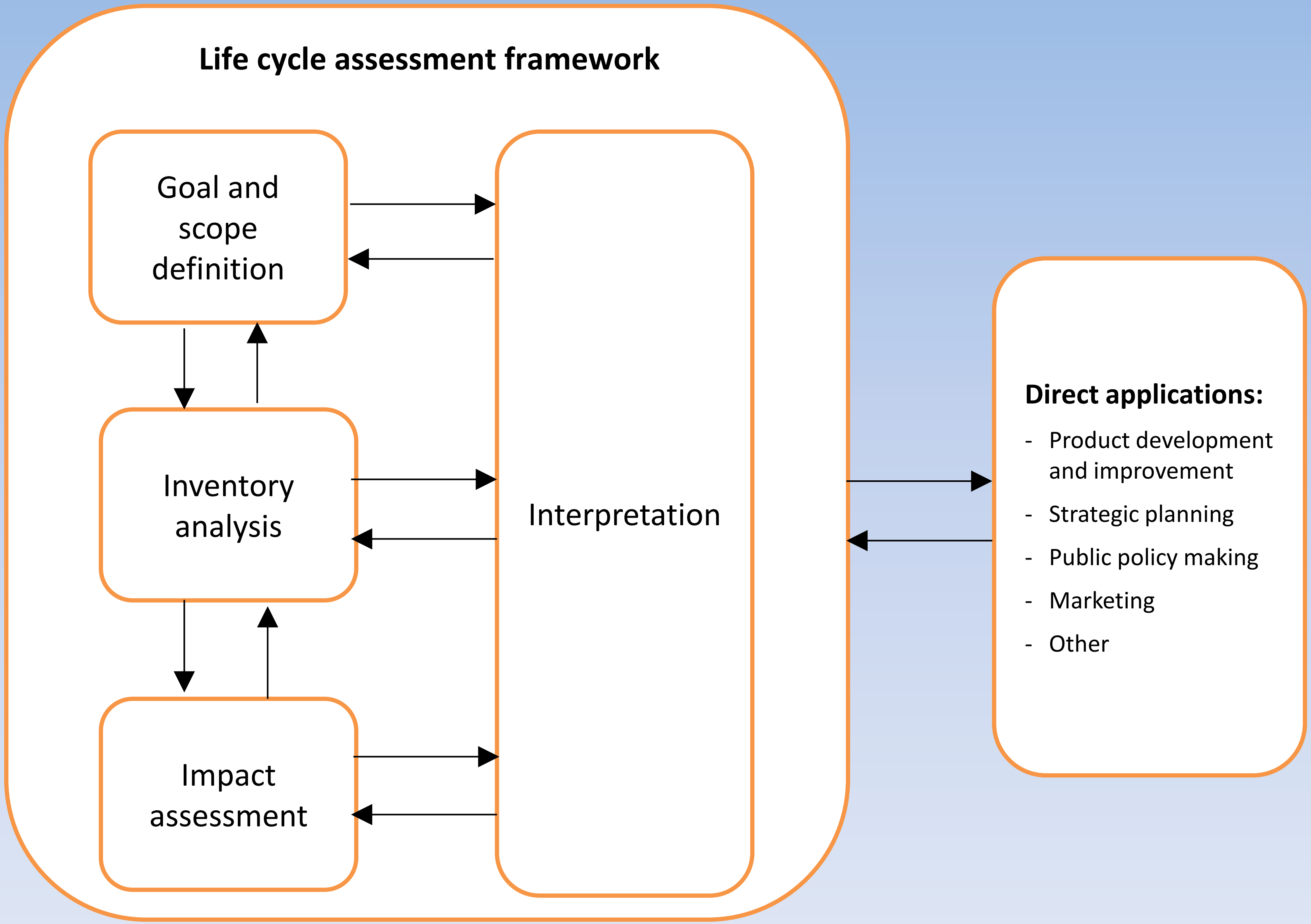
- The international Organisation for Standardization (ISO) has issued a series of standards and technical reports for LCA, referred to as the 14040 series.

Table. ISO documents on life cycle assessment

Number	Type	Title	Year
14040	International standard	Principle and framework	1996, 2006
14041	International standard	Goal and scope definition and inventory analysis	1998[a]
14042	International standard	Life cycle impact assessment	2000[a]
14043	International standard	Life cycle interpretations	2000[a]
14044	International standard	Requirements and guidelines	2006[b]
14047	Technical report	Illustrative examples on how to apply ISO14044 to impact assessment situations	2003, 2012
14048	Technical report	Data documentation format	2002
14049	Technical report	Illustrative examples on how to apply ISO14044 to goal and scope definition and inventory analysis	2000, 2012

[a] Updated in 2006 and merged into 14044
[b] Replaces 14041, 14042, and 14043

LCA framework



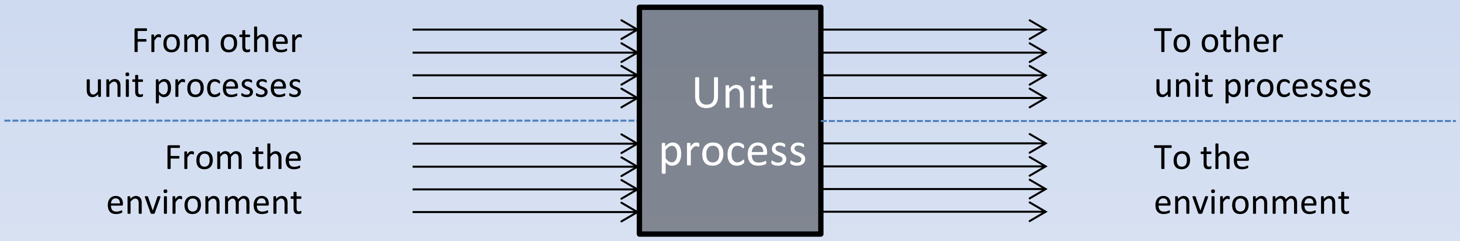
Reference: ISO 14040

Goal and scope definition

- The goal of the LCA should deal with the following topics:
  - the intended application
  - the reasons for carrying out the study
  - the intended audience
  - whether the results are to be used in comparative assertions disclosed to the public
- In the scope definition, a number of major choices are made
  - the system(s) to be studies – system boundaries
  - the function the system(s) delivers – functional unit
  - impact categories
  - treatment of uncertainty

Life cycle inventory (LCI) analysis

- ISO defines LCI analysis as the phase of LCA involving the compilation and quantification of inputs and outputs for a product/service throughout its life cycle
- Quantification is an important aspect here, and numbers, in terms of data and calculations, are of central concern in the inventory analysis
- The LCI is built on the basis of the unit process
  - A unit process is the smallest element considered in the LCI analysis for which input and output data are quantified
  - In LCA, a unit process is treated as a black box that converts a bundle of inputs into a bundle of outputs



  - Unit processes form the building blocks of an LCA

Life cycle impact assessment (LCIA)

- LCIA is the phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.
  - 2-methyl-2-butene?
- Impact assessment involves the conversion of LCI results to common units and the aggregation of the converted results within the same impact category.
- The impact category is a class representing environmental issues of concern to which LCI analysis results may be assigned.

Life cycle impact categories

Global warming

Classification: CO_2, N_2O, CH_4, CFCs, HCFCs, CH_3Br

Characterisation factor: Global warming potential (CO_2 equivalents)

Resource depletion

Classification: quantity of minerals used, quantity of fossil fuels used

Characterisation: Resource depletion potential (ratio of quantity of resources used *vs* quantity of resource left in reserve)

Stratospheric ozone depletion

Classification: CFCs, HCFCs, Halons, CH_3Br

Characterisation: Ozone depleting potential (CFC-11 equivalents)

Photochemical smog

Classification: Non-methane hydrocarbon

Characterisation: Photochemical oxidant creation potential (C_2H_6 equivalents)

Life cycle impact categories

Acidification

Classification: SO_x, NO_x, HCl, HF, NH_3

Characterisation: Acidification potential (H^+ equivalents)

Eutrophication

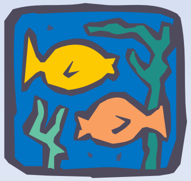
Classification: phosphate, nitrate, ammonia

Characterisation: Eutrophication potential (phosphate equivalents)

Terrestrial toxicity

Classification: Toxic chemical with a reported lethal concentration to rodents

Characterisation: LC_{50}

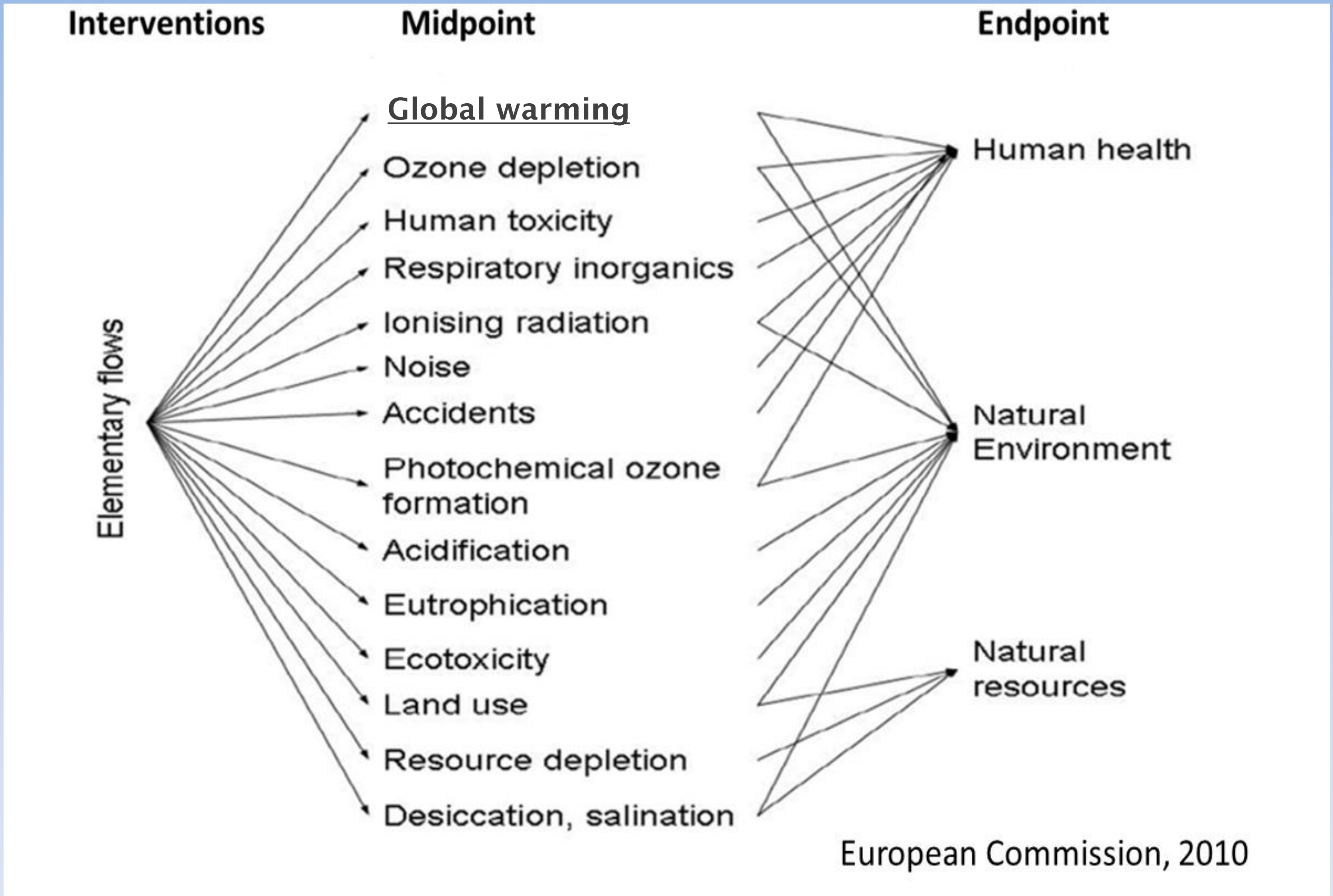


Aquatic toxicity

Classification: Toxic chemical with a reported lethal concentration to fish

Characterisation: LC_{50}

Life cycle impact categories



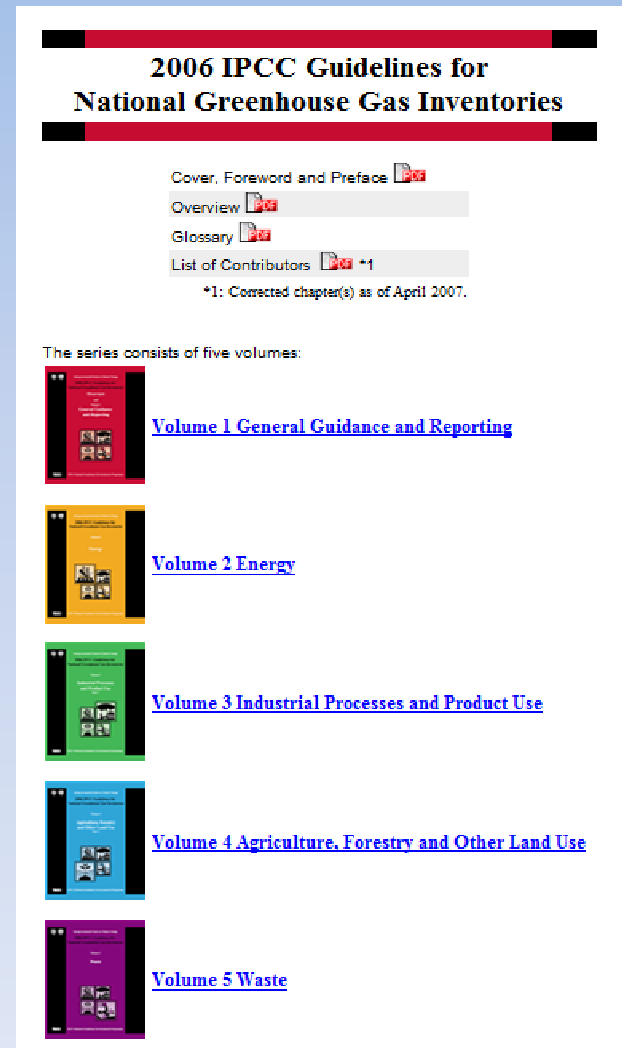
Life cycle impact assessment (LCIA)

- Impact assessment in ISO is structured into a number of steps:
  - Selection of
    - ✓ impact categories
    - ✓ category indicators
    - ✓ characterisation models
  - Classification
  - Characterisation
  - Normalisation
  - Grouping
  - Weighting
  - Data quality analysis

Selection of, Classification, Characterisation: mandatory

Normalisation, Grouping, Weighting: optional

Global warming potentials, IPCC 2006		
CO_2	CH_4	N_2O
1	25	298



Interpretation

- ISO defines interpretations as the phase of LCA in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations
- Several elements are mentioned by ISO:
  - Identification of significant issues
  - An evaluation that considers completeness, sensitivity and consistency checks
  - Conclusions, limitations, and recommendations
  - Appropriateness of the definitions of the system functions, the functional unit and system boundary
  - Limitations identified by the data quality assessment and the sensitivity analysis

An AD case study

- by Dr Andrew Salter, University of Southampton

Average large dairy farm in the UK

Category	Quantity	Recommended nutrient application N – P_2O_5 – K_2O (kg ha^{-1})
Dairy cows	178 (60% housed)	
Other cattle	167 (20% housed)	
Grass	41 ha, (silage) 89.3 ha (grazed)	250 – 105 – 290 250 – 40 – 30
Winter wheat	9 ha	220 – 90 – 95
Winter barley	3.4 ha	180 – 90 – 95
Spring barley	2.7 ha	150 – 75 – 83
Oilseed rape	1.1 ha	220 – 65 – 75
Peas and beans	0.4 ha	0 – 60 – 65
Fodder crop	13 ha	170 – 75 – 225
Fallow land	12.6 ha	
Uncropped land	0.5 ha	

Livestock

- Produce slurries and manures
  - Dairy cows ≈ 19.3 tonnes $year^{-1}$
  - Other cattle ≈ 11.6 tonnes $year^{-1}$
  - These contain nutrients approximately:

    5.2 kg N $tonne^{-1}$; 2.2 kg P_2O_5 $tonne^{-1}$; 4 kg K_2O $tonne^{-1}$

- Give off GHG emissions
  - From the slurry and manures

EQUATION 10.23
CH_4 EMISSION FACTOR FROM MANURE MANAGEMENT

$$EF_{(T)} = \left(VS_{(T)} \bullet 365\right) \bullet \left[B_{o(T)} \bullet 0.67\, kg/m^3 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet MS_{(T,S,k)}\right]$$

EQUATION 10.25
DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

$$N_2O_{D(mm)} = \left[\sum_{S}\left[\sum_{T}\left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)}\right)\right] \bullet EF_{3(S)}\right] \bullet \frac{44}{28}$$

Reference: 2006 IPCC Guidelines for National Greenhouse Gas Inventories

  - From enteric sources

Energy use & GHG emissions

- Reference case

Crop production
Diesel 7,033 litres
23.4 tonnes CO_2 eq

Fertiliser production
298 GJ
51.1 tonnes CO_2 eq

Grid electricity in dairy
211 GJ
26.5 tonnes CO_2 eq

Manure management
5,500 tonnes
288.5 tonnes CO_2 eq

Total
391 tonnes CO_2 eq

Anaerobic digestion – slurry only

- 2061 tonnes of slurry year^{-1}
- 254 m^3 digester
  - 175 tonnes of concrete; 8.8 tonnes steel; 1.1 tonnes insulation
  - Embodied energy 482 GJ (16 GJ year^{-1} for a lifespan of 30 years)
  - 455 GJ year^{-1} heat; 84 GJ year^{-1} electricity
- 78,536 m^3 biogas year^{-1}
  - 47,122 m^3 methane year^{-1}
- CHP (20 kW$_{electricity}$)
  - 591 GJ electricity generated year^{-1}

Energy use & GHG emissions

- Install AD

Crop production
Diesel 7,033 litres
23.4 tonnes CO_2 eq

Fertiliser production
298 GJ
51.1 tonnes CO_2 eq

Grid electricity in dairy
0 GJ
0 tonnes CO_2 eq

Manure management
5,500 tonnes
176.2 tonnes CO_2 eq

Grid electricity replaced
295 GJ

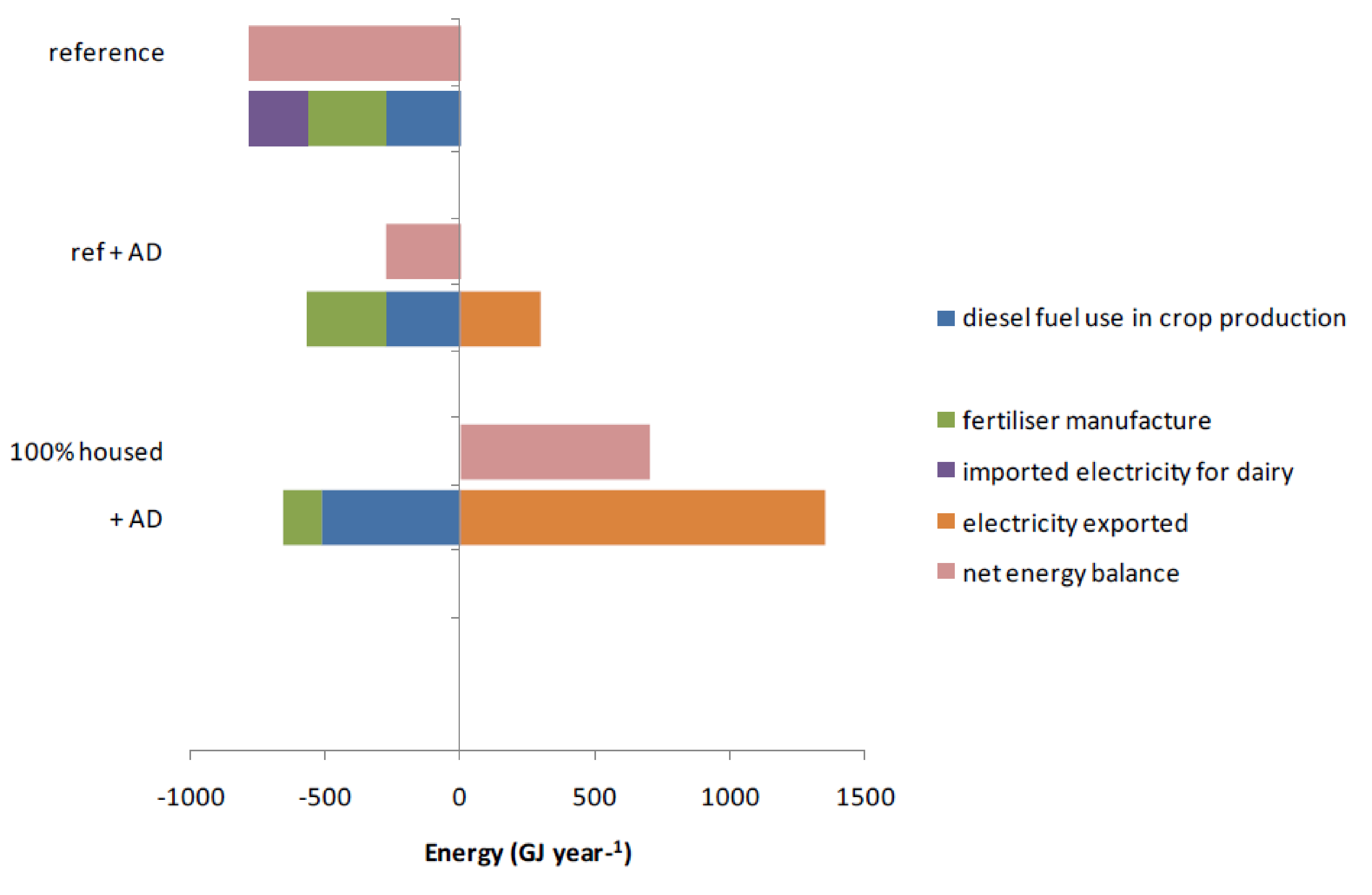
CHP electricity emissions
591 GJ

Total
281 tonnes CO_2 eq

Cattle housing

- Digester feedstock comes from housed cattle
- Manure deposited in fields emits methane
- House all of the cattle all of the time (100% housing):
  - 3435 tonnes of slurry
  - Plus 2452 tonnes of FYM (mix of slurry and straw)
- 750 m^3 digester
- 140,657 m^3 methane $year^{-1}$
- CHP (60 $kW_{electricity}$)
  - 1763 GJ electricity generated $year^{-1}$

Energy balance



Nutrients

- Reference case
  - Some manures deposited in fields, some mineral fertiliser required:

    5350 kg N; 3350 kg P_2O_5; 4900 kg K_2O

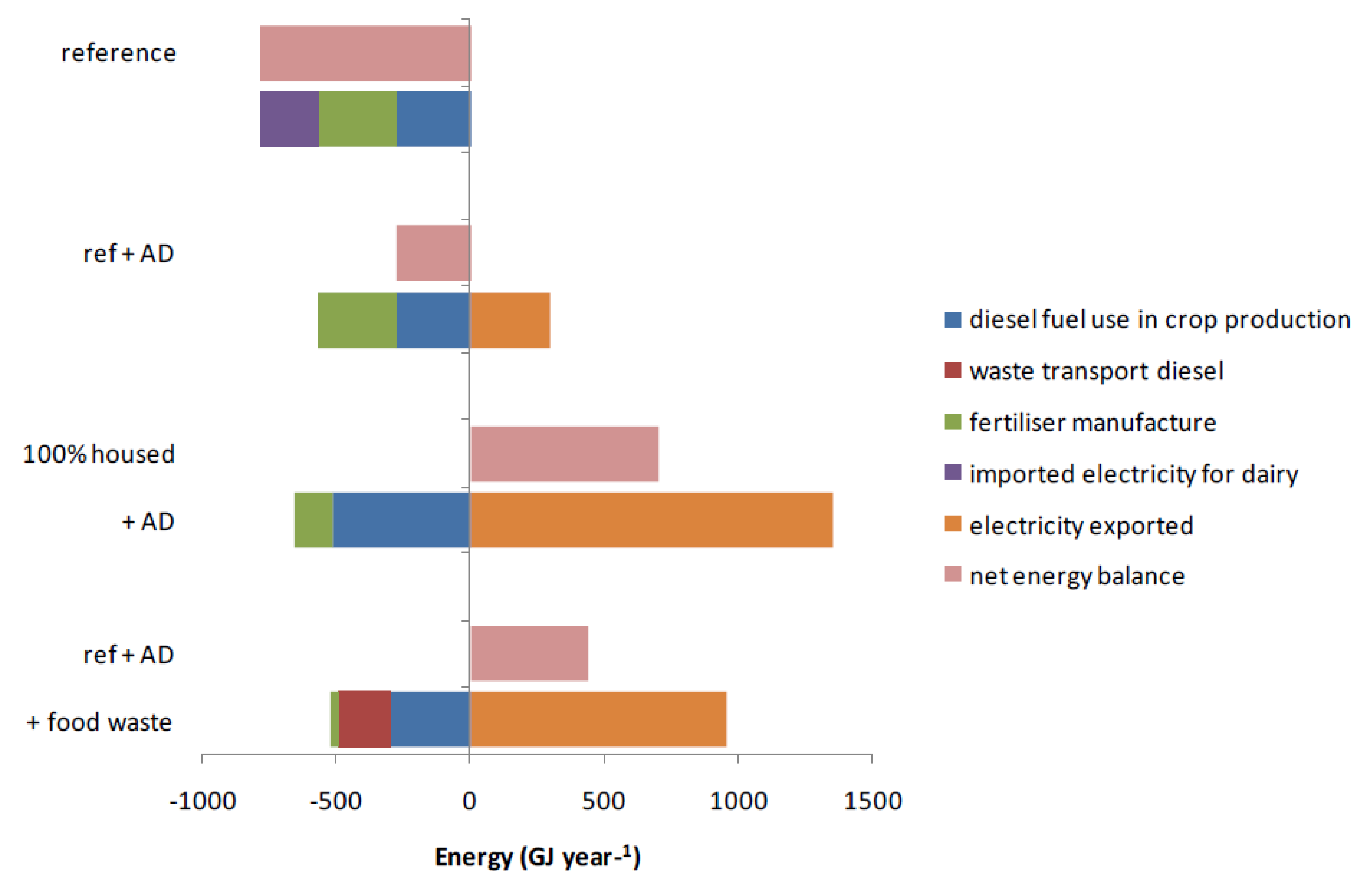
- Cattle housed all year
  - All manures collected 'in house', digested and returned to fields, some mineral fertiliser required:

	N	P_2O_5	K_2O
Quantity (kg)	2450	2100	3513
Embodied energy (GJ)	105	12.6	34.8
Embodied GHG (tonnes CO_2 eq)	16.7	3.6	6.4

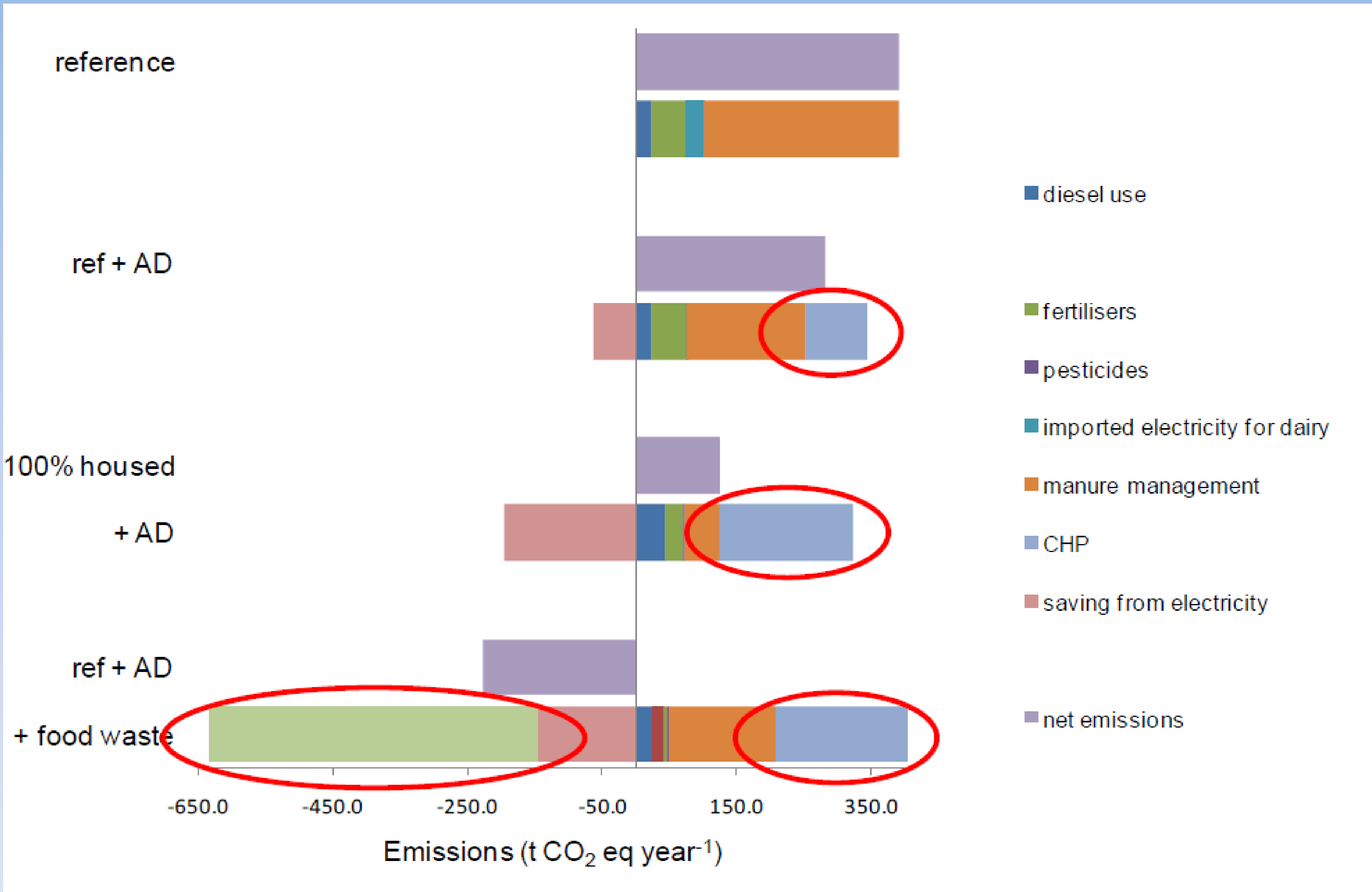
Food waste

- Nutrient contents
  - 8.1 kg N $tonne^{-1}$
  - 1.3 kg P_2O_5 $tonne^{-1}$
  - 3.4 kg K_2O $tonne^{-1}$
- 661 tonnes replaces all the N requirement

Energy balance – 4 scenarios



GHG emissions – 4 scenarios



Assumptions

- No changes to fertiliser applications due to increased nutrient availability
- Methane values based on BMP results
- Continuous operations at optimal conditions
- No methane losses
  - Sealed tanks
  - No fugitive emissions from CHP

LCA development

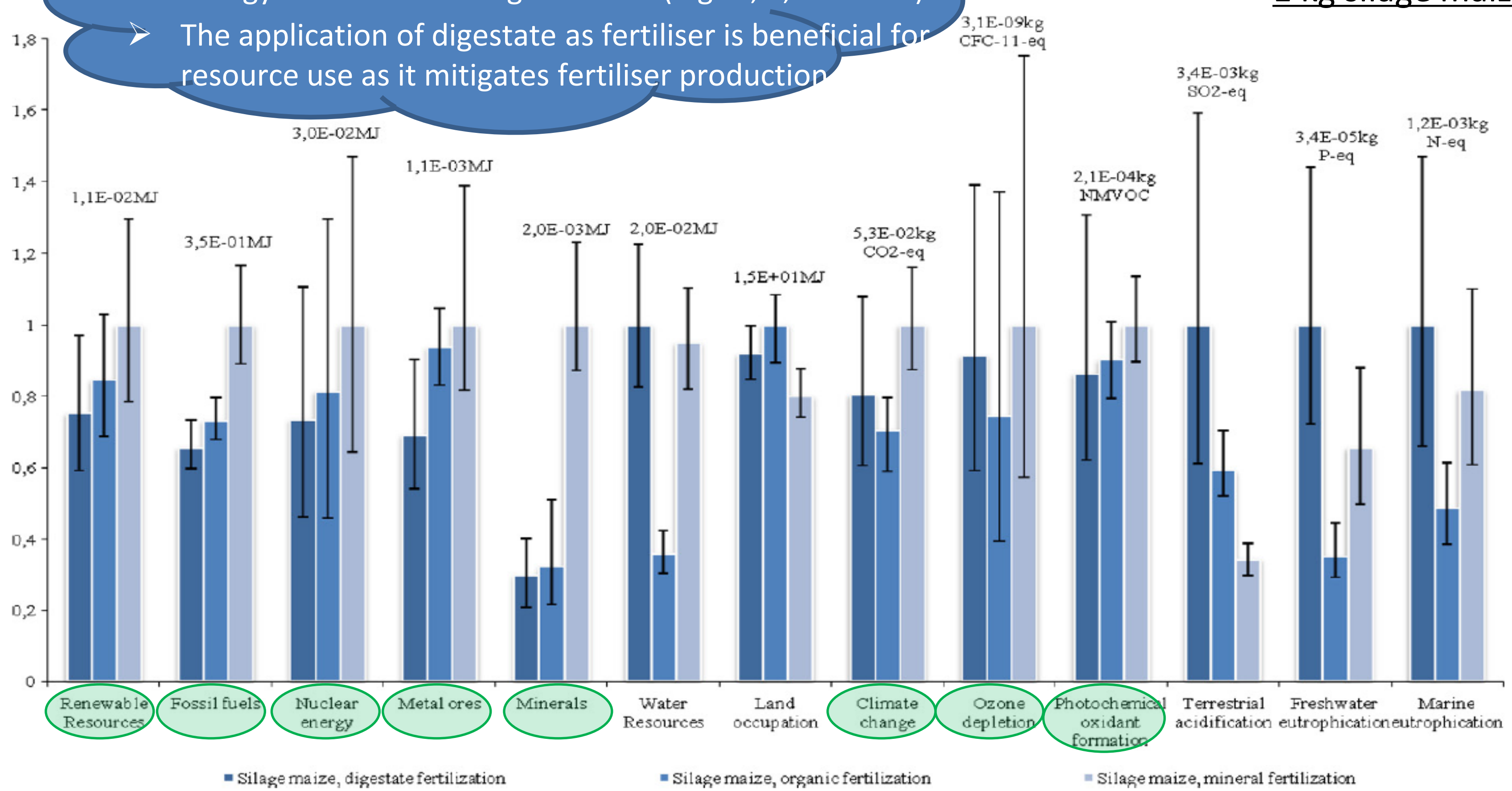
Prosuite project – an example

Case study on anaerobic digestion: comparison of cultivation of silage maize with digestate as a fertiliser with the 'traditional' intensive production and organic cultivation

(reference: Meester et al. (2012) The environmental sustainability of anaerobic digestion as a biomass valorization technology. Bioresource Technology 121, 396-403)

- AD is an efficient technology to convert biomass to energy while maintaining nutrients (e.g. N, P, K and TE)
- The application of digestate as fertiliser is beneficial for resource use as it mitigates fertiliser production

Functional unit:
<u>1 kg silage maize</u>



Prosuite project – an example

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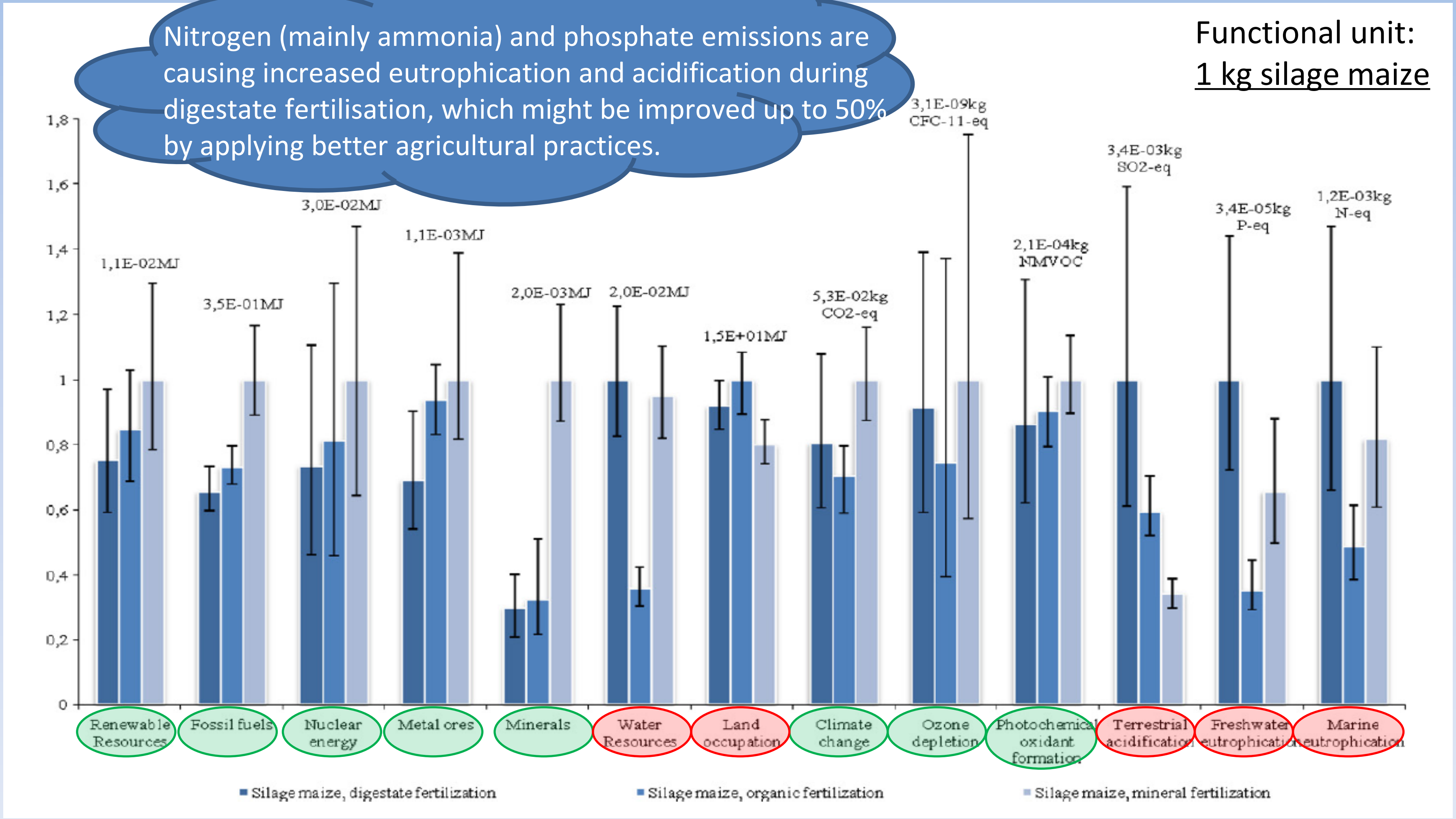
(reference: Meester et al. (2012) The environmental sustainability of anaerobic digestion as a biomass valorization technology. Bioresource Technology 121, 396-403)

Nitrogen (mainly ammonia) and phosphate emissions are causing increased eutrophication and acidification during digestate fertilisation, which might be improved up to 50% by applying better agricultural practices.

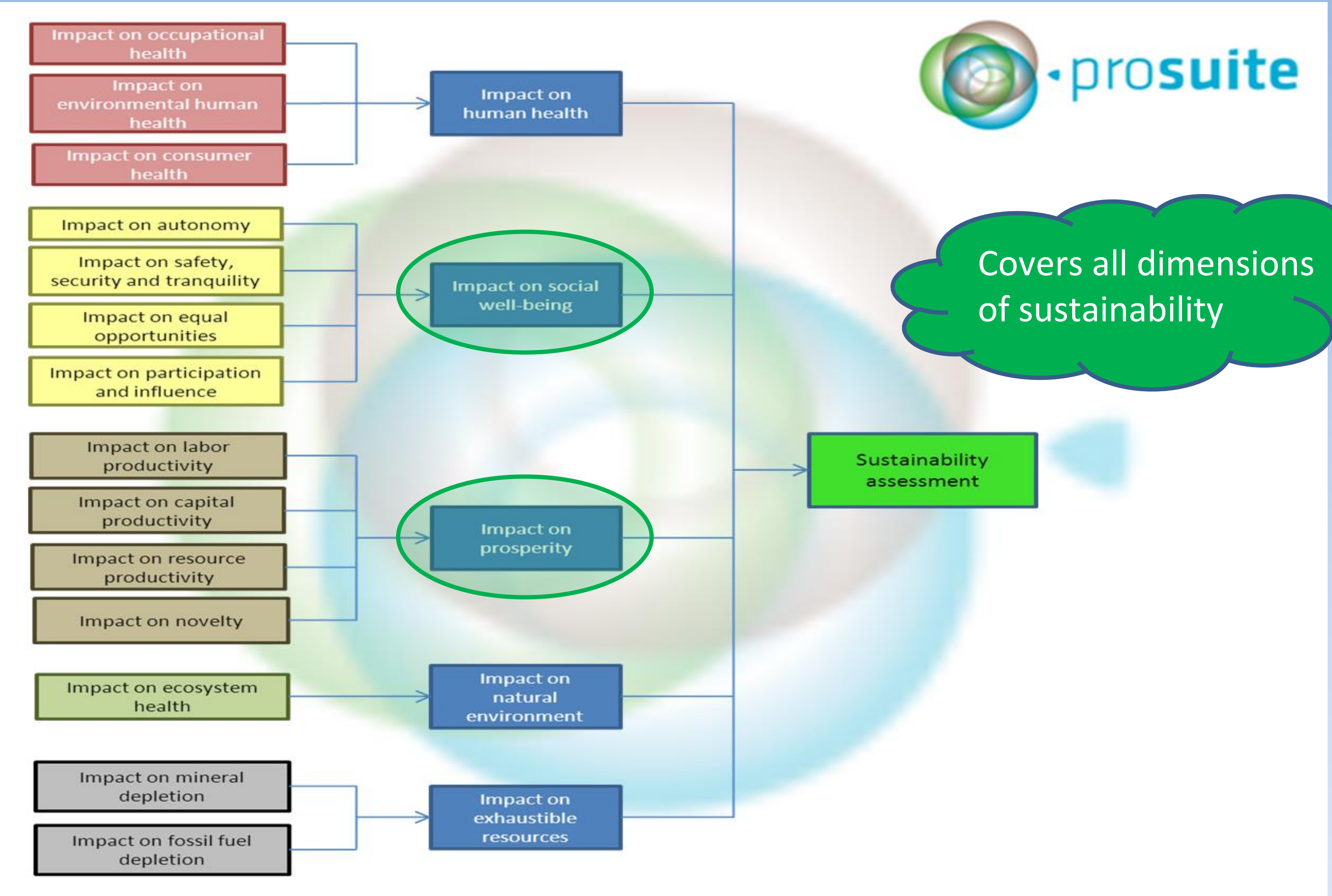
Functional unit:
1 kg silage maize



Prosuite project – an example

- Development and application of a standardised methodology for a prospective sustainability assessment of technologies
  - Covers social, economic and environmental impacts
  - Development of a user-friendly publicly available software tool
- Problems of conventional methodologies for sustainability assessment
  - Often too specific for certain products
  - Not applicable to wide range of technologies
  - No clear aggregation of various impacts
- There is a need for sustainability assessment method that
  - Is applicable to a wide range of technologies
  - Covers all dimensions of sustainability in a comprehensive way
  - Pursues a rigorous assessment along the cause-effect chain to ultimate scores

Prosuite project – an example



Closing notes

- It is not the product, but the life-cycle of the product that determines its environmental impact.
- To conduct a LCA
  - Apply systematic analysis
  - Identify system boundaries and functional unit
  - Identify all related sources and sinks of energy and materials
- Even if the life-cycle is mapped out, there still exist many uncertainties as to the environmental impact of the processes involved. There is still an immense lack of reliable data.
- The LCA currently has to be a compromise between practicality and completeness
- Life cycle sustainability analysis is in development

Thank You