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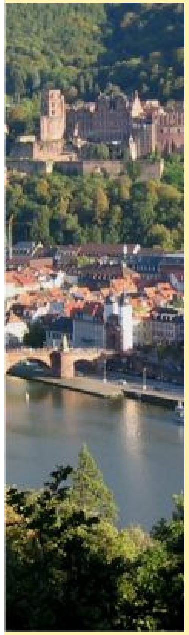
Life cycle assessments of selected future energy crops for Europe

Nils Rettenmaier

4th Workshop of the 4F CROPS project
Lisbon, 19 November 2010

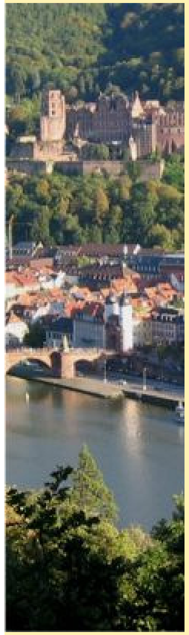
Who we are - What we do



IFEU - Institute for Energy and Environmental Research Heidelberg, since 1978

- **Independent scientific research institute**
- **organised as a private non profit company with currently about 40 employees**
- **Research / consulting on environmental aspects of**
  - Energy (including Renewable Energy)
  - Transport
  - Waste Management
  - Life Cycle Analyses
  - Environmental Impact Assessment
  - Renewable Resources
  - Environmental Education

Who we are - What we do



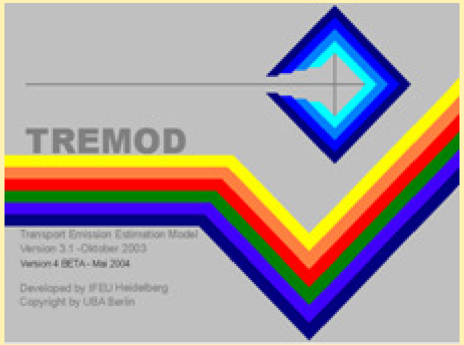
IFEU focuses regarding the topic of biomass

- **Research / consulting on environmental aspects of**
  - transport biofuels
  - biomass-based electricity and heat
  - biorefinery systems
  - biobased materials
  - agricultural goods and food
  - cultivation systems (conventional agriculture, organic farming, etc.)
- **Potentials and future scenarios**
- **Technologies / technology comparisons**
- **CO_2 avoidance costs**
- **Sustainability aspects / valuation models**

Who we are - What we do

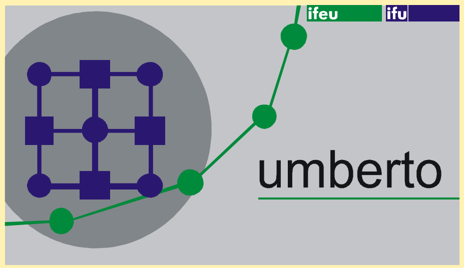
TREMOD: Transport Emission Model

- Modelling emissions of road vehicles, trains, ships and airplanes
- Official database of the German Ministries for emission reporting

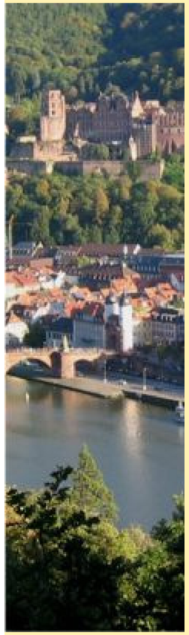


Life cycle analyses (LCA) and technology impact assessments since 1990:

- Biofuels (all biofuels, all applications)
- Alternative transportation modes
- Renewable Energy



Who we are - What we do



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Our clients (on biomass studies)

- World Bank
- UNEP, FAO, UNFCCC, GTZ, etc.
- European Commission
- National and regional Ministries
- Associations (industrial, scientific)
- Local authorities
- WWF, Greenpeace, Friends of the Earth etc.
- Companies (Daimler, German Telecom, Shell etc.)
- Foundations (German Foundation on Environment, etc.)

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Life cycle analyses for 4F CROPS

Modeling and Analysis

Biofpr
Biofuels, Bioproducts & Biorefining

Life cycle assessment of selected future energy crops for Europe

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Abstract: Life cycle assessment (LCA) methodology is increasingly used to determine the potential environmental impacts of biofuels and bioenergy. This paper presents the outcomes of screening LCAs of 13 future energy crops for Europe summarizing the results of the EC-funded project *4F CROPS – Future Crops for Food, Feed, Fiber and Fuel*. For analysis, these dedicated energy crops – representing seven environmental zones in Europe – are combined with a multitude of processing and utilization options, resulting in 120 different biofuel and bioenergy chains. Compared to fossil fuels and energy carriers, all biofuel and bioenergy chains show environmental advantages in terms of life-cycle energy use and greenhouse gas (GHG) emissions but mostly disadvantages regarding other environmental impact categories. Quantitative results vary widely across environmental zones, depending on crop species, agricultural inputs, and yield. Moreover, coproduct accounting and coproduct utilization, as well as the agricultural and fossil reference system play an important role. In view of environmental advantages and disadvantages, subjective trade-offs are required between the environmental impact categories. If saving GHG emissions is given the highest environmental priority, combined heat and power generation from herbaceous lignocellulosic crops is the most efficient option in terms of land use, provided that the biomass is cultivated on surplus agricultural land, thus avoiding indirect land-use change. © 2010 Society of Chemical Industry and John Wiley & Sons, Ltd

Keywords: biofuels; bioenergy; energy crops; life cycle assessment (LCA), greenhouse gas (GHG) emissions; land-use change (LUC)

Introduction

Climate change and concerns of energy security are the main drivers for the promotion of renewable energy carriers. One of the main pillars of the strategy to mitigate climate change and save non-renewable energy carriers is the use of biomass for energy. Strong incentives have been put in place to increase the use of bioenergy both in the transport as well as in the energy sector, mainly in the form of mandatory targets.[1,2] Many countries have implemented policies to foster biofuels and bioenergy, including tax exemptions or relief, feed-in tariffs or quotas. Despite considerable potential to mitigate climate

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Life cycle assessment of selected future energy crops for Europe

Article based on results of the 4F CROPS project.

Authors:
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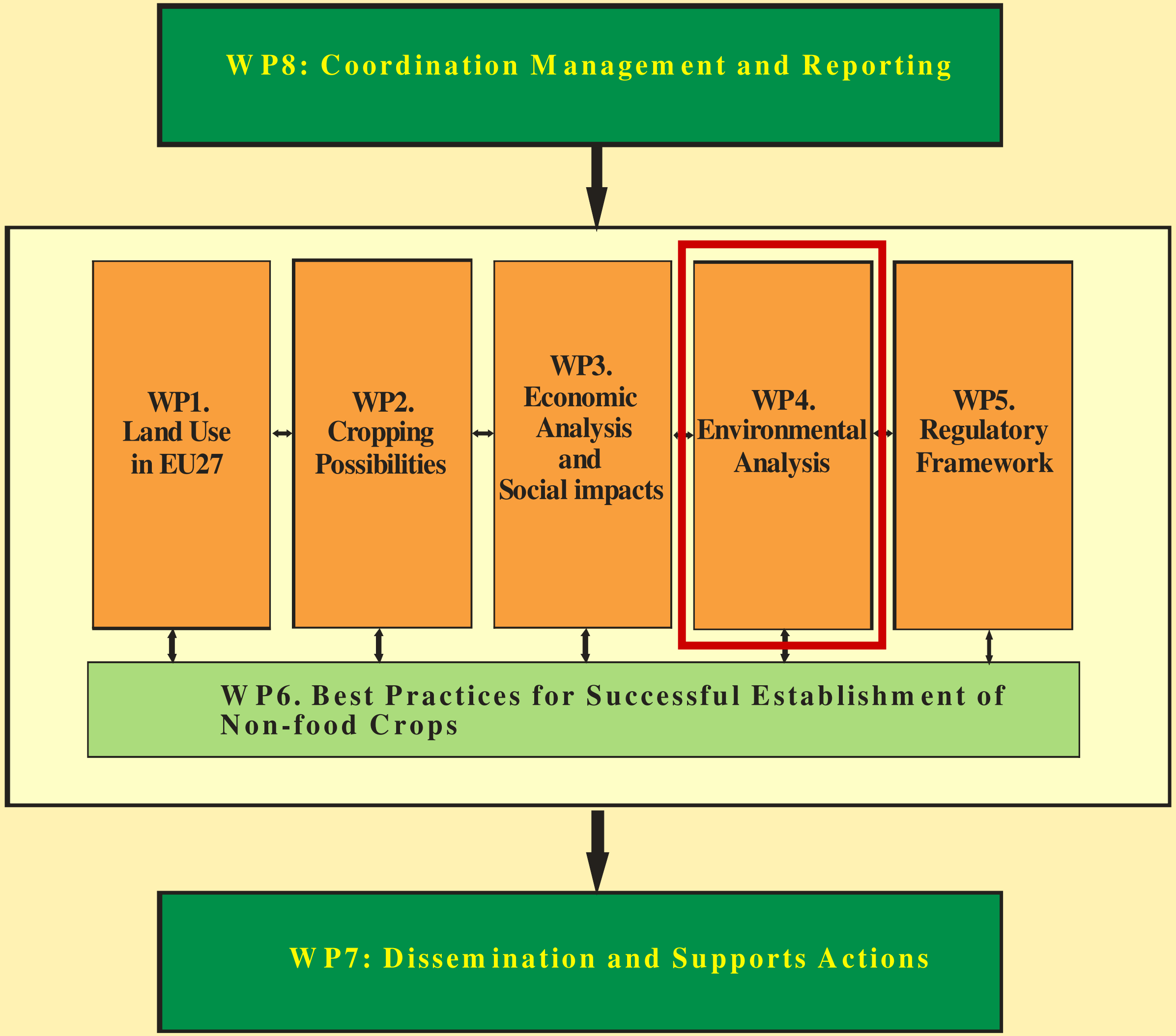
Project duration:
Jun 2008 – Nov 2010

4F CROPS: Environmental analysis



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- Conclusions

Biofuels and bioenergy

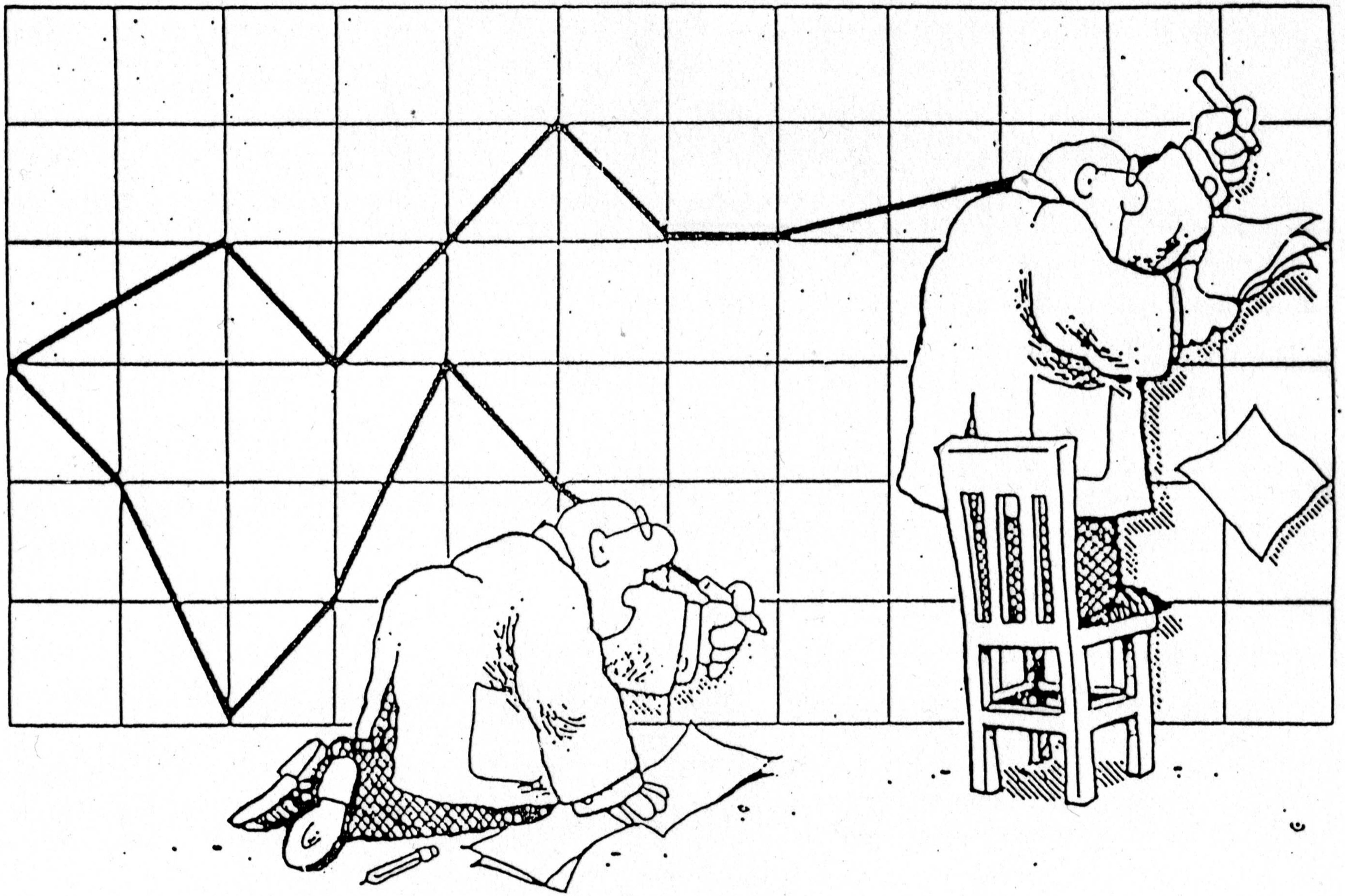
Environmental advantages and disadvantages:

+	−
• CO_2 neutral	• Land use
• Save energetic resources	• Eutrophication of surface water
• Organic waste reduction	• Water pollution by pesticides
• Less transport	• Energy intensive production
• etc.	• etc.

Total:

positive or negative

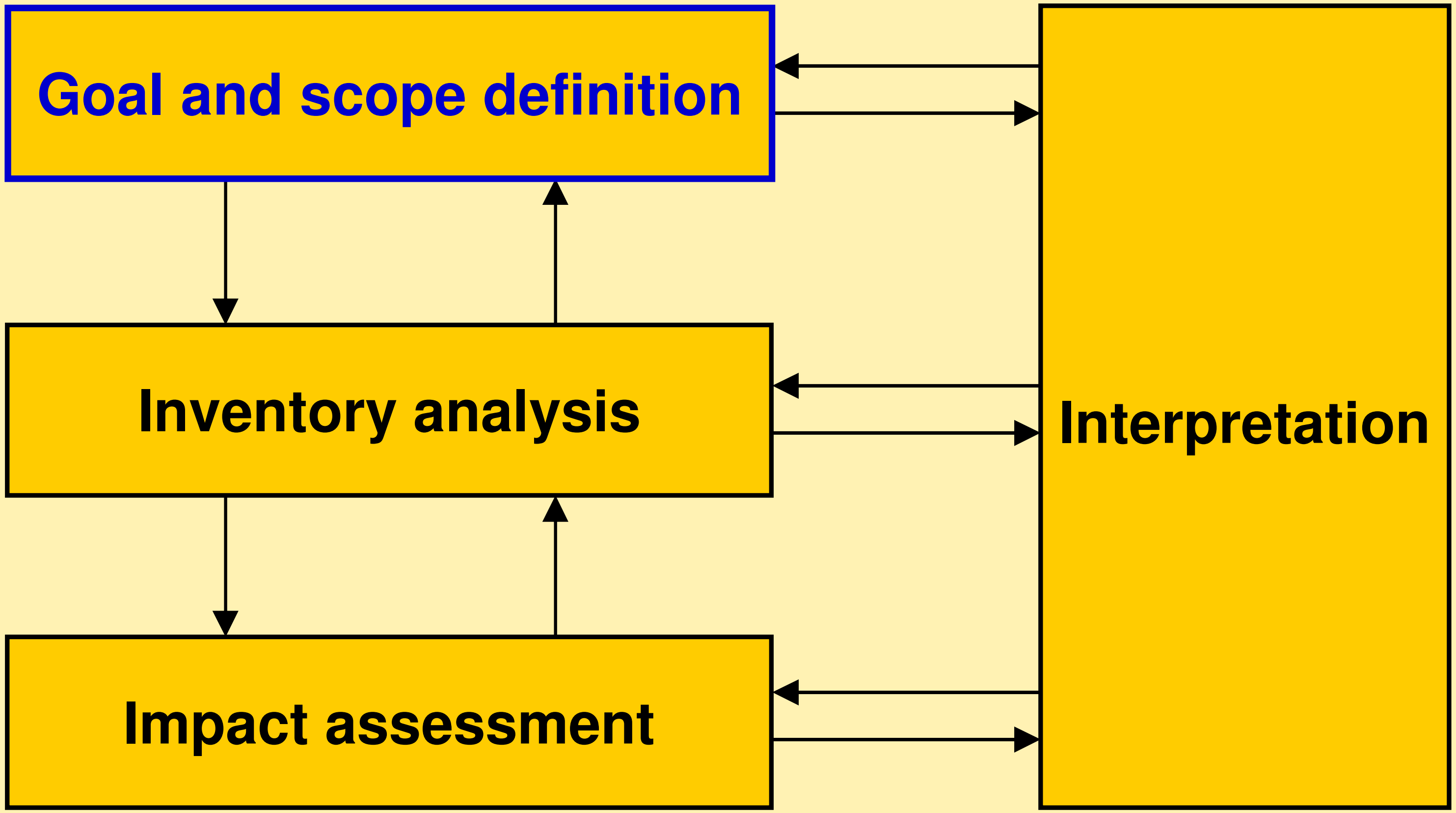
?



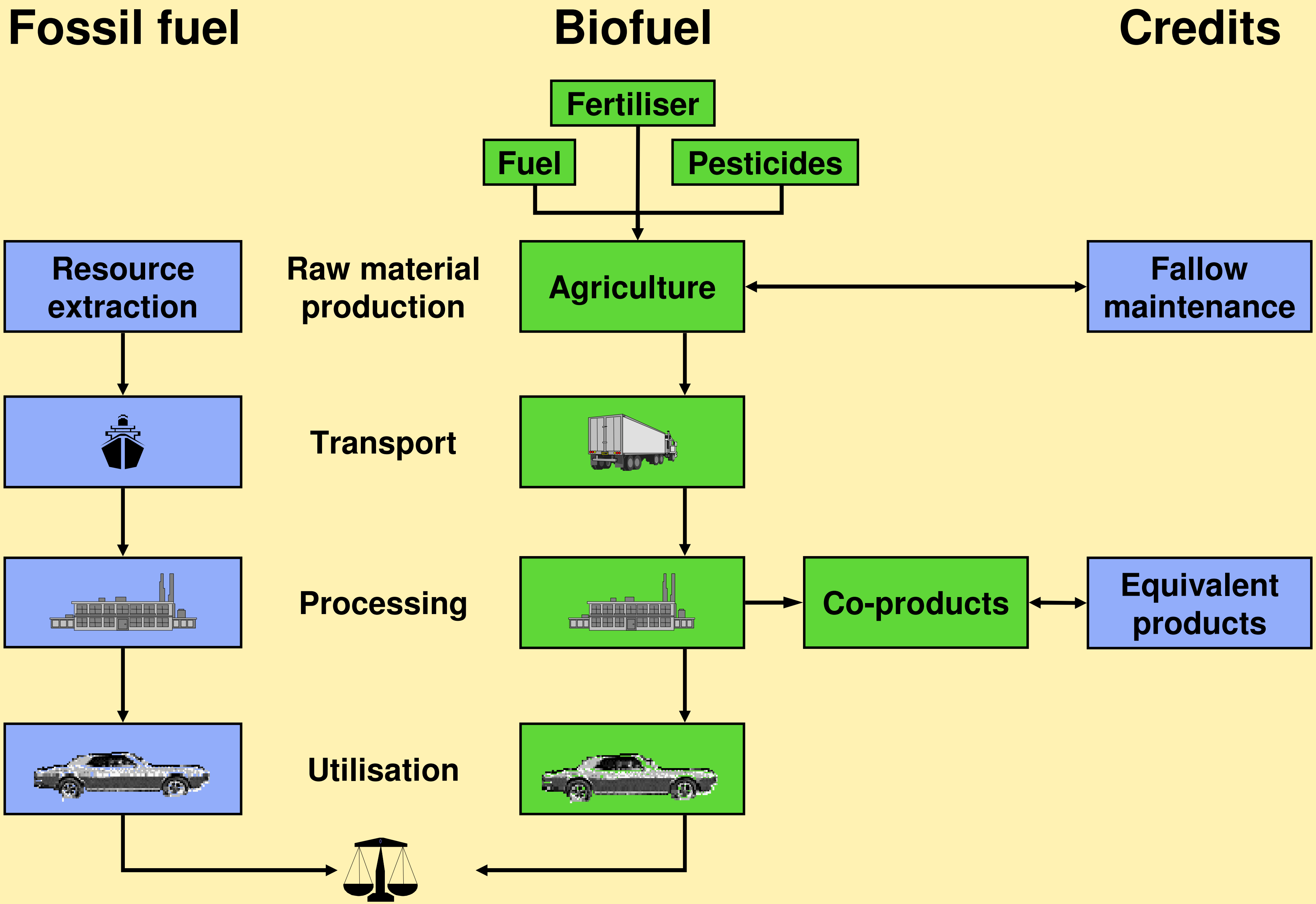
"HEY, I THOUGHT WE WERE WORKING WITH THE SAME DATA..."

Life cycle analysis (LCA)

ISO 14040 & 14044

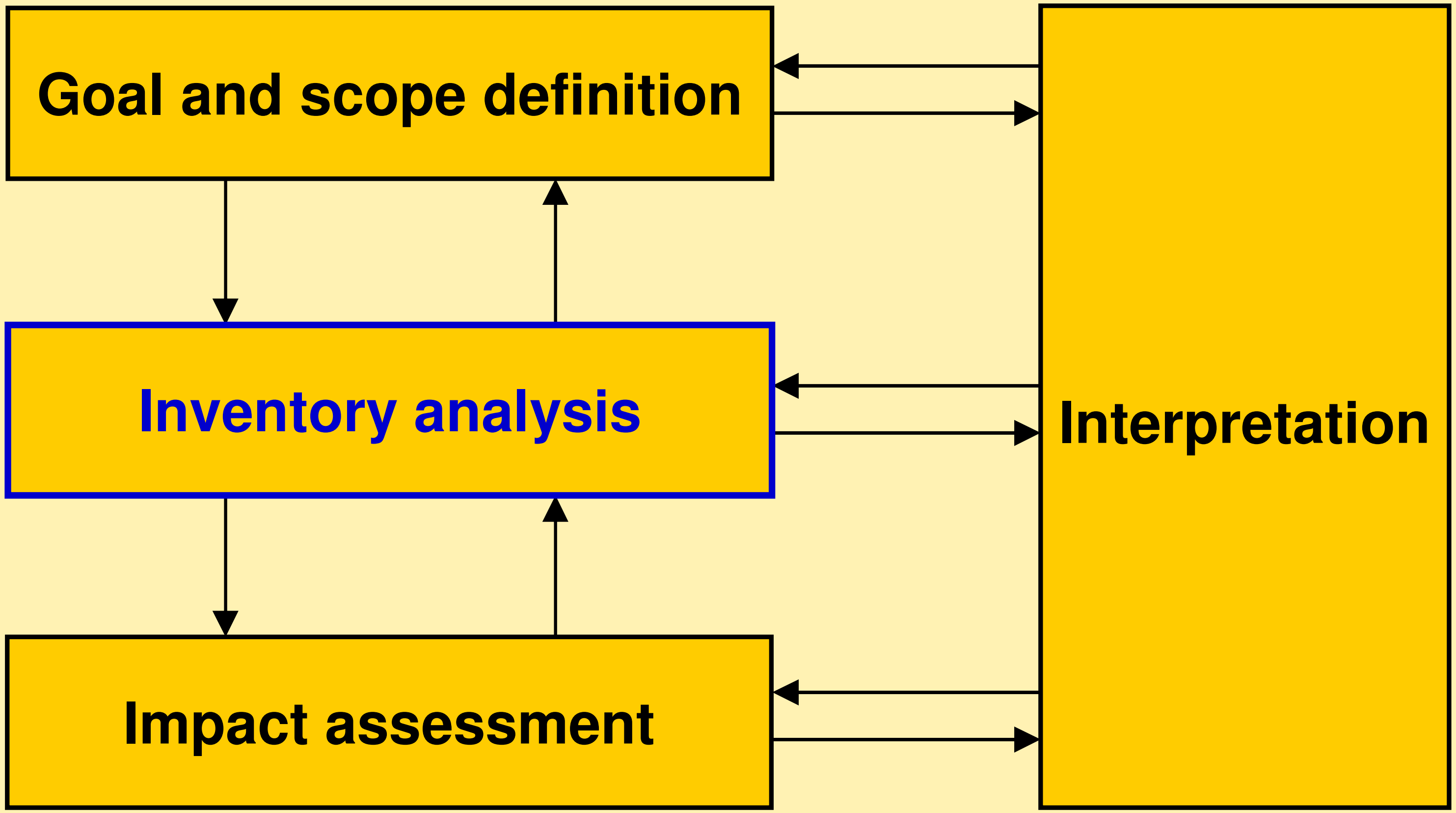


LCA: Life cycle comparison



Life cycle analysis (LCA)

ISO 14040 & 14044

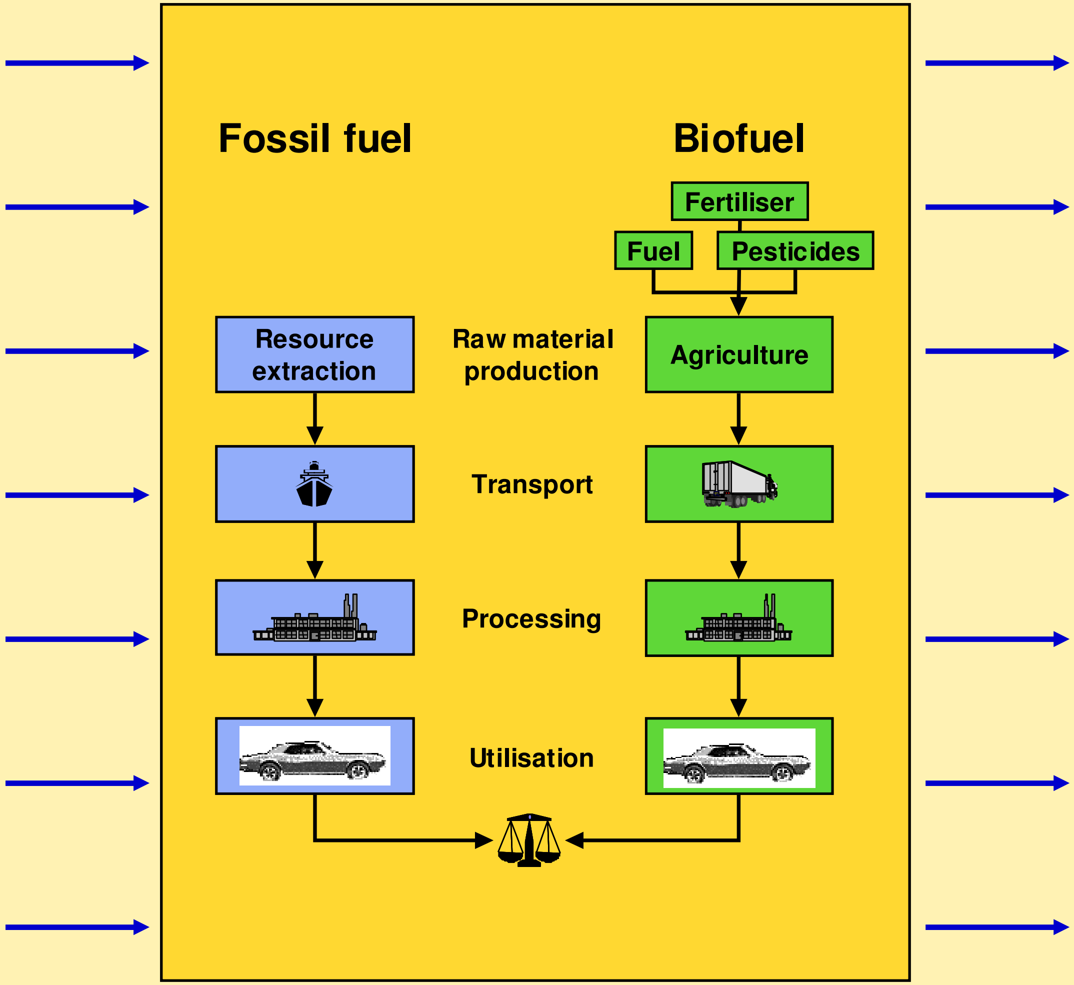


LCA: Inventory Analysis

Inputs

e.g.:

- natural gas
- crude oil
- brown coal
- hard coal
- uranium
- water



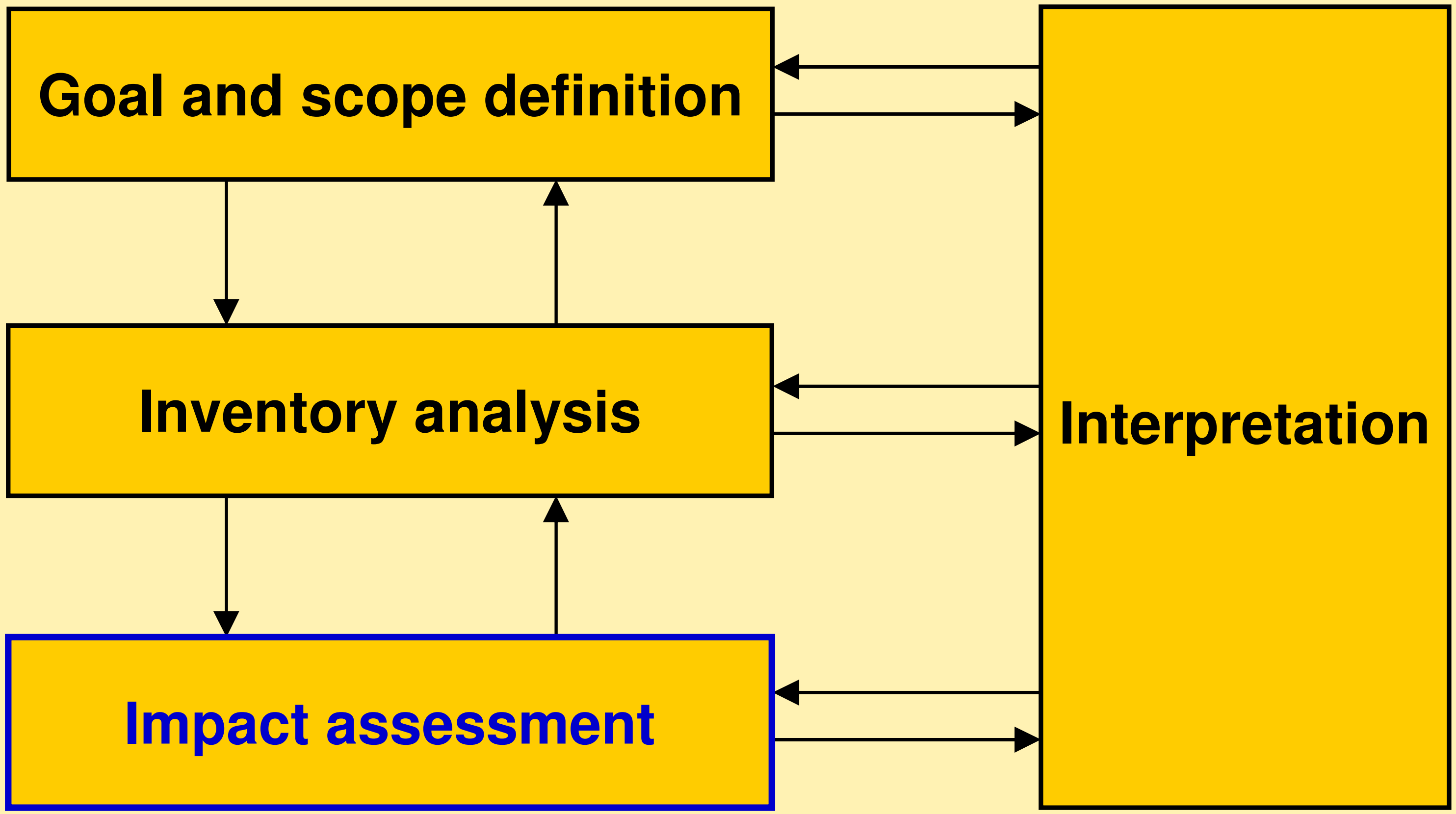
Outputs

e.g.:

- CO_2
- SO_2
- CH_4
- NO_X
- NH_3
- N_2O
- HCl
- CO
- C_6H_6
- VOC

Life cycle analysis (LCA)

ISO 14040 & 14044



LCA: Impact assessment

Impact category	Parameter	Substances (LCI)
Resource demand	Sum of depletable primary energy carriers Mineral resources	Crude oil, natural gas, coal, Uranium, … Lime, clay, metal ores, salt, pyrite, …
Greenhouse effect	CO_2 equivalents	Carbon dioxide, dinitrogen monoxide, methane, different CFCs, methyl bromide, …
Ozone depletion	CFC-11 equivalents	Dinitrogen monoxide, CFC, halone, methyl bromide, …
Acidification	SO_2 equivalents	Sulphur dioxide, hydrogen chloride, nitrogen oxides, ammonia, …
Eutrophication	PO_4 equivalents	Nitrogen oxides, ammonia, phosphate, nitrate
Photosmog	C_2H_4 equivalents	Hydrocarbons, nitrogen oxides, carbon monoxide, chlorinated hydrocarbons, …
Human toxicity	PM10 equivalents	Nitrogen oxides, carbon monoxide, hydrogen chloride, diesel particles, dust, ammonia, benzene, benzo(a)pyrene, sulphur dioxide, dioxines (TCDD), …

Normalisation

Inhabitant equivalents: average footprint of EU27 citizen

Environmental impact category	Unit	EU27 inhabitant equivalent
Primary energy use	GJ / yr	82
Greenhouse effect	t CO_2 equivalent / yr	11
Acidification	kg SO_2 equivalent / yr	49
Eutrophication	kg PO_4 equivalent / yr	6
Summer smog (POCP)	kg C_2H_4 equivalent / yr	20
Ozone depletion	kg CFC-11 equivalent / yr	0.069
Human toxicity	kg PM10 equivalent / yr	40

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Selection of crops

MAIN PRODUCT	CLIMATIC AREA						
	Nemoral	Continental	Atlantic Central	Atlantic North	Lusitanian	Mediterra-nean North	Mediterra-nean South
Oil	Rapeseed	Rapeseed	Rapeseed	Rapeseed	Rapeseed	Sunflower	Ethiopian mustard
Ligno-cellulosic: Wood	Poplar	Willow	Poplar	Willow	Willow	Poplar	Eucalyptus
Ligno-cellulosic: Herbaceous	Reed canary grass	Miscanthus	Miscanthus + Switchgrass		Miscanthus	Giant reed	Cardoon
Sugar	-	Sugar beet	Sugar beet	-	Sweet Sorghum	Sweet Sorghum	Sweet Sorghum

Source: UNICT 2009

Data collection

Projected average yields of marketable product for 2020

[t fresh matter / ha]	ATC	ATN	CON	MDS	MDN	NEM	LUS
Ethiopian mustard				2.1			
Rapeseed	3.5	2.5	3.1			2.1	2.1
Sunflower					2.9		
Eucalyptus				10.4			
Poplar	7.3				12.1	9.6	
Willow		8.3	8.8				6.8
Cardoon				20.3			
Giant reed					51.3		
Miscanthus	31.8	15.9	32.3				33.8
Reed canary						14.7	
Switchgrass	18.4	12.2					
Sugar beet	88.4		90.9				
Sweet Sorghum				8.4	6.4		5.8

Source: UNICT 2009

Selection of conversions & products

IFEU has selected representative conversion paths and products taking into account relevant literature.

Crop category	Conversion path	Main product	Use
Oil crops	Combustion	Heat & power	Light fuel oil & UCTE mix
		Heat	Light fuel oil
		Power	UCTE mix
	Transesterification	Biodiesel (FAME)	Diesel fuel
	Hydrotreatment	Biofuel (HVO)	Diesel vuel
Lignocellulosic crops (woody & herbaceous)	Combustion	Heat & power	Light fuel oil & UCTE mix
		Heat	Light fuel oil
		Power	UCTE mix
	Hydrolysis & fermentation	Second generation EtOH	Gasoline
	Gasification & FT synthesis	FT-diesel	Diesel fuel
Sugar crops	Fermentation	First generation EtOH	Gasoline

Source: Rettenmaier et al. 2010

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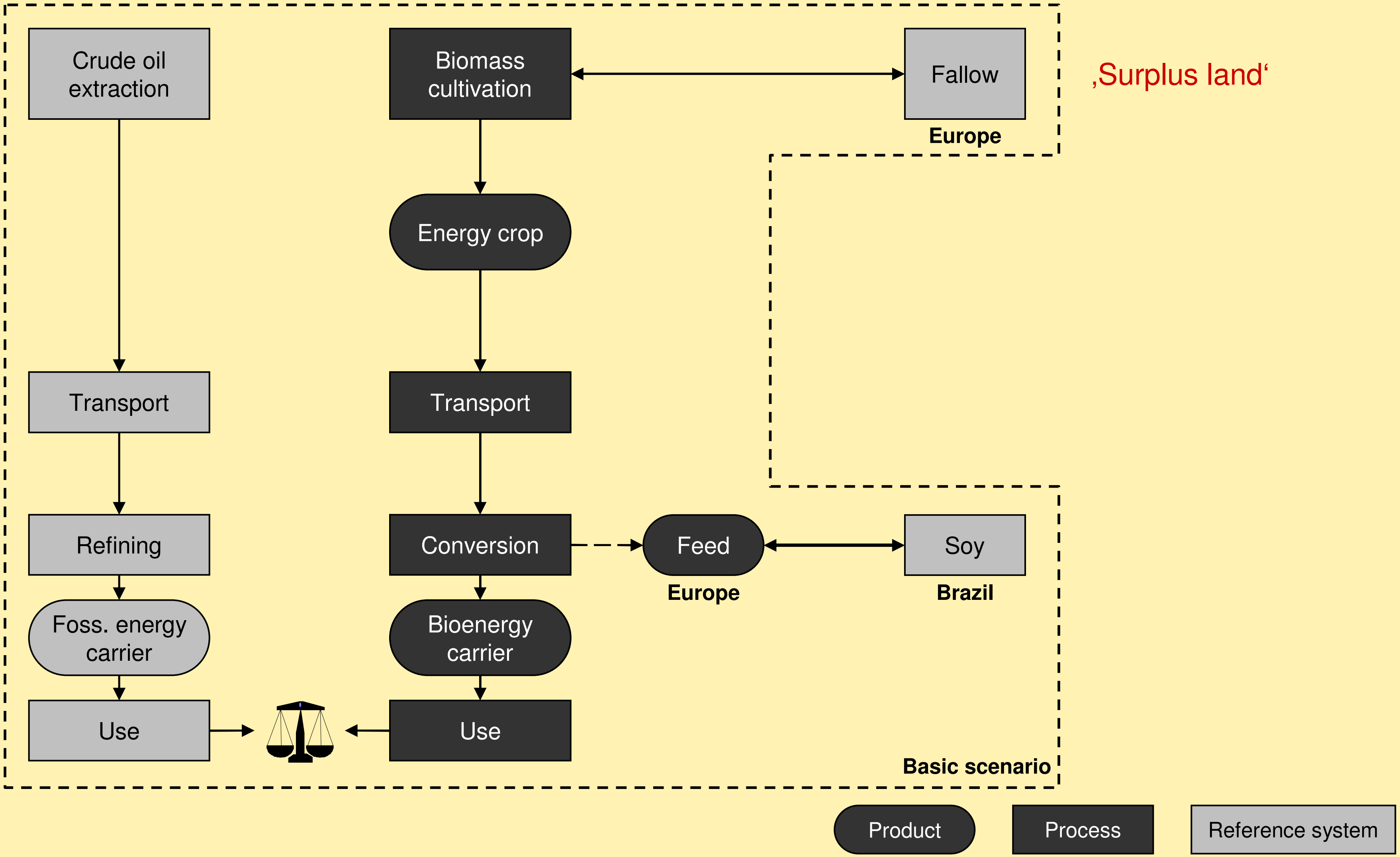
System boundaries



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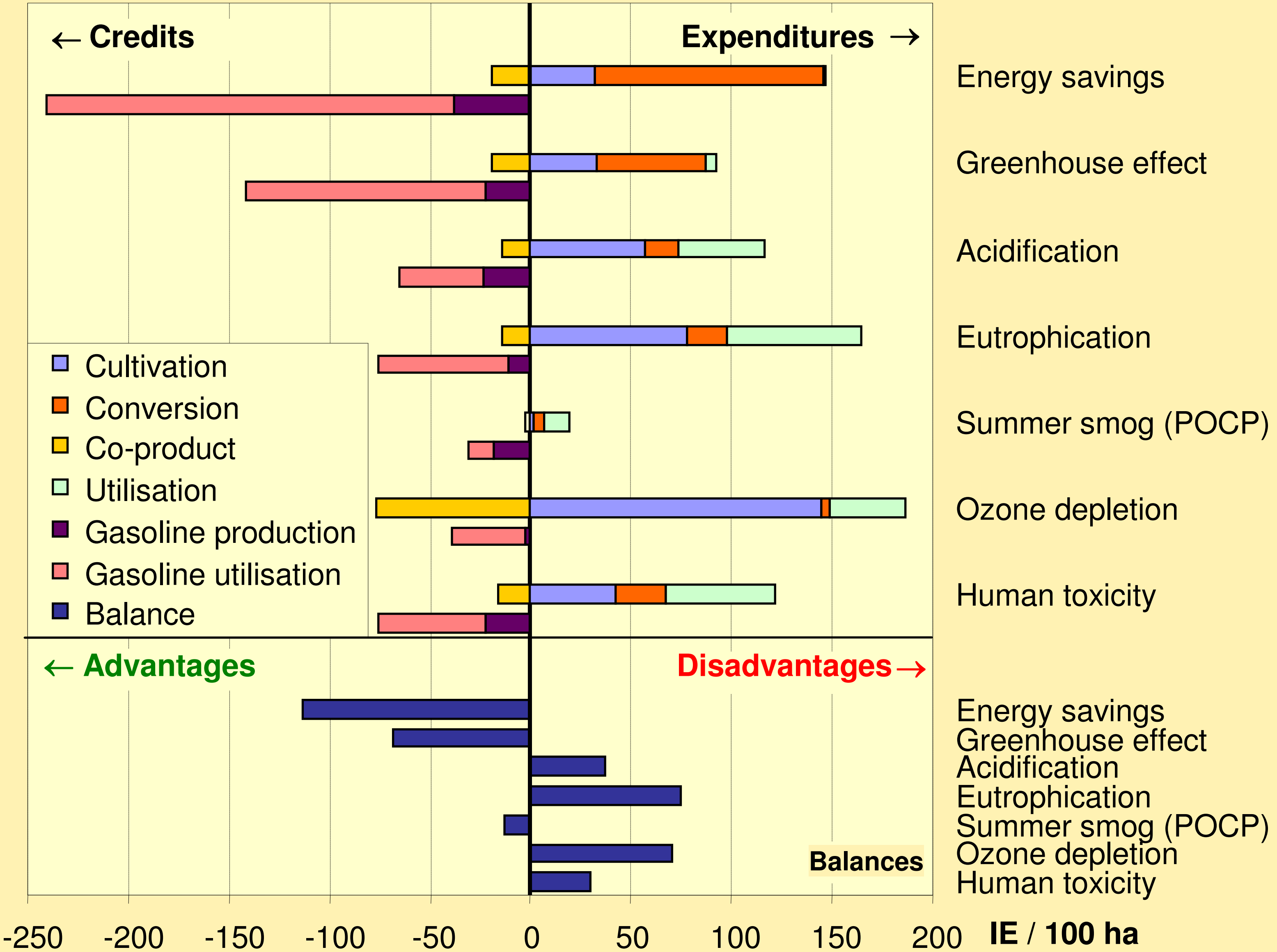
Detailed results: Sugar beet EtOH



Source: Rettenmaier et al. 2010

Overall environmental performance

Biofuel	Energy savings	Green-house effect	Acidifi-cation	Eutro-phication	Summer smog	Ozone depletion	Human toxicity
Oil crops – FAME	+	o	o	–	o	– –	o
Oil crops – HVO	+	o	o	–	o	– –	–
Oil crops – Heat & power	+	o	–	–	o	– –	–
Oil crops – Heat	+	o	–	–	o	– –	–
Oil crops – Power	+	o	–	–	o	– –	–
Woody crops – FT diesel	+	o	o	o	o	o	o
Woody crops – 2nd gen. EtOH	+	+	–	–	o	–	–
Woody crops – Heat & power	+ +	+	o	o	o	o	o
Woody crops – Heat	+	+	o	o	o	o	o
Woody crops –Power	+	o	o	o	o	o	o
Herb. crops – FT diesel	+ +	+	o	–	o	–	o
Herb. crops – 2nd gen. EtOH	+ +	+ +	–	–	+	–	–
Herb. crops – Heat & power	+ + +	+ +	o	–	o	–	o
Herb. crops – Heat	+ +	+ +	–	–	o	–	–
Herb. crops – Power	+ +	+	o	–	o	–	–
Sugar crops – 1st gen. EtOH	+ +	+	–	–	o	–	–

IE values per 100 hectares:
"+ + +": <-400; "++": -400 to – 100; "+": - 100 to -25; "o": -25 to 25; "-": 25 to 100; "- -": 100 to 400;

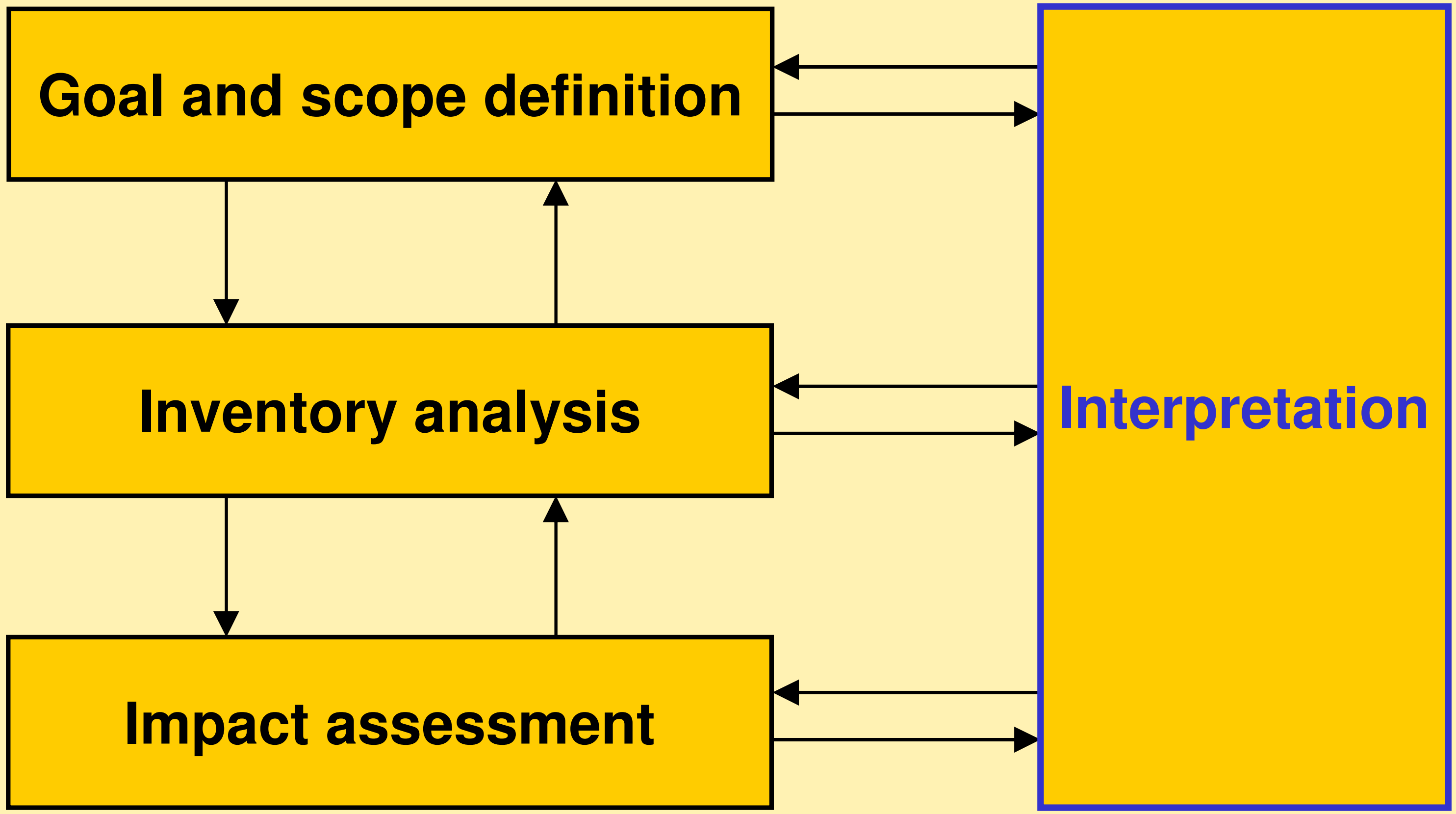
Source: Rettenmaier et al. 2010

Results: Bioenergy vs. fossil energy

1. All assessed biofuels and bioenergy carriers show environmental advantages as well as disadvantages when compared to their fossil / conventional equivalents.
2. Most biofuels and bioenergy carriers show advantages with regard to energy savings and greenhouse effect.
3. In contrast, most biofuels and bioenergy carriers show disadvantages with regard to acidification, eutrophication, ozone depletion and human toxicity.
4. The results don‘t show clear tendencies with regard to summer smog.

Life cycle analysis (LCA)

ISO 14040 & 14044



LCA: Interpretation

Statistics about Heidelberg

Inhabitants	130.000
School buildings (including university)	180
Bridges	5
Dogs	220
Tourists per day	5.500
Total	**135.905**

LCA: Interpretation

Impact category	Parameter	Ecological significance
Resource demand	Cumulative energy demand (non-renew.)	important
Greenhouse effect	CO_2 equivalents	very important
Ozone depletion	CFC-11 equivalents	(very) important
Acidification	SO_2 equivalents	medium relevance
Eutrophication	PO_4 equivalents	medium relevance
Human- and Ecotoxicity	Nitrogen oxide	medium relevance
Human- and Ecotoxicity	Diesel particulates	very important

Results: Bioenergy vs. fossil energy

5. An objective decision for or against a particular biofuel or bioenergy carrier cannot be made. However, based on subjective value-choices, a decision is possible.
6. If, for example, energy savings and greenhouse effect is given the highest priority, all biofuels and bioenergy carriers assessed are to be preferred over their fossil equivalents.
7. The amount of energy and greenhouse gases that can be saved greatly differs depending on the crops, conversion paths and main products, i.e. the entire life cycle has to be taken into account.

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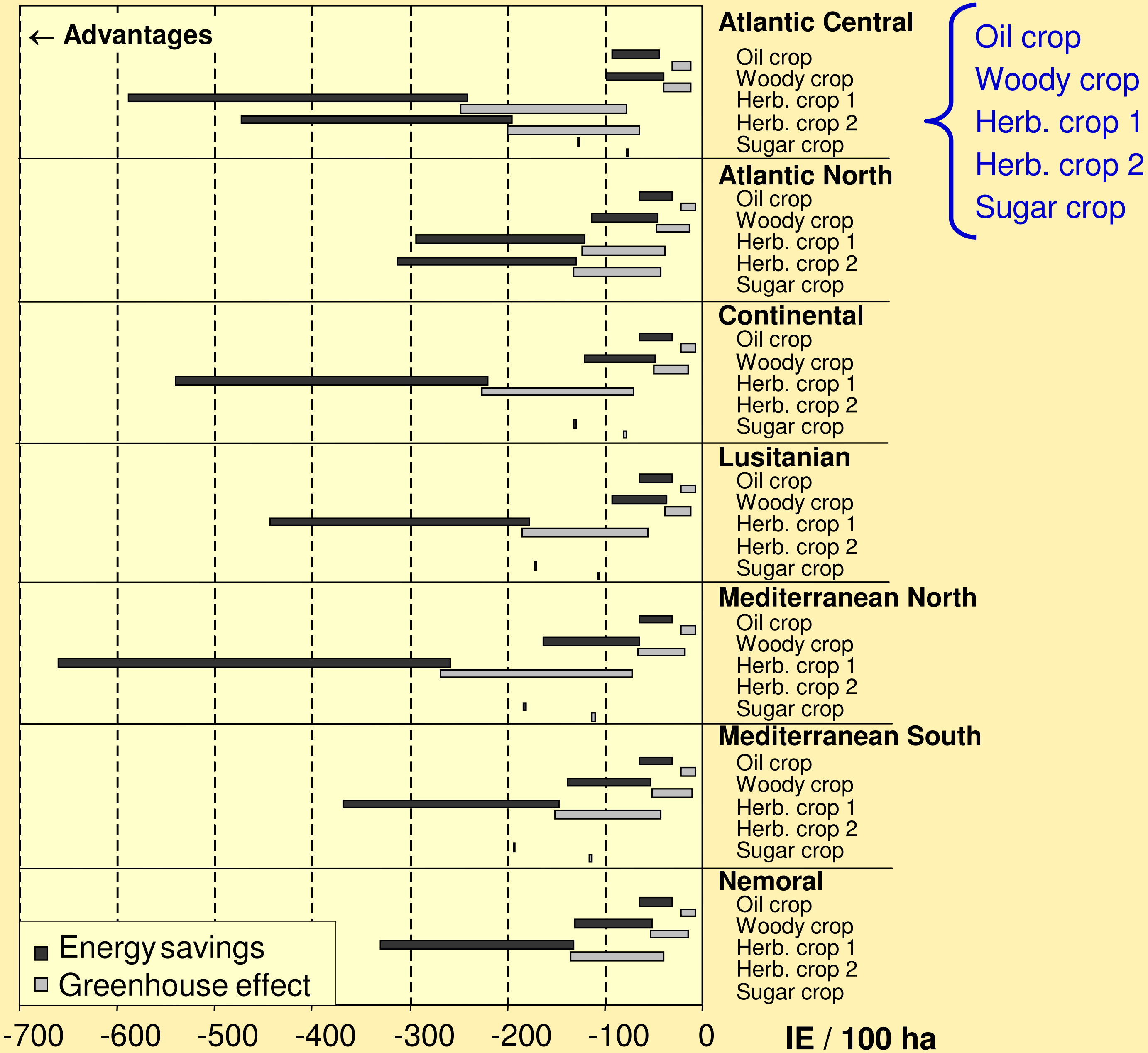
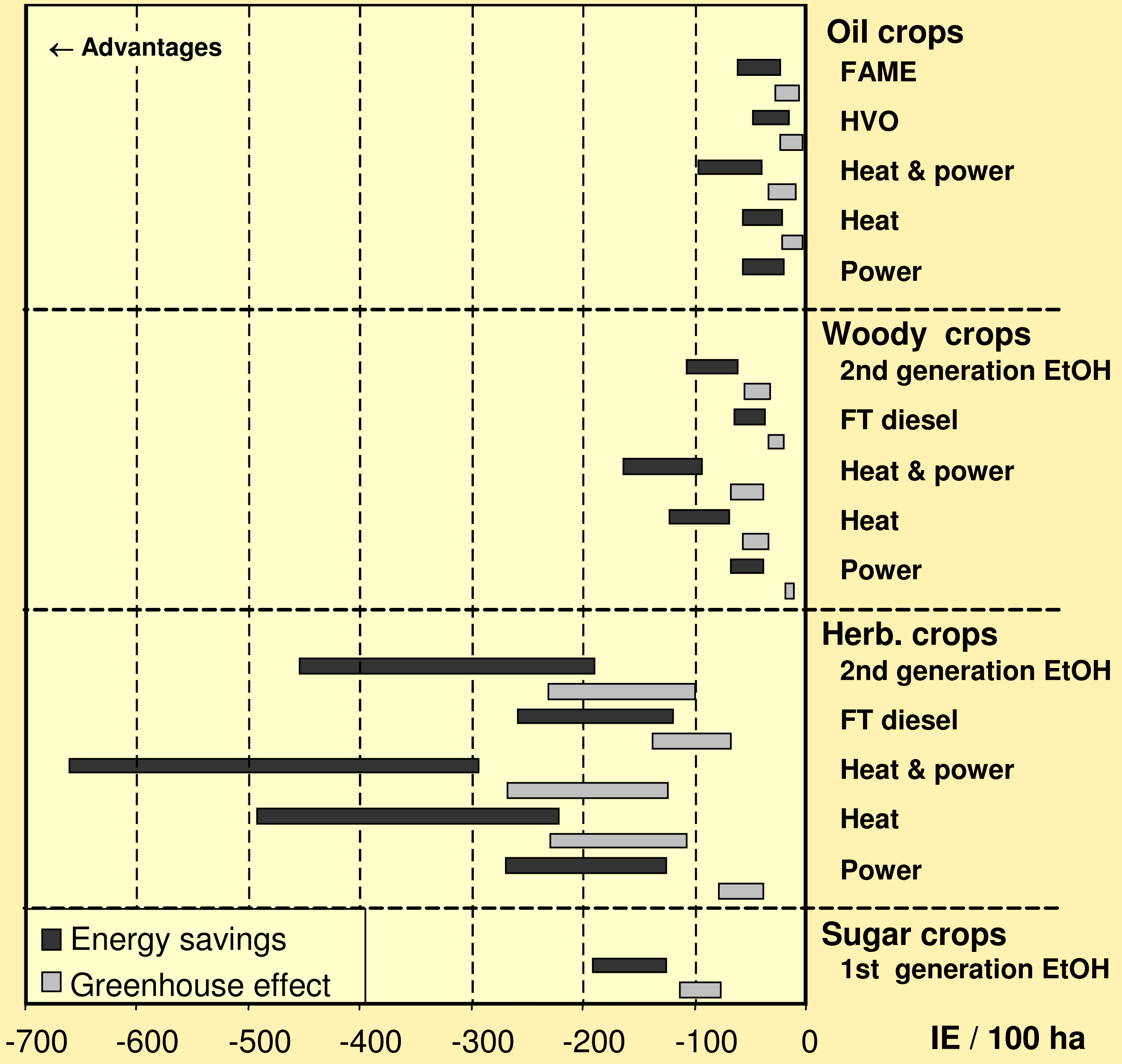
Comparison of environment. zones



Source: Rettenmaier et al. 2010

Comparison of bioenergy chains



Source: Rettenmaier et al. 2010

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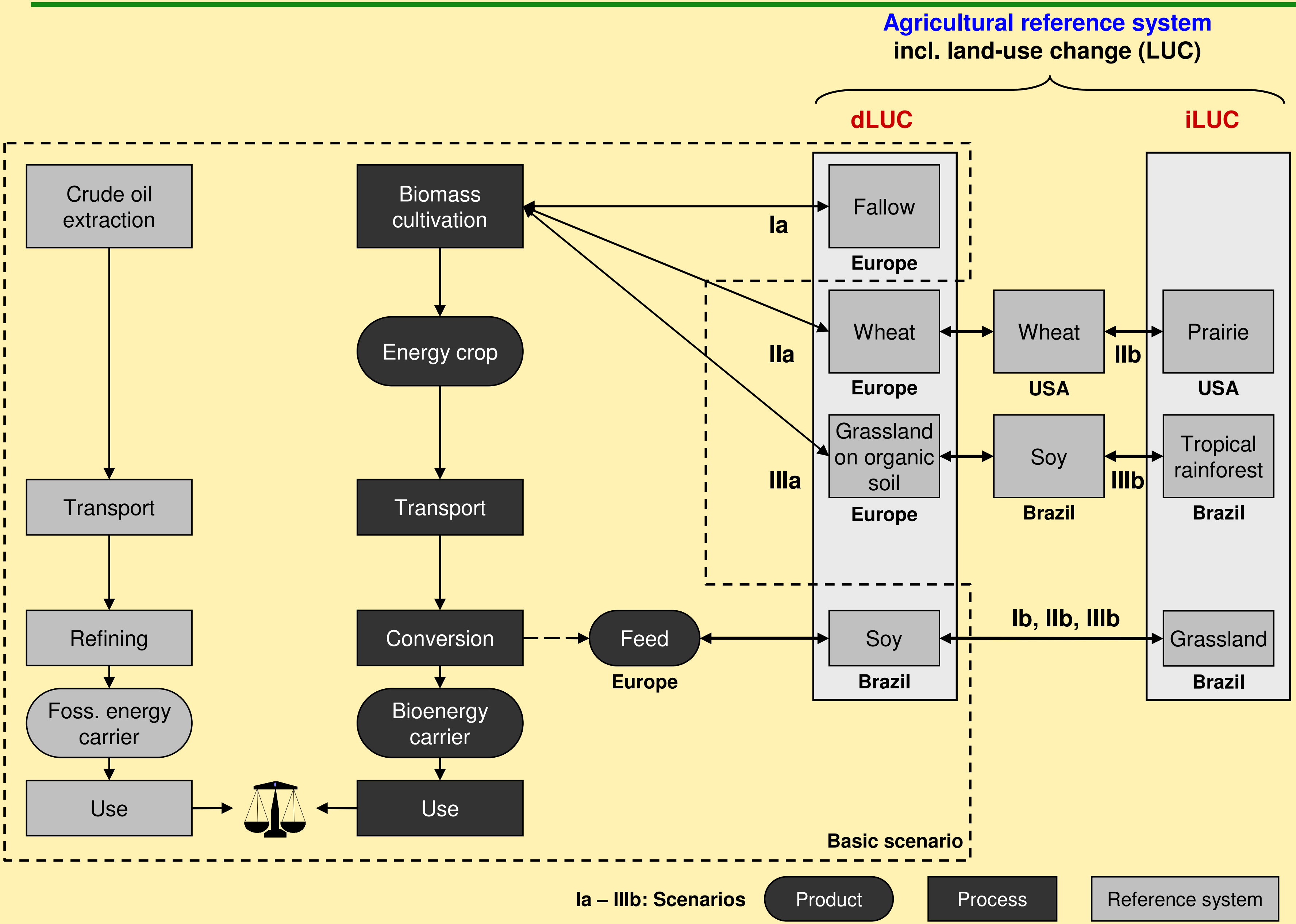
Sensitivity analyses

Variations & sensitivity analyses done:

- Variation of agricultural reference system
- Variation of yields
  - Differences between environmental zones
  - Yield increase over time (2008 vs. 2020 vs. 2030)
- Variation of co-product use
- Variation of co-product allocation
- Variation of stationary energy use
- Variation of substituted power mix

Agricultural ref. system and LUC



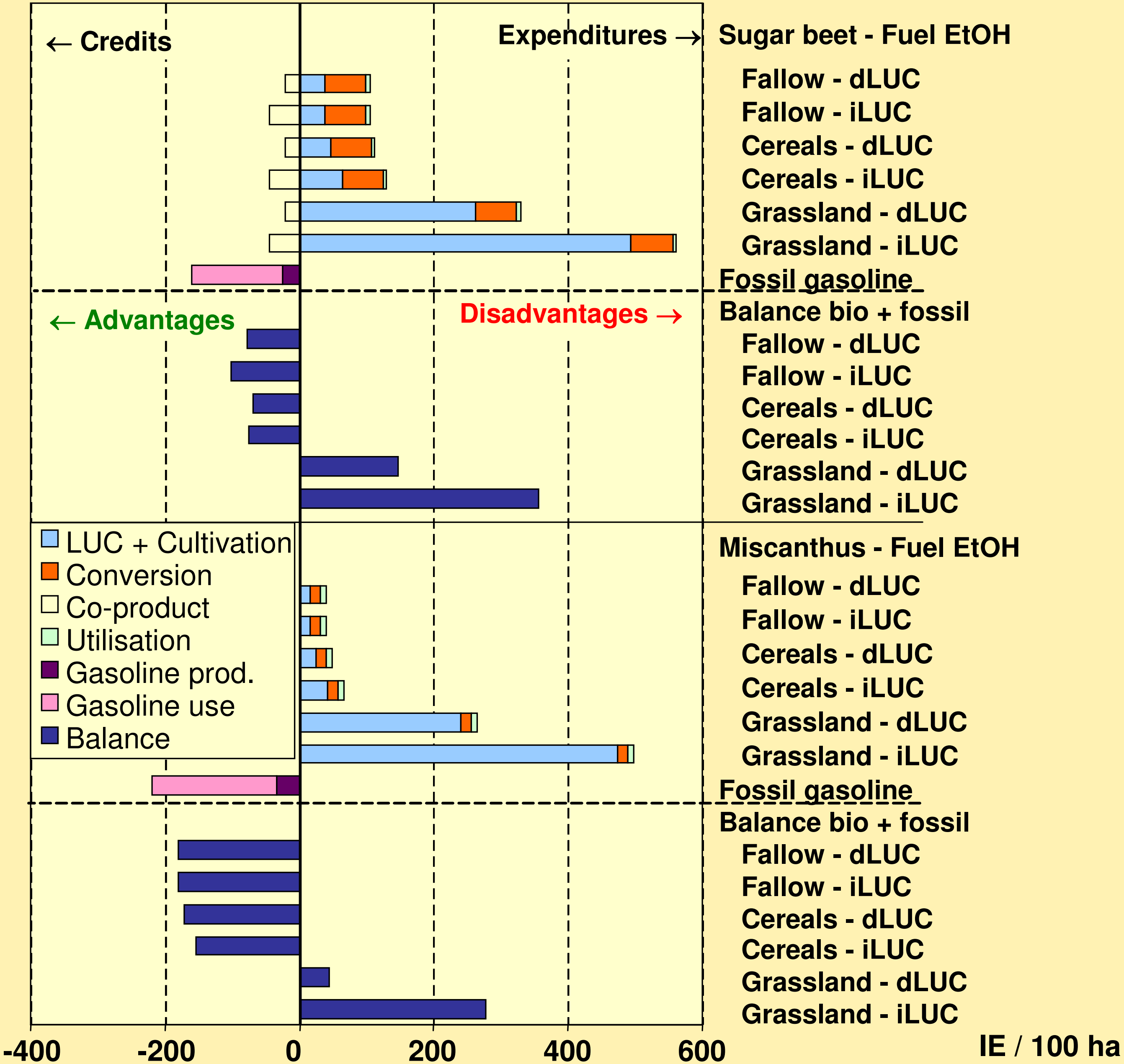
Source: Rettenmaier et al. 2010

LUC: Carbon stock changes

Name	N°	Carbon stock changes & GHG emissions due to crop cultivation (Miscanthus & sugar beet)	Carbon stock changes due to co-products (only sugar beet)
Fallow dLUC	I a	Replacing fallow: ±0 t C / ha	Land release not considered
Fallow iLUC	I b	Replacing fallow: ±0 t C / ha	Land release in Brazil: +10 t C / ha [30]
Cereals dLUC	II a	Replacing cereals in Europe: ±0 t C / ha	Land release not considered
Cereals iLUC	II b	Replacing cereals in Europe: ±0 t C / ha Displacing cereal production to US prairie: -10 t C / ha [30]	Land release in Brazil: +10 t C / ha [30]
Grassland dLUC	III a	Replacing grassland on organic soil in Europe: –13 t C / ha [30] Continuous GHG emissions from organic soil: 6 t C / (ha*yr) [31]	Land release not considered
Grassland iLUC	III b	Replacing grassland on organic soil in Europe: –13 t C / ha [30] Continuous GHG emissions from organic soil: 6 t C / (ha*yr) [31] Displacing feed production to Brazilian forests: -160 t C / ha [30]	Land release in Brazil: +10 t C / ha [30]

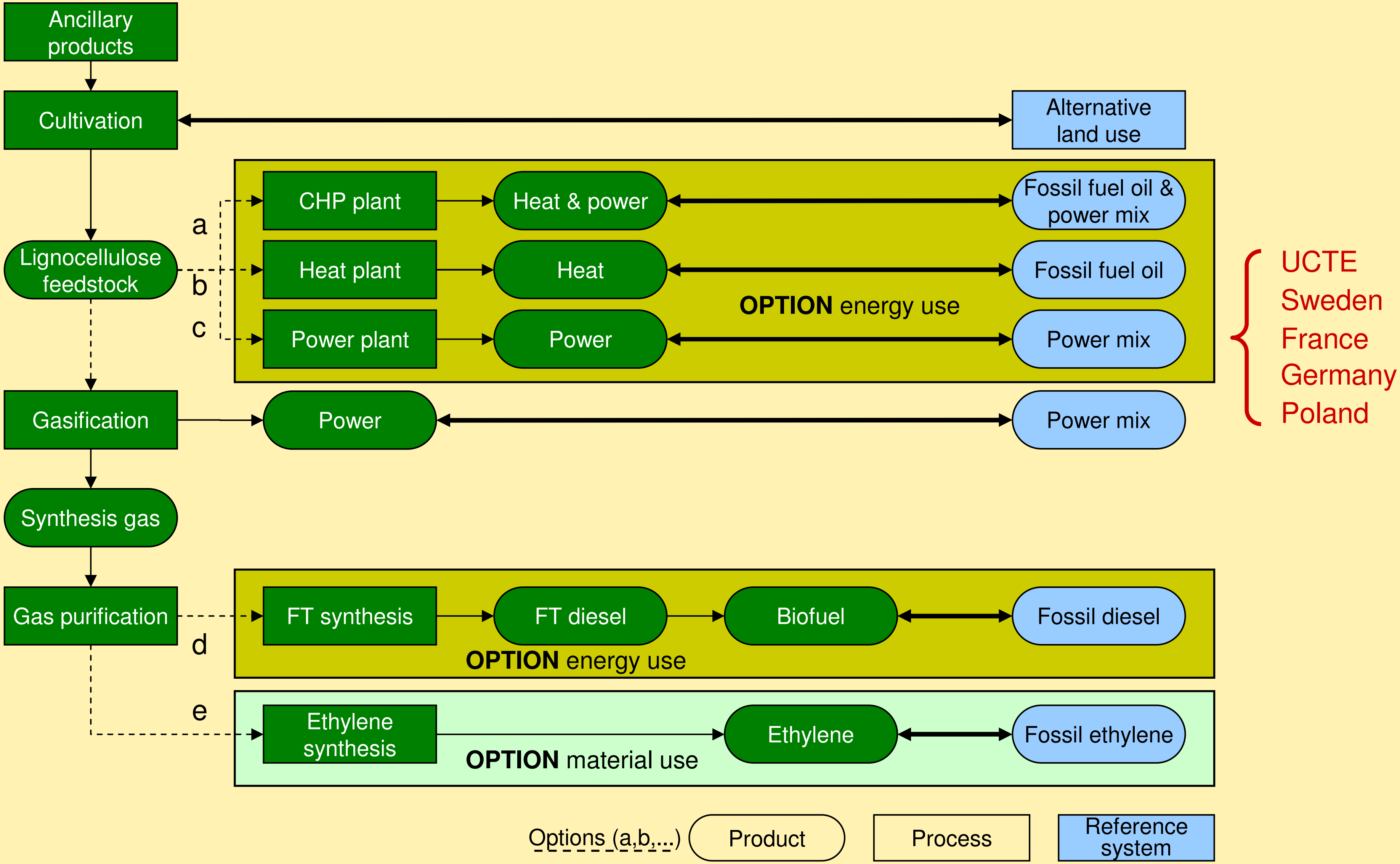
Source: Rettenmaier et al. 2010

Agricultural ref. system and LUC



Source: Rettenmaier et al. 2010

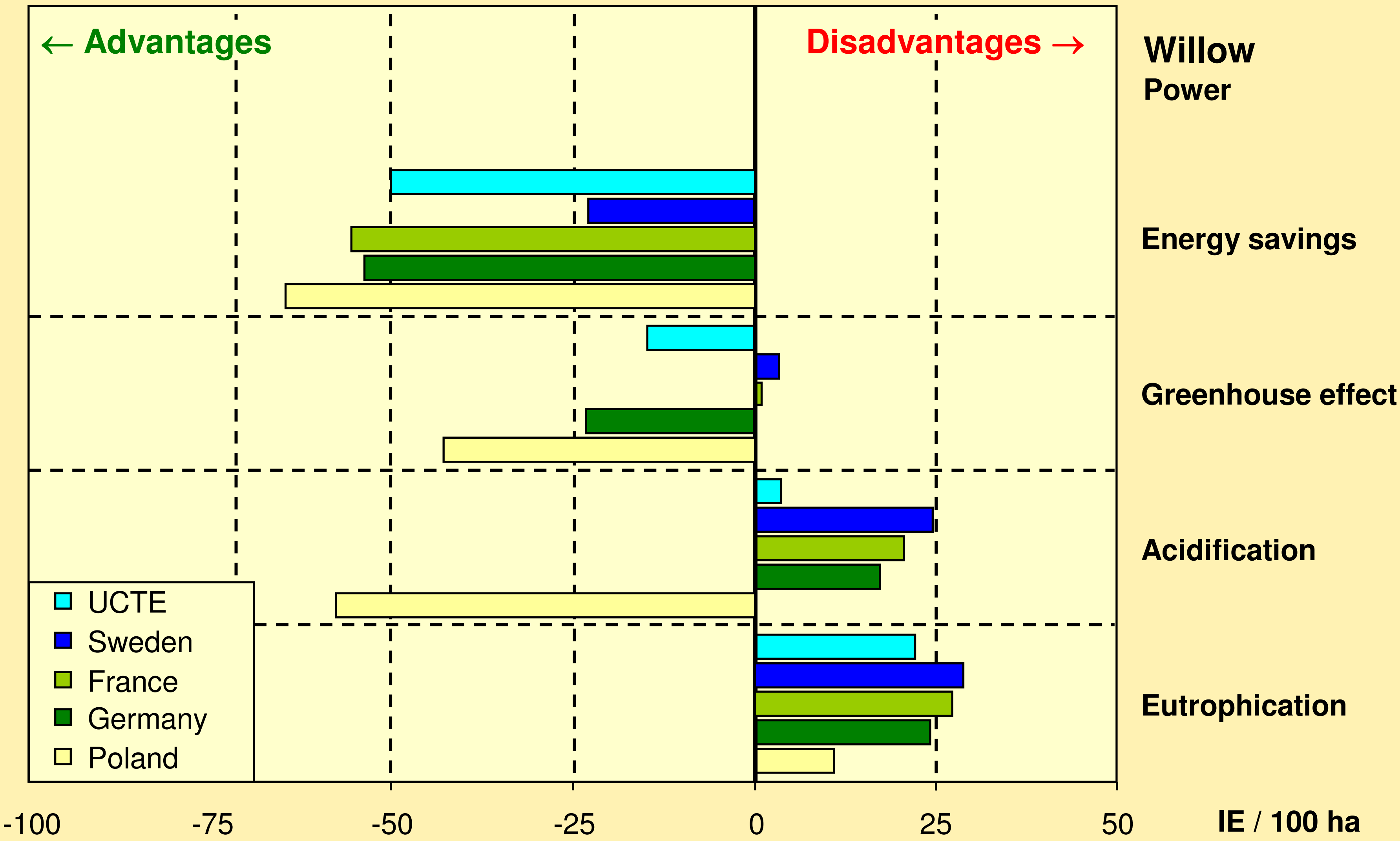
Variation of substituted power mix



Variation of substituted power mix

	Fuel oil & natural gas	Coal	Uranium	Hydro	Other renewable
UCTE	19%	33%	40%	6%	2%
Sweden	2%	3%	57%	29%	8%
France	4%	7%	84%	5%	1%
Germany	10%	57%	28%	2%	3%
Poland	4%	93%	1%	1%	1%

Variation of substituted power mix



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Results: Bioenergy vs. fossil energy

Environmental advantages and disadvantages

- Environmental advantages in terms of energy and GHG savings for all crops, environmental zones, and bioenergy chains
- But: Ambiguous results or even disadvantages other impact categories
- No scientifically objective conclusion regarding overall environmental performance can be drawn.
- The conclusion has to be drawn on subjective value-choices.

Results: Bioenergy vs. bioenergy

Best energy crops and bioenergy chains

- Herbaceous lignocellulosic crops are the most land-use-efficient options in terms of energy and GHG savings
- Stationary use of biomass (heat and/or power) usually outperforms the mobile use as transport biofuel
  - But: Quantitative results depend on case-specific conditions, in particular the replaced power mix.
- Bioethanol shows better results than all diesel substitutes
- Regarding first and second generation EtOH, no clear tendency could be found

Results: Sensitivity anlyses

Effects of methodological data choices

- **Most important single factor influencing the LCA is choice of agricultural reference systems including LUC.**
- **In case of bioenergy production on non-surplus land (replacement of food and feed production) even higher GHG emissions than by using fossil energy carriers possible.**
  - **But: research on iLUC still in its infancy.**

Conclusions

1. As land-use competitions are increasing, it is necessary to allocate the limited amount of biomass to the different sectors (food / feed / fiber and fuel) in such a way which achieves the highest environmental benefits.
2. LCAs are a suitable tool for environmental assessments. By means of sensitivity and weakness analyses, optimisation potentials can be identified.
3. The use of biomass can be significantly optimized from an environmental point of view by taking into account different biomass and co-product uses or site-specific conditions, e.g. power mixes in different countries.

Conclusions

4. Hence, LCA is a suitable scientific tool for policy analysis and decision making.
5. However, if local or regional concerns come into play, an Environmental Impact Assessment (EIA) will be necessary.

Thank you for your attention !

Sven Gärtner

Maria Müller-Lindenlauf

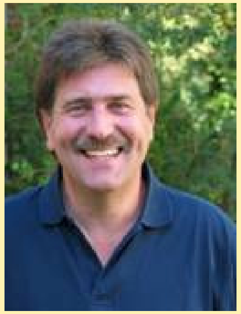
Guido Reinhardt

Regine Vogt

Horst Fehrenbach

Susanne Köppen

Bernd Franke



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