Camelina und Crambe:

Nachhaltige Alternativen für die Landwirtschaft?

Dr Guido Reinhardt

C.A.R.M.E.N.-Symposium 2019: Energie- & Ressourcenwende: Impulse aus dem ländlichen Raum

Straubing, 1 – 2. Juli 2019

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 80 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

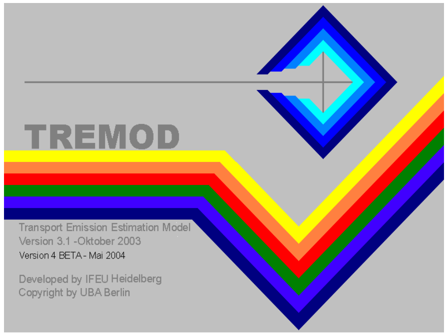
- Research / consulting on environmental aspects of
  - transport biofuels
  - biomass-based electricity and heat
  - biorefinery systems
  - biobased materials
  - agricultural goods and food
  - cultivation systems (conventional agriculture, organic farming, etc.)
- Potentials and future scenarios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

Who we are - What we do

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

- **Our clients (on biomass studies)**
  - World Bank
  - UNEP, GTZ, UNIDO, FAO, UNFCCC etc.
  - European Commission
  - National and regional Ministries
  - Associations (national and international)
  - Local authorities
  - WWF, Greenpeace, Friends of the Earth etc.
  - Companies (Daimler, German Telekom, etc.)
  - Foundations (German Foundation on Environment, British Foundation on Transport etc.)

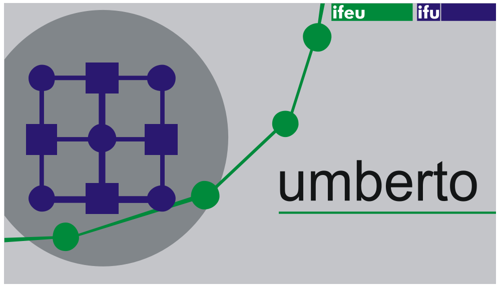
Who we are - What we do



TREMOD: Transport Emission Model

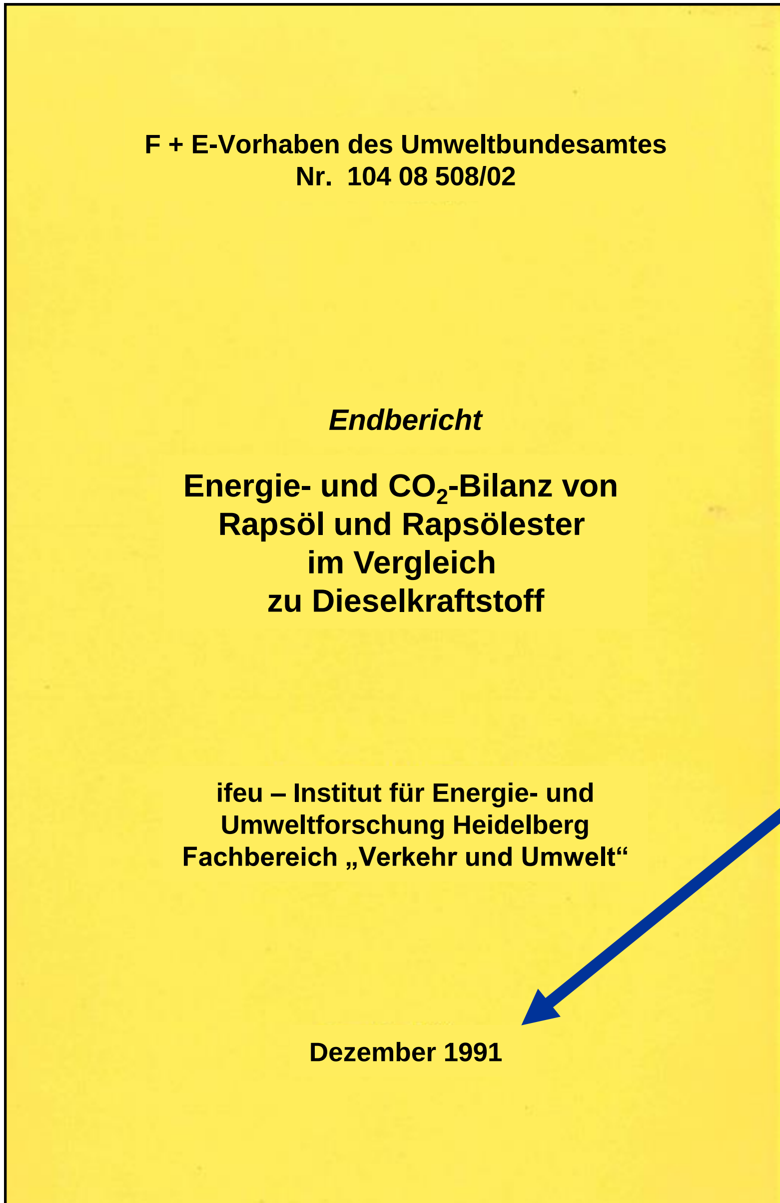
- **Modelling emissions of road vehicles, trains, ships and airplanes**
- **Official database of the German Ministries for emission reporting**

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



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

25 + years of experience


F + E-Vorhaben des Umweltbundesamtes
Nr. 104 08 508/02

Endbericht

Energie- und CO_2-Bilanz von Rapsöl und Rapsölester im Vergleich zu Dieselkraftstoff

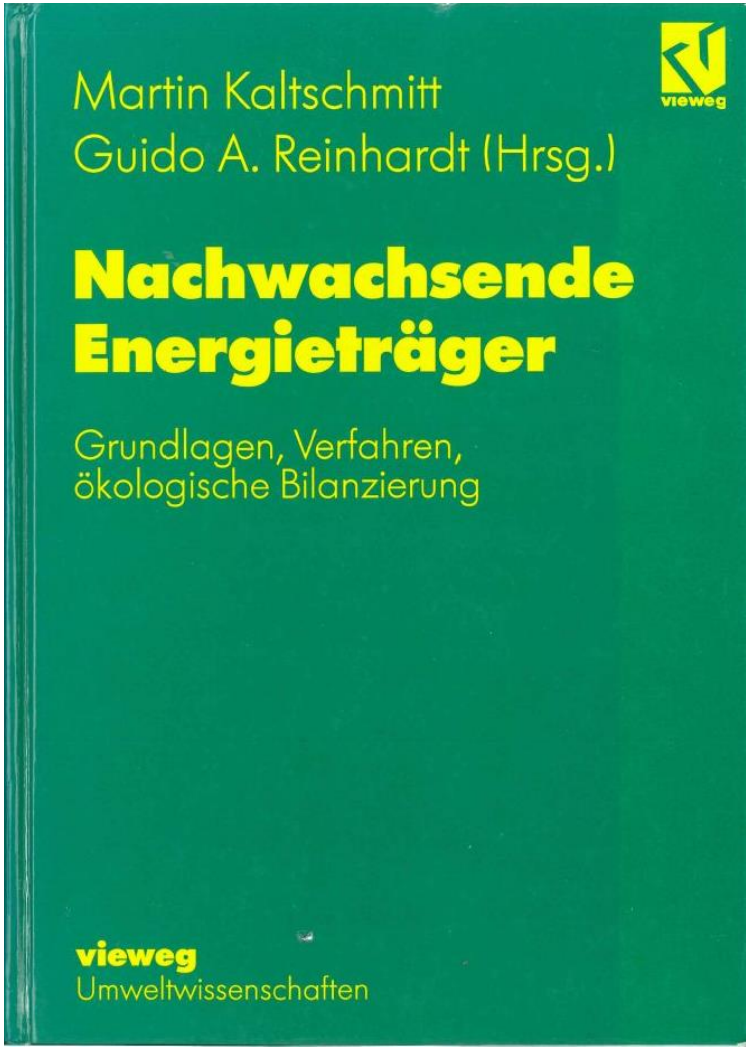
ifeu – Institut für Energie- und Umweltforschung Heidelberg
Fachbereich „Verkehr und Umwelt“

Dezember 1991

First full life cycle balance on biodiesel in Europe

1991

1997



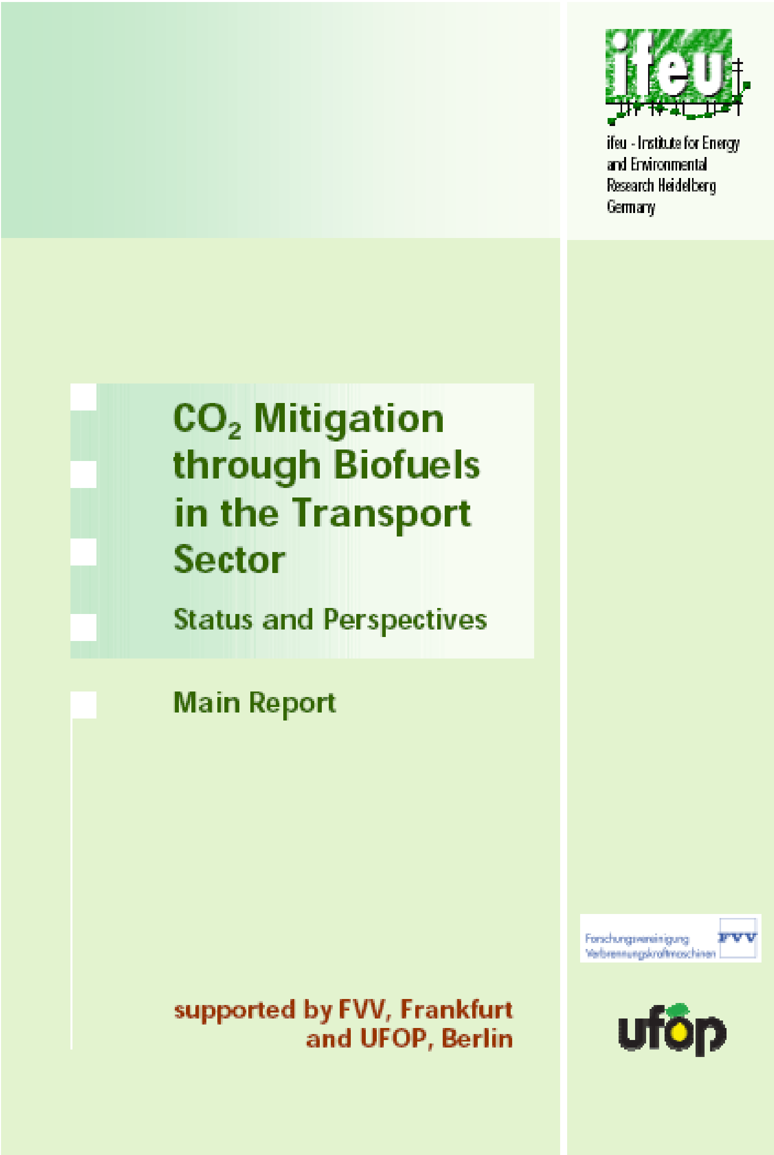
First conclusive life cycle assessment for biofuels in Europe:

Ca. 20 biofuels for:

- **Transportation**
- **Green heat**
- **Green electricity**

Team: IFEU, IUS, IER und KTBL

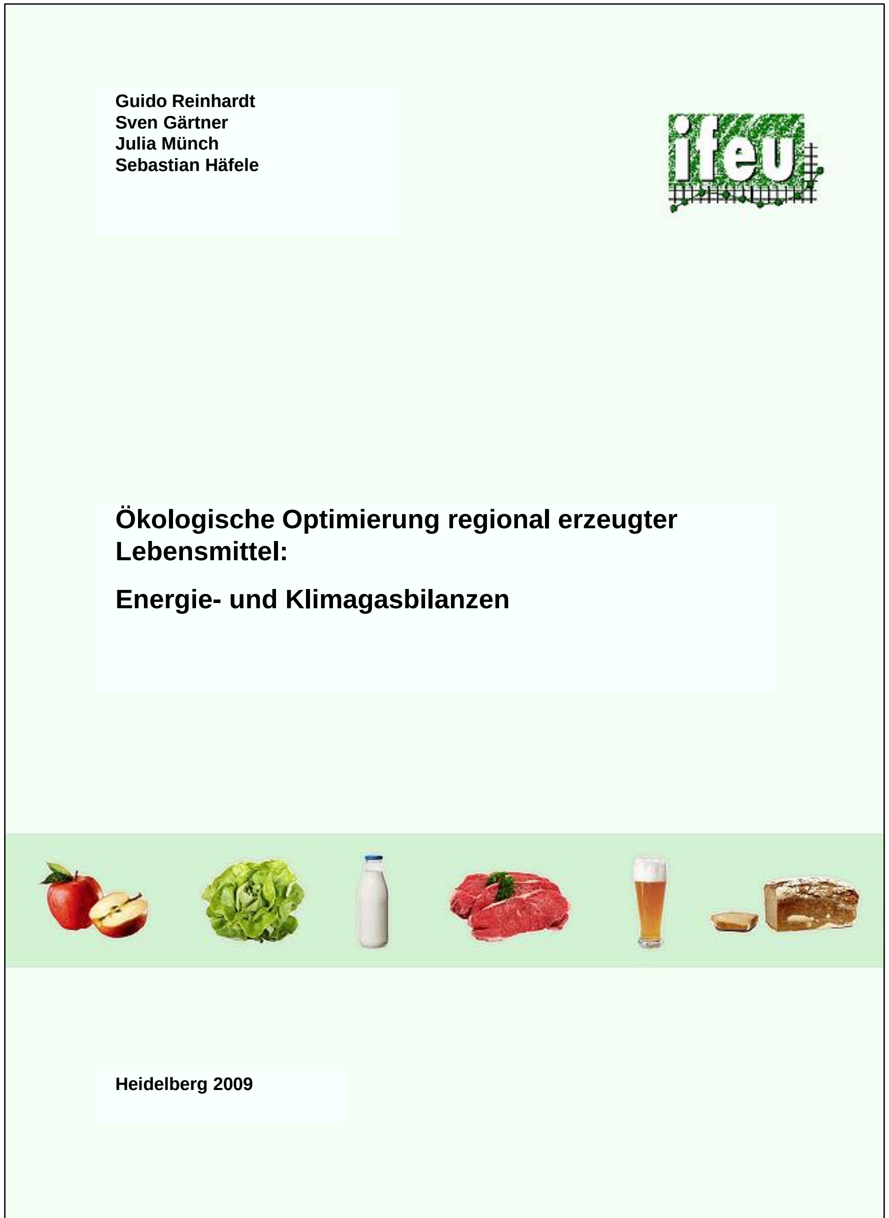
Background



Study on 28 different biofuels

Authors:
M. Quirin, S.O. Gärtner, M. Pehnt, G.A. Reinhardt

Hintergrund


Guido Reinhardt
Sven Gärtner
Julia Münch
Sebastian Häfele

Ökologische Optimierung regional erzeugter Lebensmittel:

Energie- und Klimagasbilanzen

Heidelberg 2009

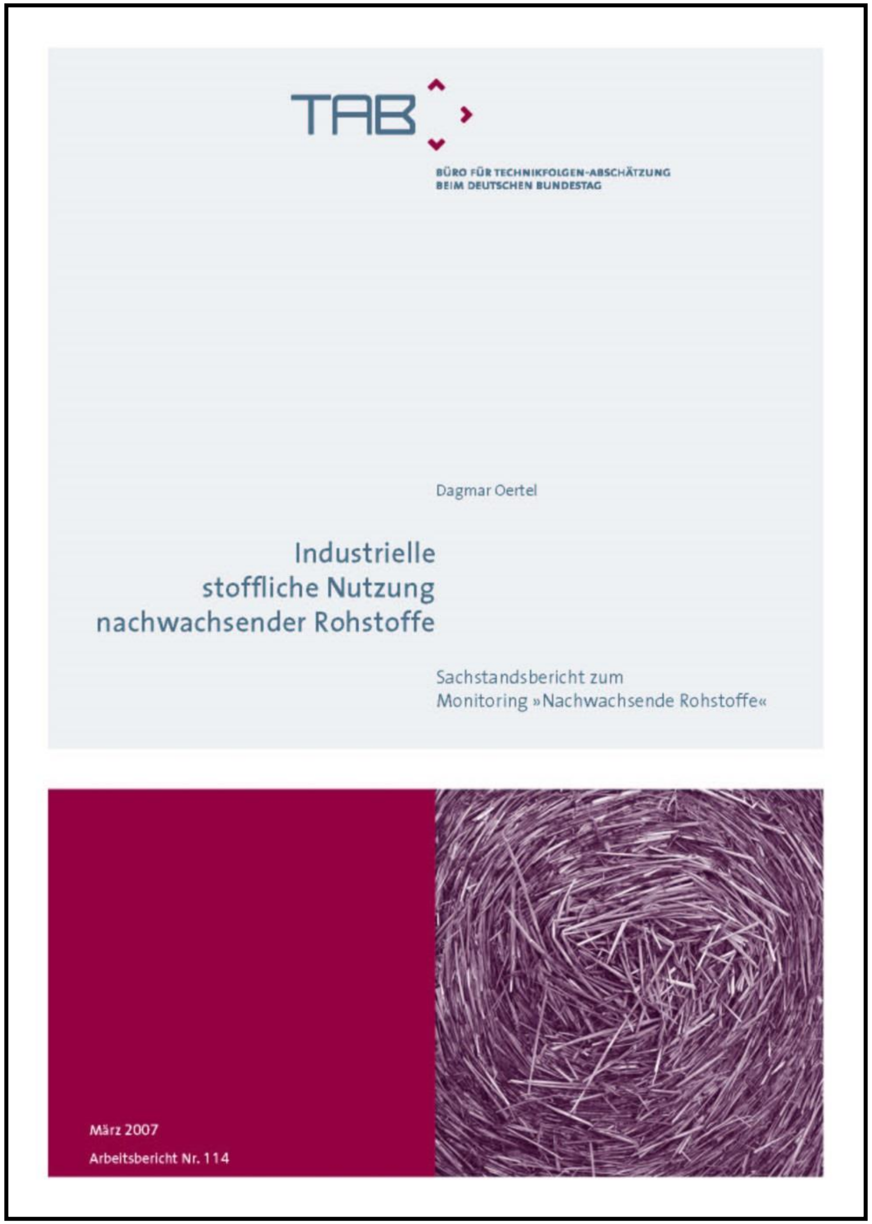
“Ökologische Optimierung regional erzeugter Lebensmittel:

Energie- und Klimagasbilanzen“

Autoren:
Guido Reinhardt,
Sven Gärtner,
Julia Münch,
Sebastian Häfele

Gefördert durch das Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV)

Background



„Industrielle stoffliche Nutzung nachwachsender Rohstoffe“

Bericht angefertigt vom Büro für Technikfolgen-Abschätzung des Deutschen Bundestages (TAB).

TAB-Autorin:
Dagmar Oertel

IFEU-Beitrag:
„Zukünftige Nutzung nachwachsender Rohstoffe“
(Kapitel IV)

IFEU-Autoren:
Guido Reinhardt, Sven Gärtner & Andreas Patyk

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Two “new“ oil crops: Brassicaceae family

Camelina sativa *(Leindotter)*

Crambe abyssinica

(Meerkohl, Krambe)

© Courtesy of Linnaeus Plant Sciences

© Wageningen

Background

- **Oleochemical industry relies predominantly on tropical oils: coconut, palm, palm kernel, castor.**



Medium-chain fatty acids

C12:0, C14:0
Palm kernel & coconut markets

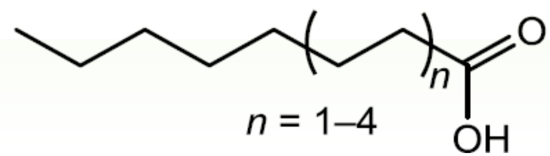
Background

- Oleochemical industry relies predominantly on tropical oils: coconut, palm, palm kernel, castor.



- No European alternatives for tropical medium-chain fatty acids (MCFA):

C8, C10, C12, C14



- Prices of MCFA are higher and more volatile than those from more common oilseed crops

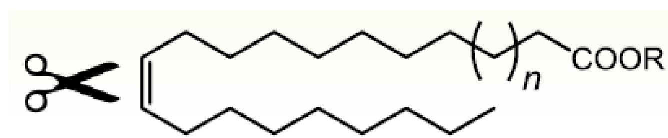
Camelina sativa and *Crambe abyssinica*

- **Agronomic advantages:**
  - **Suitable for growth in Europe**
  - **Limited nutrient requirements**
  - **Resistance to common *Brassica* pests and diseases**
  - **Tolerance to drought and low temperature**

- **Contain special MUFA*: interest to oleochemical industry**

Camelina

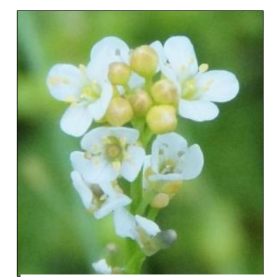
© Courtesy of Linnaeus Plant Sciences



n = 1: *gondoic acid* (C20:1n9)

n = 3: *erucic acid* (C22:1n9)

Crambe



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* MUFA = monounsaturated fatty acid, i.e. with only one C=C bond

Camelina and Crambe cultivation

Poland

Italy

Greece

Source: www.cosmos-H2020.eu

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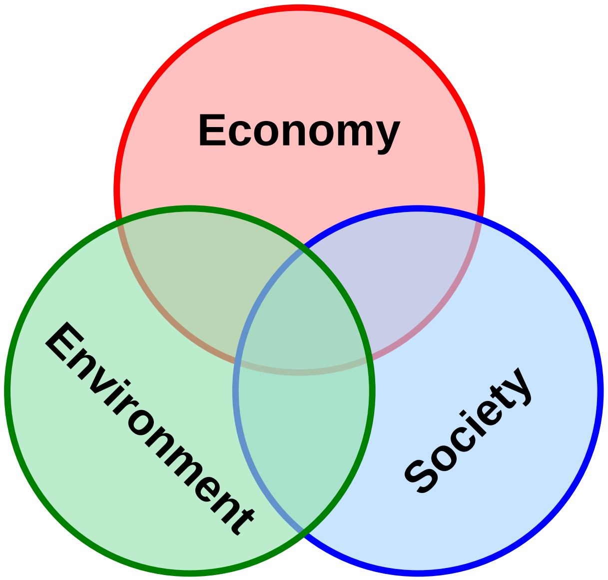
Definition

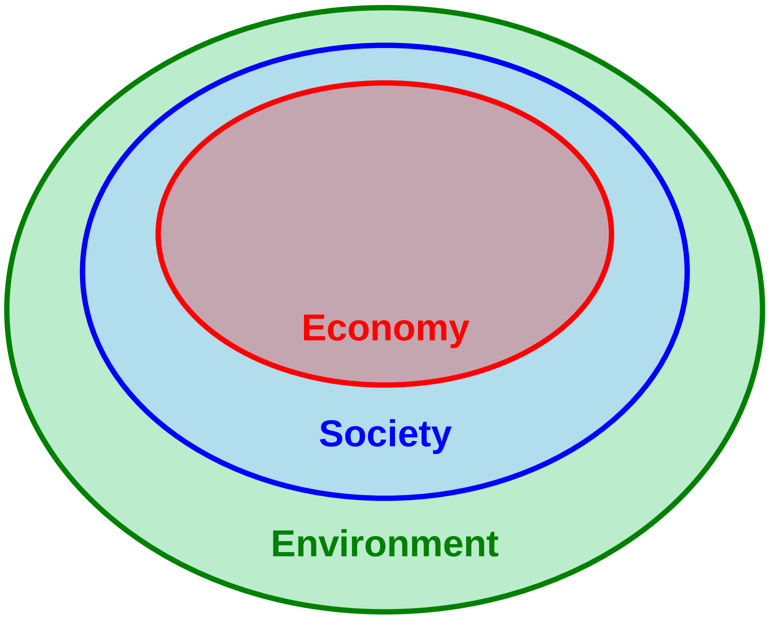
"Meeting the needs of the present generation without compromising the ability of future generations to meet their needs."

Brundtland Commission 1987

The principle of sustainability

The principle of sustainability

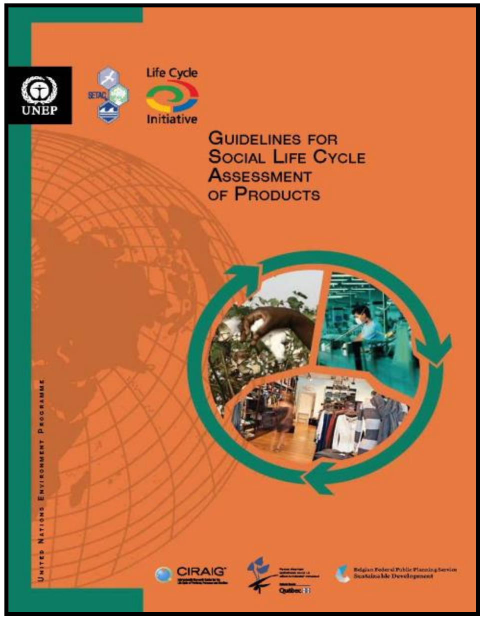




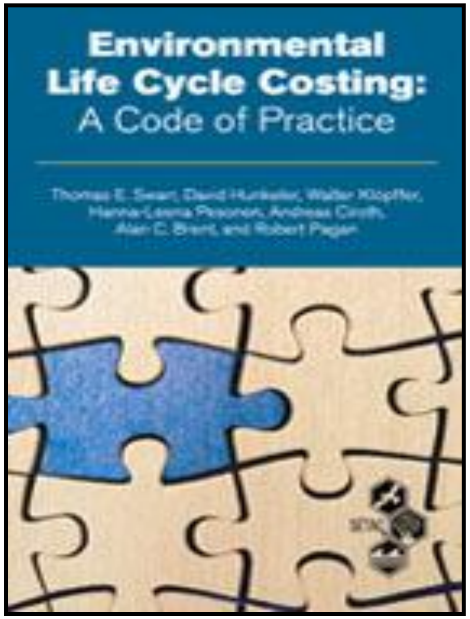
Sustainability

Life Cycle Assessment (LCA)

Social Life Cycle Assessment (sLCA)

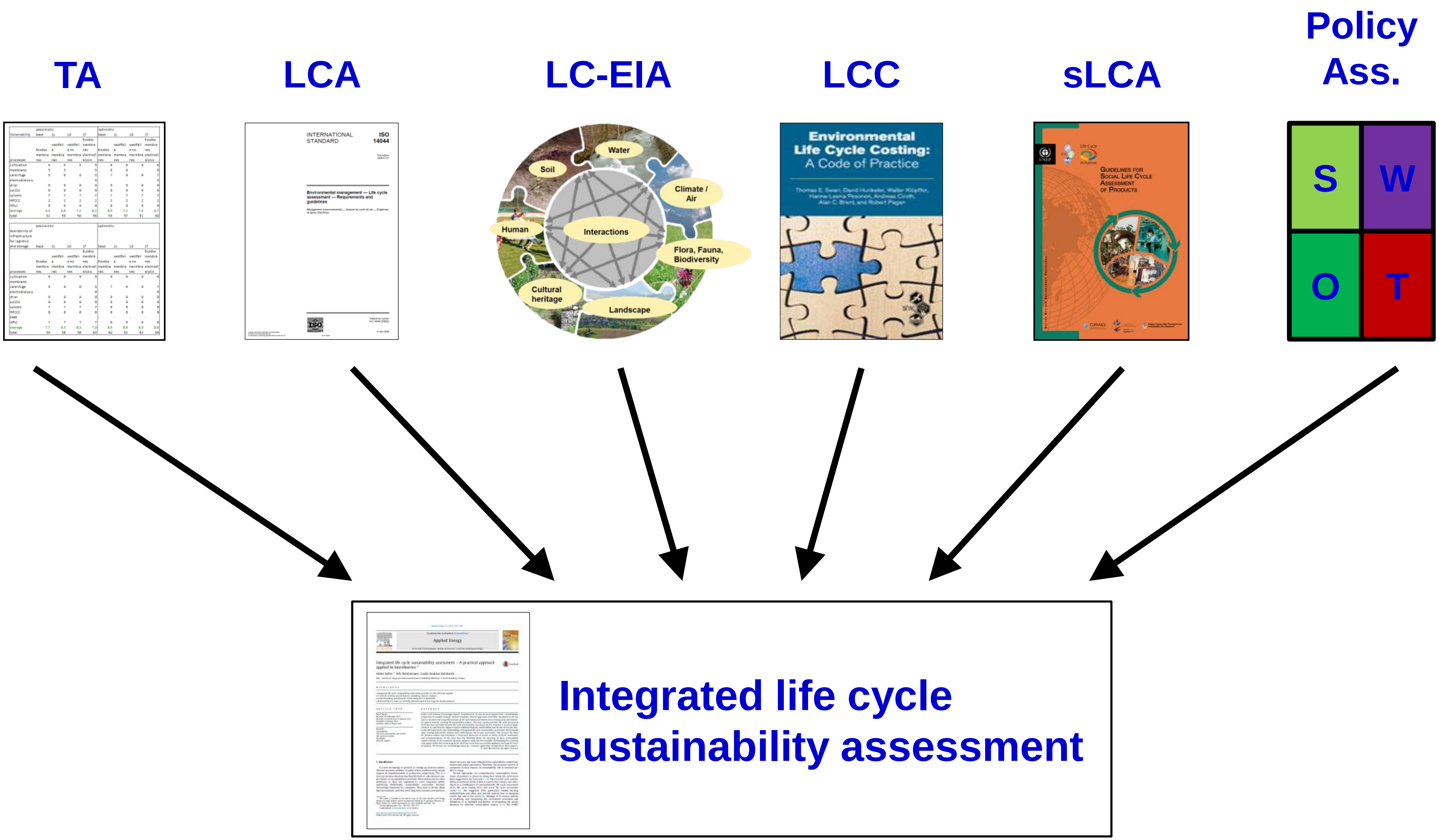


Environmental Life Cycle Costing (eLCC)



→ **Not sufficient: e. g. technological, legal and political issues are not addressed sufficiently.**

Sustainability assessment



Crambe and Camelina pathways

Camelina

Crambe

Cultivation

- Idle land
- Double cropping
- Productivity

Oil use

- MCFA
- PA 11
- PUFAs

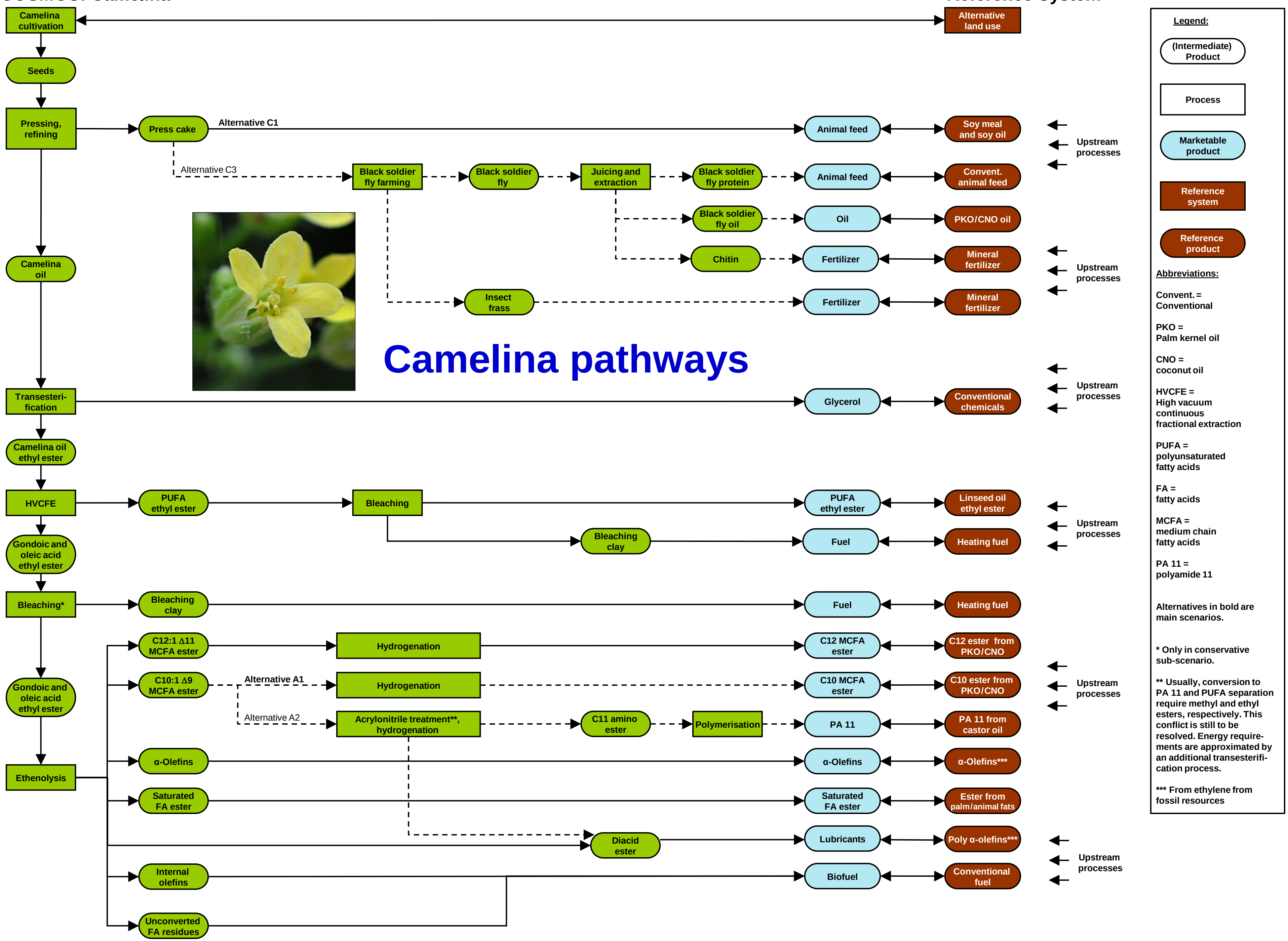
Cake use

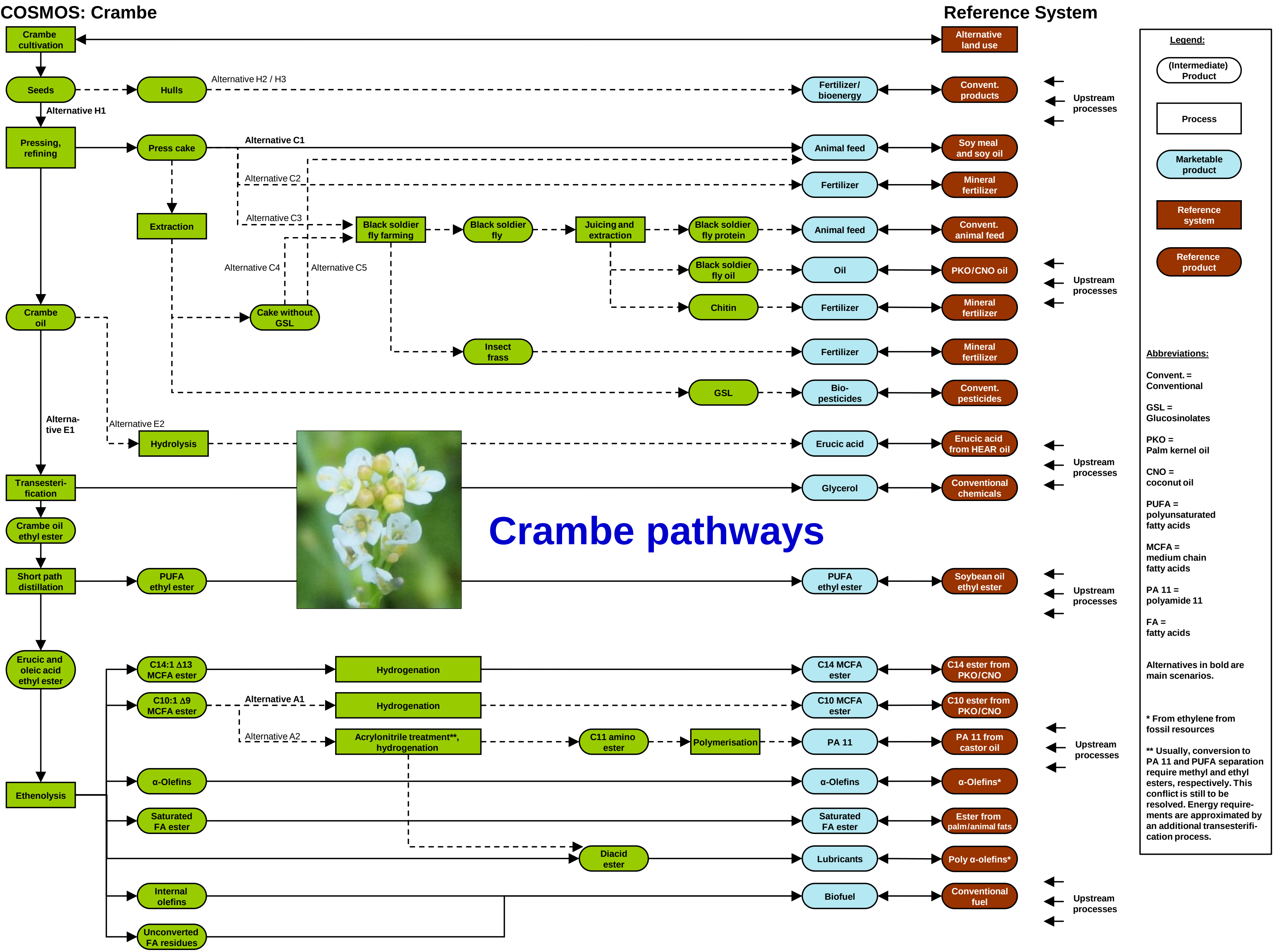
- Feed
- Insects

Crambe hulls

- No use
- Bioenergy
- Fertiliser

COSMOS: Camelina




COSMOS: Crambe
Reference System
Crambe cultivation
Alternative land use
Seeds
Hulls
Alternative H2 / H3
Fertilizer/ bioenergy
Convent. products
Alternative H1
Pressing, refining
Press cake
Alternative C1
Animal feed
Soy meal and soy oil
Alternative C2
Fertilizer
Mineral fertilizer
Extraction
Alternative C3
Black soldier fly farming
Black soldier fly
Juicing and extraction
Black soldier fly protein
Animal feed
Convent. animal feed
Alternative C4
Alternative C5
Black soldier fly oil
Oil
PKO/CNO oil
Crambe oil
Cake without GSL
Chitin
Fertilizer
Mineral fertilizer
Insect frass
Fertilizer
Mineral fertilizer
GSL
Bio-pesticides
Convent. pesticides
Alterna-tive E1
Alternative E2
Hydrolysis
Erucic acid
Erucic acid from HEAR oil
Transesteri-fication
Glycerol
Conventional chemicals
Crambe oil ethyl ester
Crambe pathways
Short path distillation
PUFA ethyl ester
PUFA ethyl ester
Soybean oil ethyl ester
Erucic and oleic acid ethyl ester
C14:1 Δ13 MCFA ester
Hydrogenation
C14 MCFA ester
C14 ester from PKO/CNO
C10:1 Δ9 MCFA ester
Alternative A1
Hydrogenation
C10 MCFA ester
C10 ester from PKO/CNO
Alternative A2
Acrylonitrile treatment**, hydrogenation
C11 amino ester
Polymerisation
PA 11
PA 11 from castor oil
Ethenolysis
α-Olefins
α-Olefins
α-Olefins*
Saturated FA ester
Saturated FA ester
Ester from palm/animal fats
Diacid ester
Lubricants
Poly α-olefins*
Internal olefins
Biofuel
Conventional fuel
Unconverted FA residues
Upstream processes
Upstream processes
Upstream processes
Upstream processes
Upstream processes
Upstream processes
Legend:
(Intermediate) Product
Process
Marketable product
Reference system
Reference product
Abbreviations:
Convent. = Conventional
GSL = Glucosinolates
PKO = Palm kernel oil
CNO = coconut oil
PUFA = polyunsaturated fatty acids
MCFA = medium chain fatty acids
PA 11 = polyamide 11
FA = fatty acids
Alternatives in bold are main scenarios.
* From ethylene from fossil resources
** Usually, conversion to PA 11 and PUFA separation require methyl and ethyl esters, respectively. This conflict is still to be resolved. Energy requirements are approximated by an additional transesterification process.

Crambe and Camelina pathways

Camelina

Crambe

Cultivation

- Idle land
- Double cropping
- Productivity

Oil use

- MCFA
- PA 11
- PUFAs

Cake use

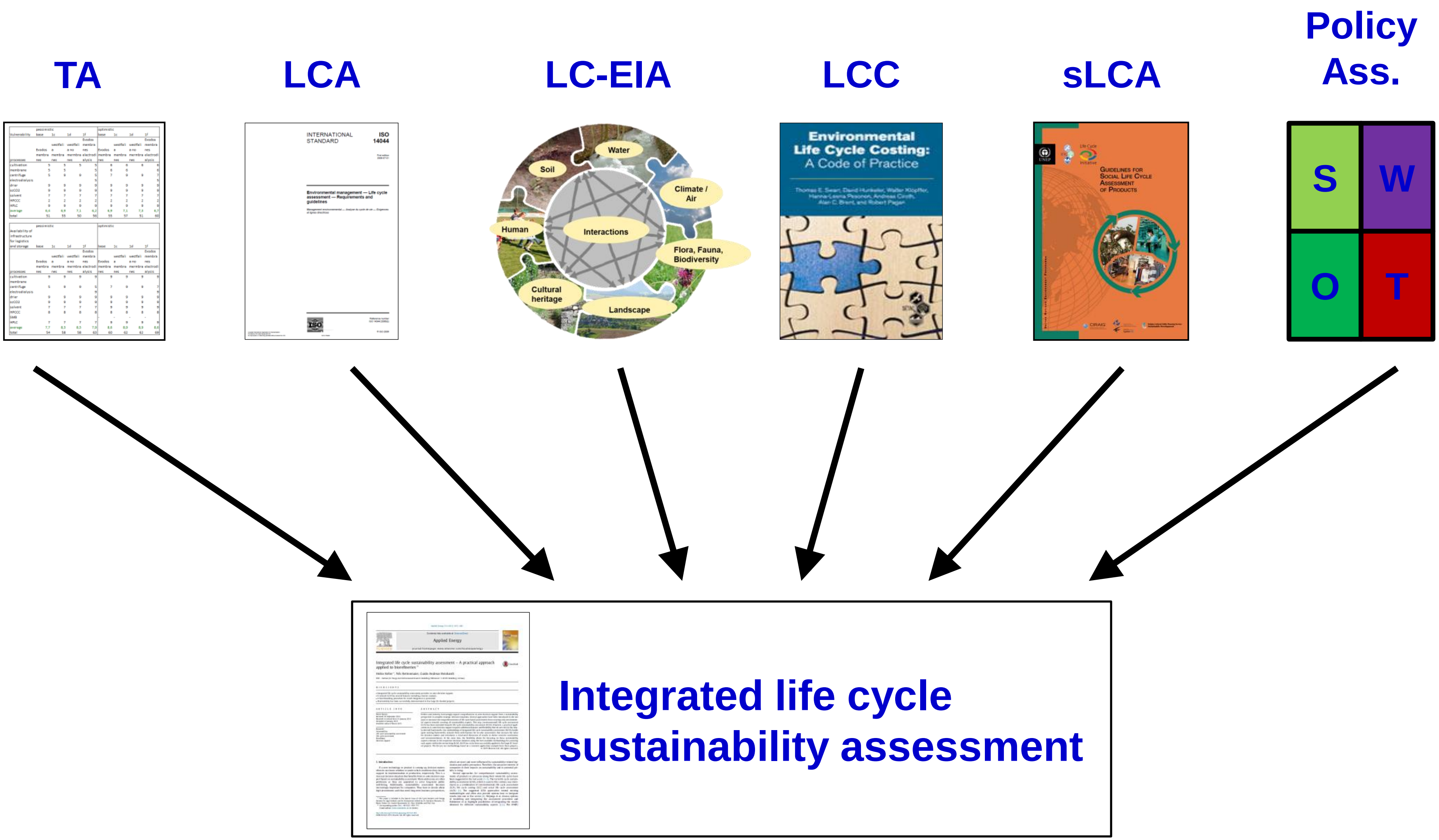
- Feed
- Insects

Crambe hulls

- No use
- Bioenergy
- Fertiliser

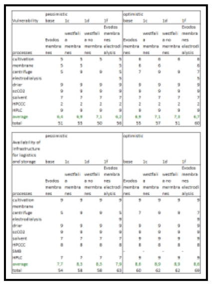
> 40 scenarios

Sustainability assessment



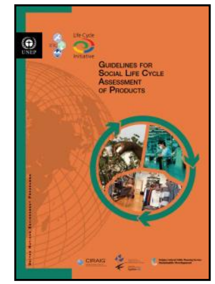
Technological assessment (TA)

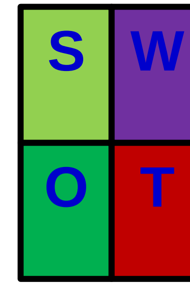
TA-parameters under investigation



Vulnerability	pessimistic base	pessimistic 1c	pessimistic 1d	pessimistic 1f	optimistic base	optimistic 1c	optimistic 1d	optimistic 1f
processes	Evodos membranes	westfalia membranes	westfalia no membranes	Evodos membranes electrodialysis	Evodos membranes	westfalia membranes	westfalia no membranes	Evodos membranes electrodialysis
cultivation	5	5	5	5	6	6	6	6
membrane	5	5		5	6	6		6
centrifuge	5	9	9	5	7	9	9	7
electrodialysis				5				5
drier	9	9	9	9	9	9	9	9
scCO2	9	9	9	9	9	9	9	9
solvent	7	7	7	7	7	7	7	7
HPCCC	2	2	2	2	2	2	2	2
HPLC	9	9	9	9	9	9	9	9
average	6,4	6,9	7,1	6,2	6,9	7,1	7,3	6,7
total	51	55	50	56	55	57	51	60

Availability of infrastructure for logistics and storage	pessimistic base	pessimistic 1c	pessimistic 1d	pessimistic 1f	optimistic base	optimistic 1c	optimistic 1d	optimistic 1f
processes	Evodos membranes	westfalia membranes	westfalia no membranes	Evodos membranes electrodialysis	Evodos membranes	westfalia membranes	westfalia no membranes	Evodos membranes electrodialysis
cultivation	9	9	9	9	9	9	9	9
membrane								
centrifuge	5	9	9	5	7	9	9	7
electrodialysis				9				9
drier	9	9	9	9	9	9	9	9
scCO2	9	9	9	9	9	9	9	9
solvent	7	7	7	7	9	9	9	9
HPCCC	8	8	8	8	8	8	8	8
SMB					-	-	-	-
HPLC	7	7	7	7	9	9	9	9
average	7,7	8,3	8,3	7,9	8,6	8,9	8,9	8,6
total	54	58	58	63	60	62	62	69





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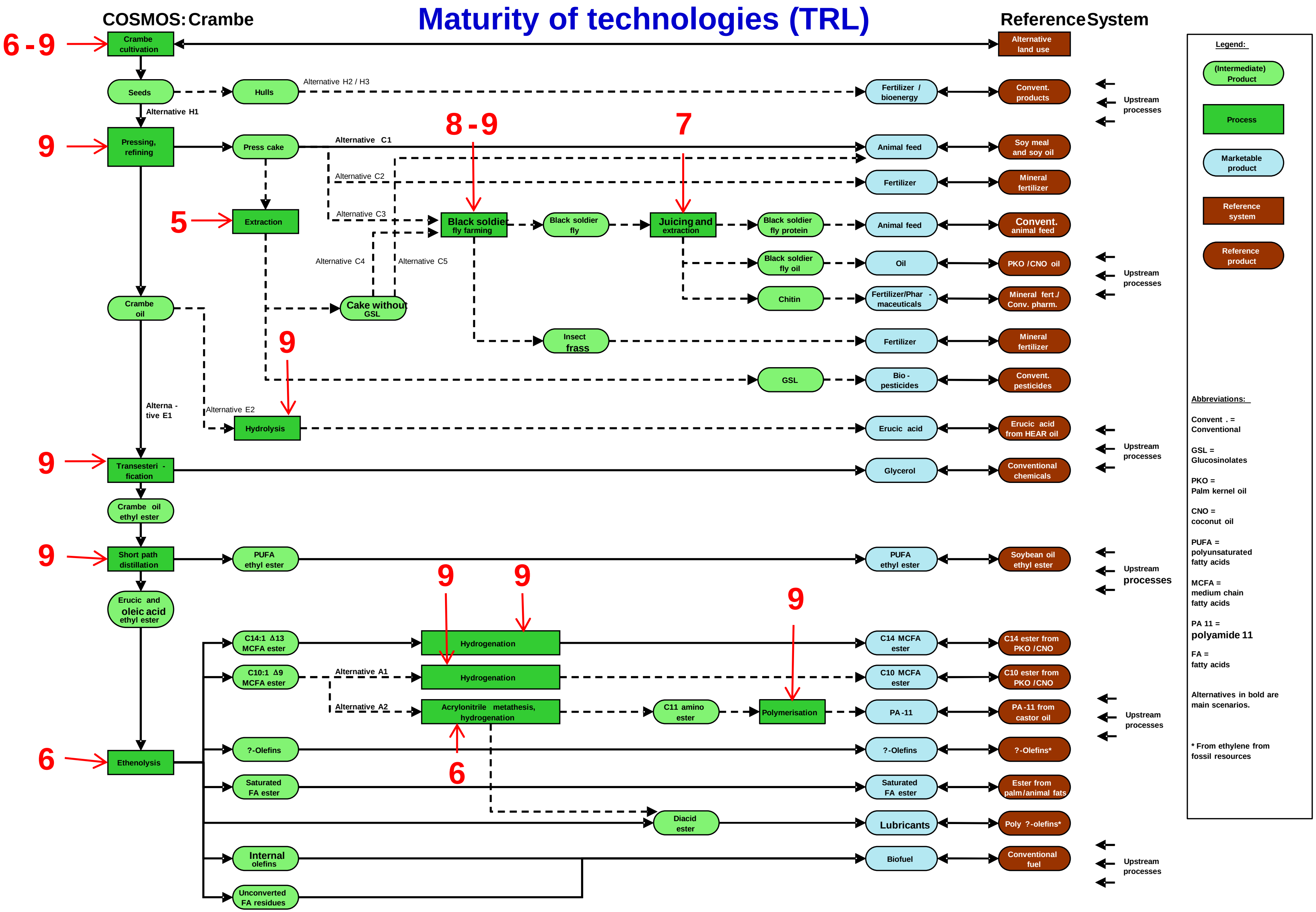
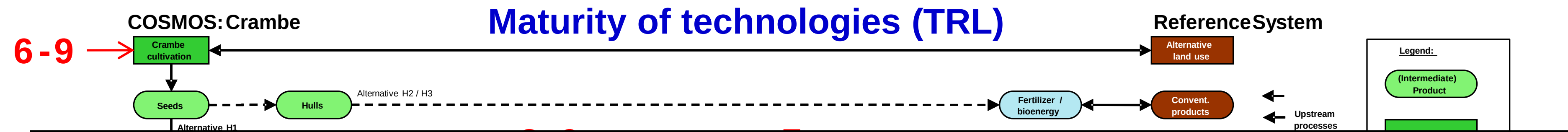
Selected indicators

Indicator	Short description
Maturity	Technical maturity of involved processes on EC's technology readiness level (TRL) scale.
Vulnerability	Risk of not reaching expected performance because of downtimes etc.
Technological risk: Hazardous substances	Risk of product contaminations by e.g. toxic substances (hazard risk).
Technological risk: Explosions and fires	Risk of explosions and fires within industrial facilities like biorefineries (hazard risk).
Use of limited feedstock	Dependence on e. g. by-products of other processes as main feedstock (potential barrier).
Legislative framework and bureaucratic hurdles	Existing regulation that are hard to fulfil (potential barrier).
Availability of infrastructure	Availability of required storage, plants, installations and facilities (potential barrier).

Technological Assessment

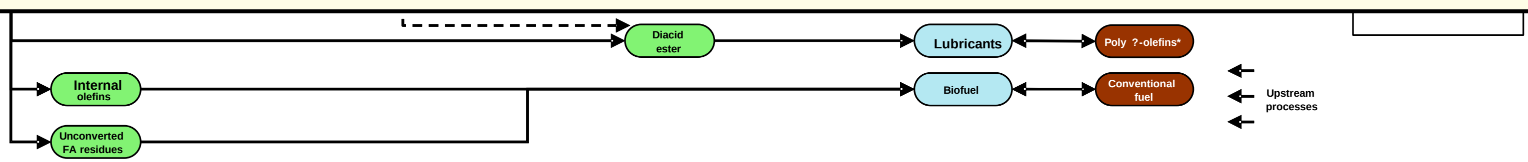


Technological Assessment



Exemplary results

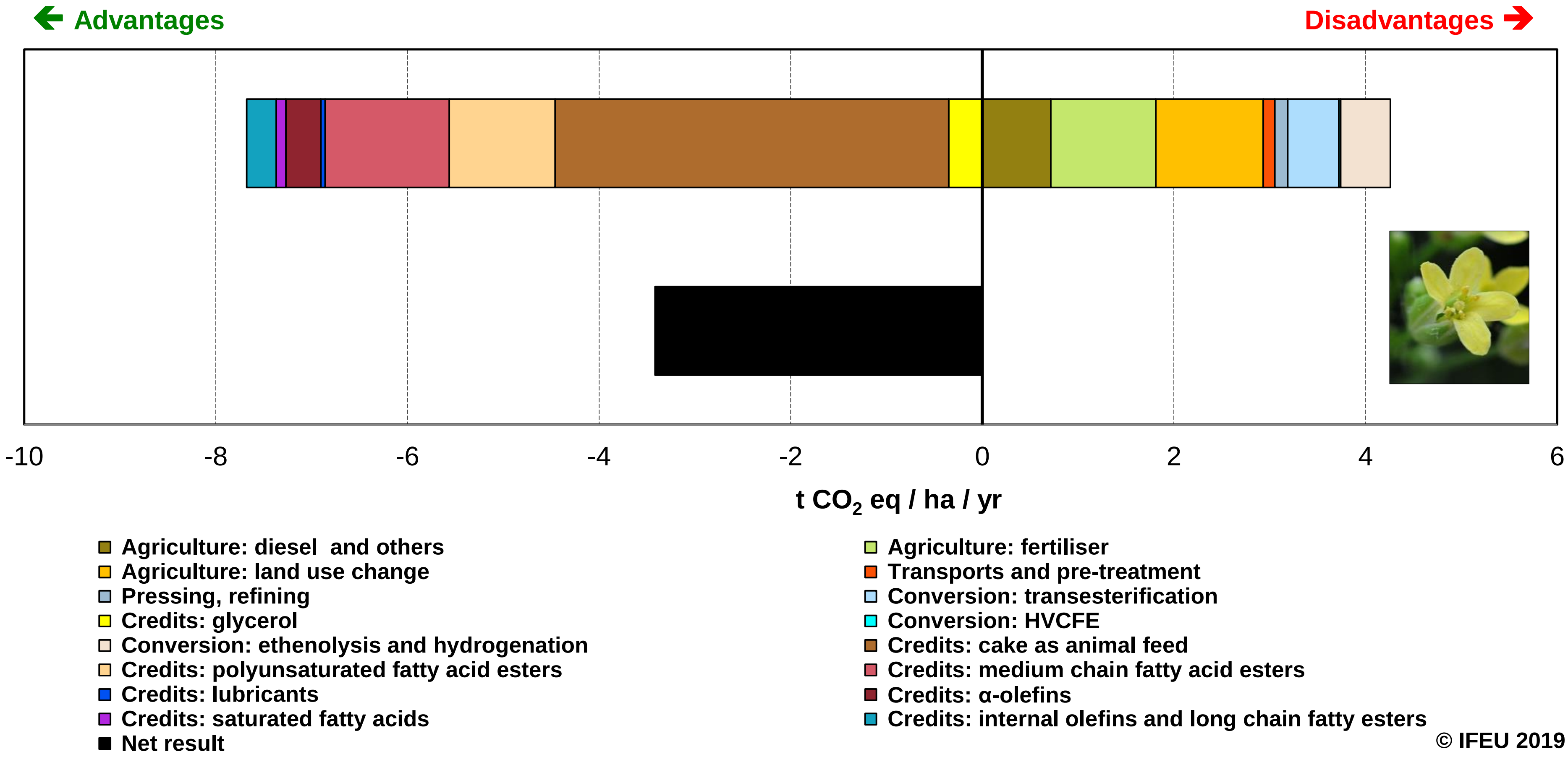
- Technology readiness levels of the processes of the main pathway configuration already well-established (TRL 9), except for ethenolysis (TRL 6).
- Harvest technology especially for Crambe seeds needs further development.
- Separation technology for hulls not yet mature.
- …



Life cycle assessment (LCA)

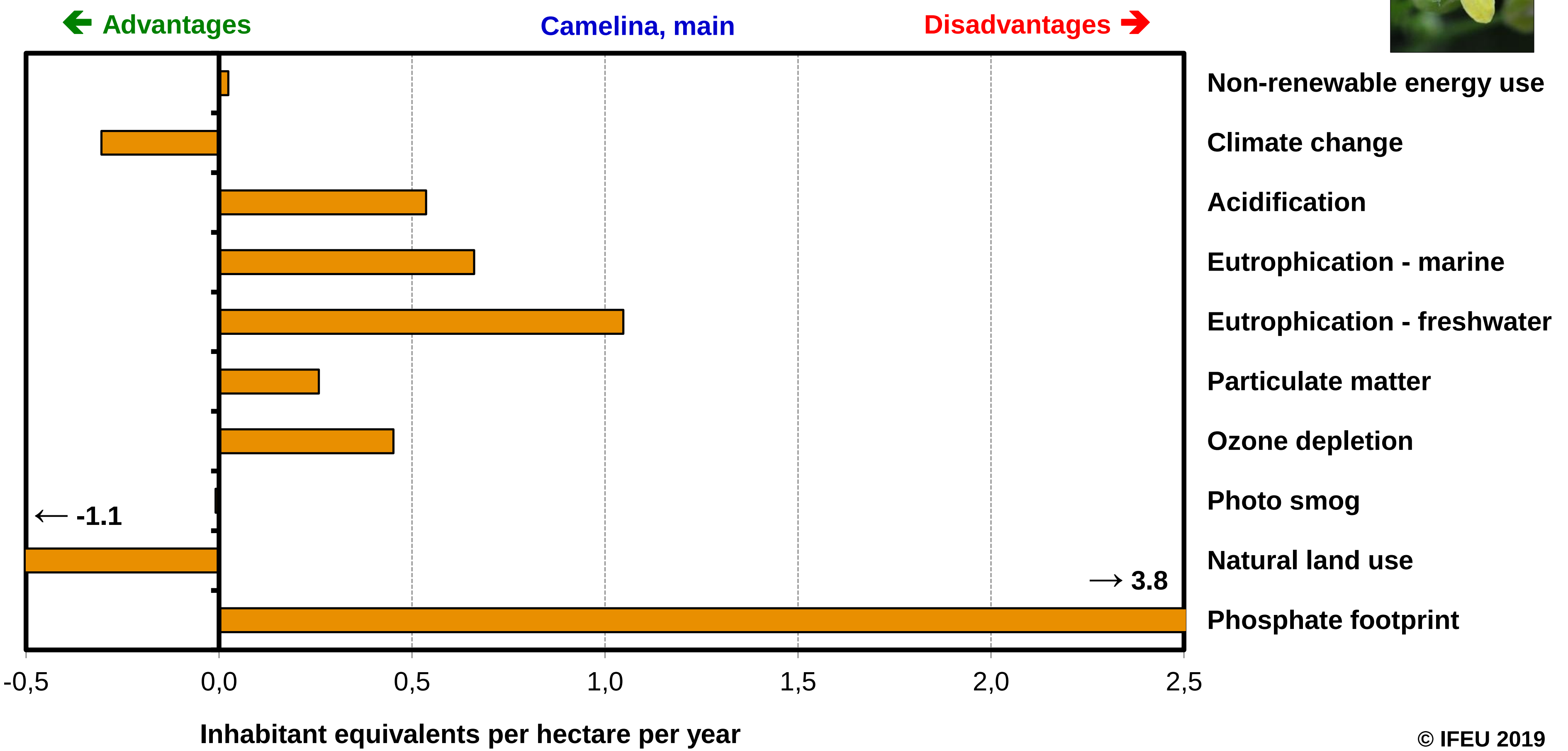
Environmental Assessment: Results

Greenhouse gas balance – Camelina, main scenario



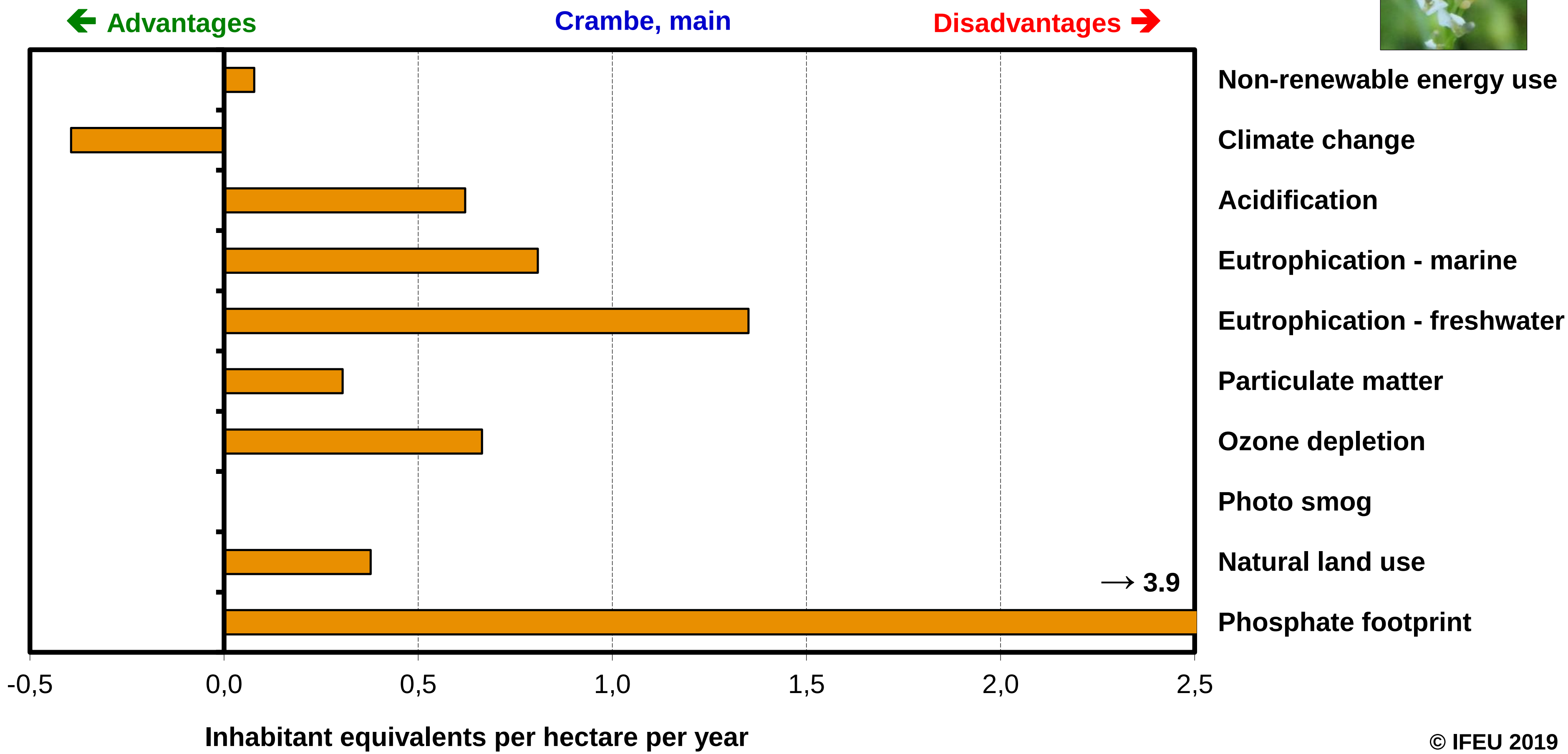
Environmental Assessment: Results

LCA results for camelina, all impact categories



Environmental Assessment: Results

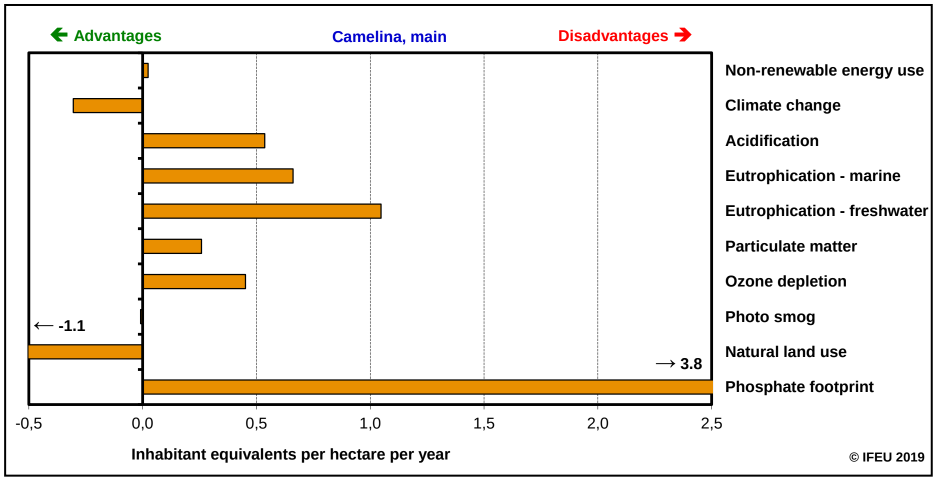
LCA results for crambe, all impact categories

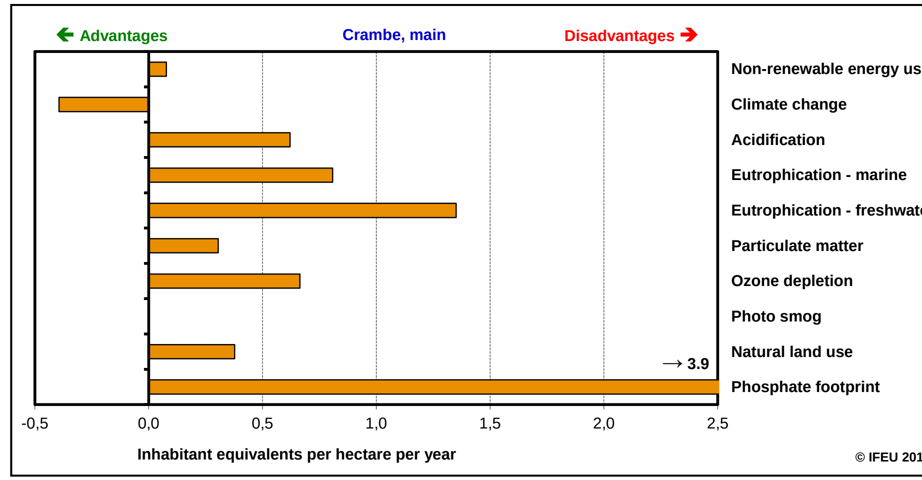


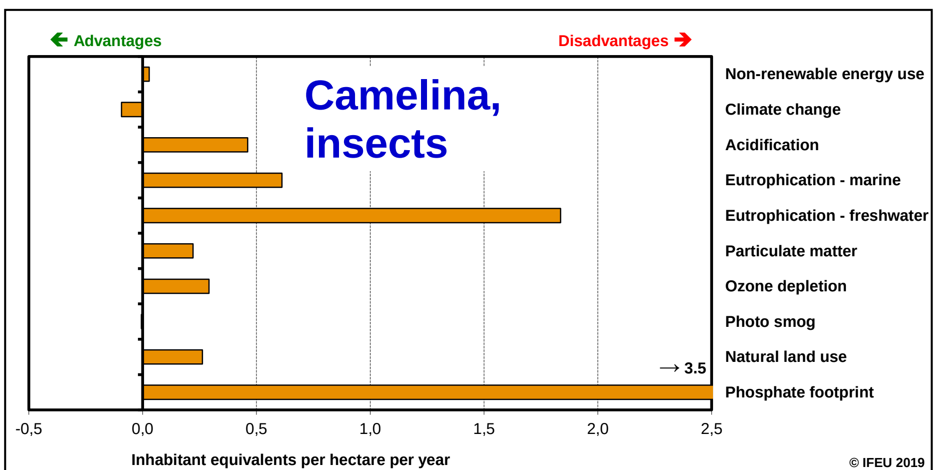
Environmental Assessment: Results

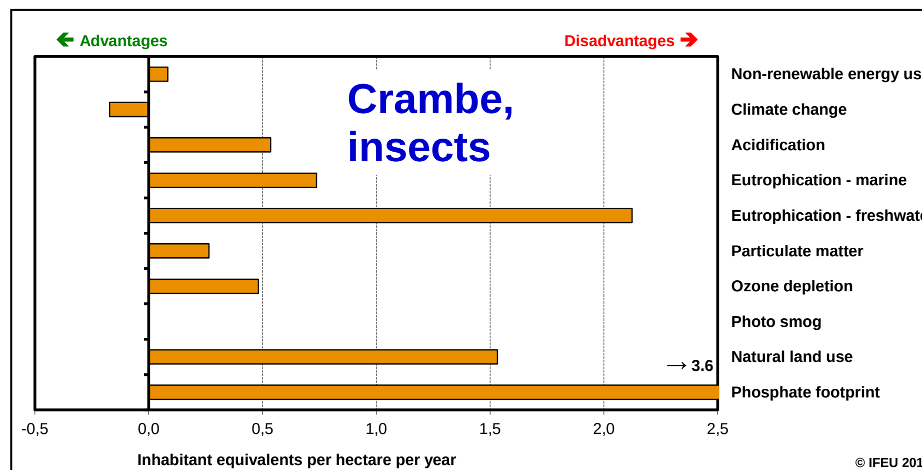
Camelina

Crambe



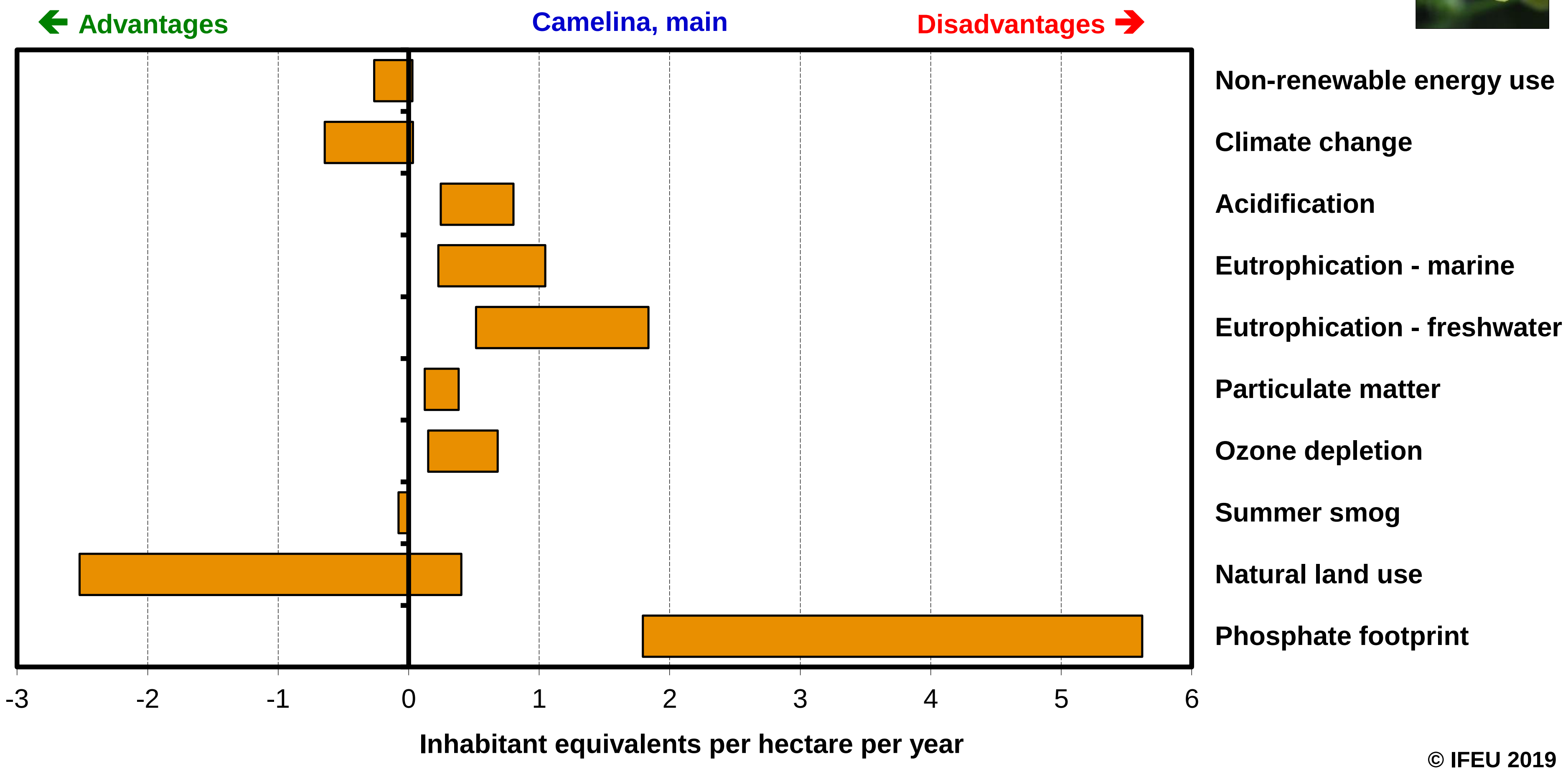






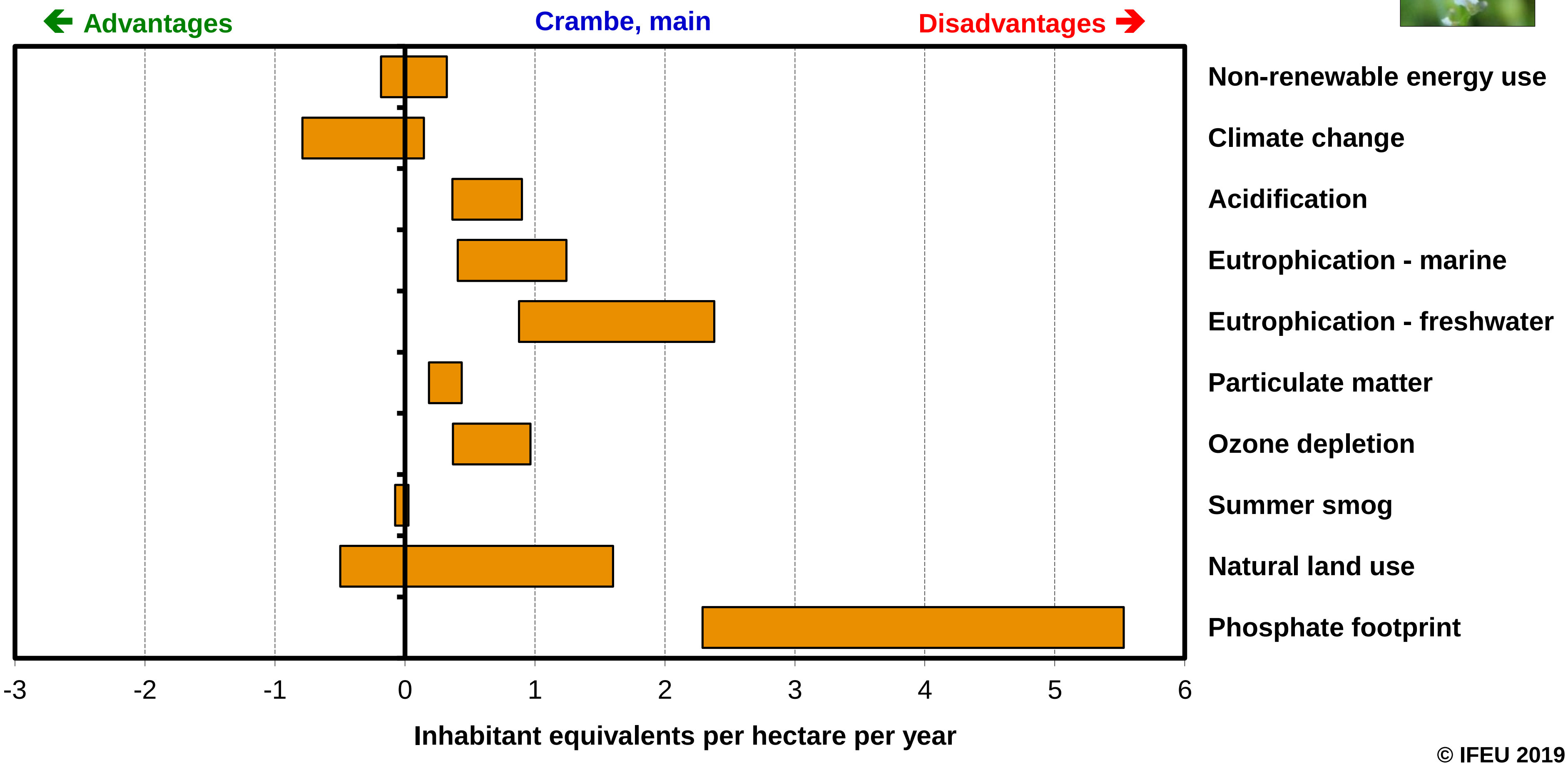
Environmental Assessment: Results

LCA results for camelina, all impact categories



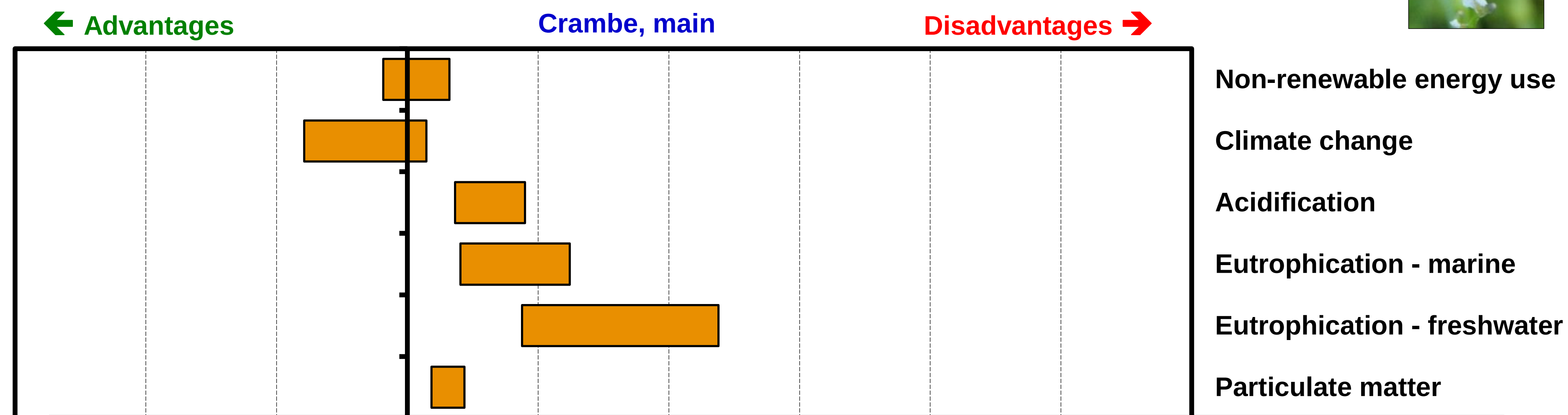
Environmental Assessment: Results

LCA results for crambe, all impact categories



Environmental Assessment: Results

LCA results for crambe, all impact categories



→ **Big result bandwidths depending on pathway configuration and specific conditions**

→ **Many options to optimise the benefits and minimise the burdens.**

Environmental Assessment: Results

LC-EIA, exemplary results

Technology related factor \ Technology / Product	COSMOS			Reference system		
	Oil mill	Biorefinery		Oil mill	Biorefinery (65% - 75%)	Oil refinery / chemical plant (35% - 25%)
	Animal feed	Oleochemicals	Bioenergy/ biofuel	Animal feed	Oleochemicals	Industrial chemicals, fuel
Impacts resulting from construction phase						
Construction works	C	C	C	C	C	C
Impacts related to buildings, infrastructure and installations						
Buildings, infrastructure and installations (size and height)	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]
Impacts resulting from operation phase						
Emission of noise	B	D	D	C	D	D
Emission of gases and particulate matter	B	C	C	C	C	D
Emission of light	B	C	C	C	C	C
Drain of water resources for production	A	D	D	B	D	D
Waste water production and treatment	A	D	D	B	D	D
Traffic (collision risk, emissions)	D / E	D / E	D / E	D / E	D / E	C[3]
Disposal of wastes / residues	B	B	B	B	B	C
Risk of accidents (explosion, fire in the facility or storage areas, release of GMO)	C	C	C	C	C	E[3,5,6]

Environmental Assessment: Results

LC-EIA, exemplary results

Technology / Product	COSMOS			Reference system		
	Oil mill	Biorefinery		Oil mill	Biorefinery	Oil refinery / chemical plant
Traffic (collision risk, emissions)						
Disposal of wastes / residues						
Risk of accidents (explosion, fire in the facility or storage area, release of GMO)						

Crop / Land use reference system / Type of risk	COSMOS	COSMOS reference system	
	Camelina	P	Soy bean	Linseed
Soil erosion			
Soil compaction			
Loss of soil organic matter			
Eutrophication			
Water demand			
Weed control / pesticides			
Loss of biodiversity			

Crop / Land use reference system / Type of risk	COSMOS	COSMOS reference system		
Crop	Crambe	P	Soy bean	
Land use reference system	idle land	r	rain forest	Cerrado
Soil erosion	B	E	E	E
Soil compaction	B	E	E	E
Loss of soil organic matter	A	E	E	E
Eutrophication	B	E	E	E
Water demand	A	E	E	E
Weed control / pesticides	B	E	E	E
Loss of biodiversity	C	E	E	E

Environmental Assessment: Results

LC-EIA, exemplary results

	COSMOS		Reference system		
Technology /					Oil refinery /

Exemplary results

- Overall biodiversity conservation is possible with some pathways, especially with crambe, though also with camelina to a lesser extent.
- Especially, savings of tropical forests are possible.
- For crambe: more land is occupied than saved. But strong benefits per hectare of saved land (biodiversity, habitats, …).
- Very promising results for double cropping of camelina.
- …

Crop rotations

Crop rotations of camelina and winter wheat

Source: UNIBO / CRES 2019

Crop rotations

Crop rotations of camelina and winter wheat

→ **Most sustainable option: double cropping (though for camelina only)**

Source: UNIBO / CRES 2019

Environmental Assessment

Key results

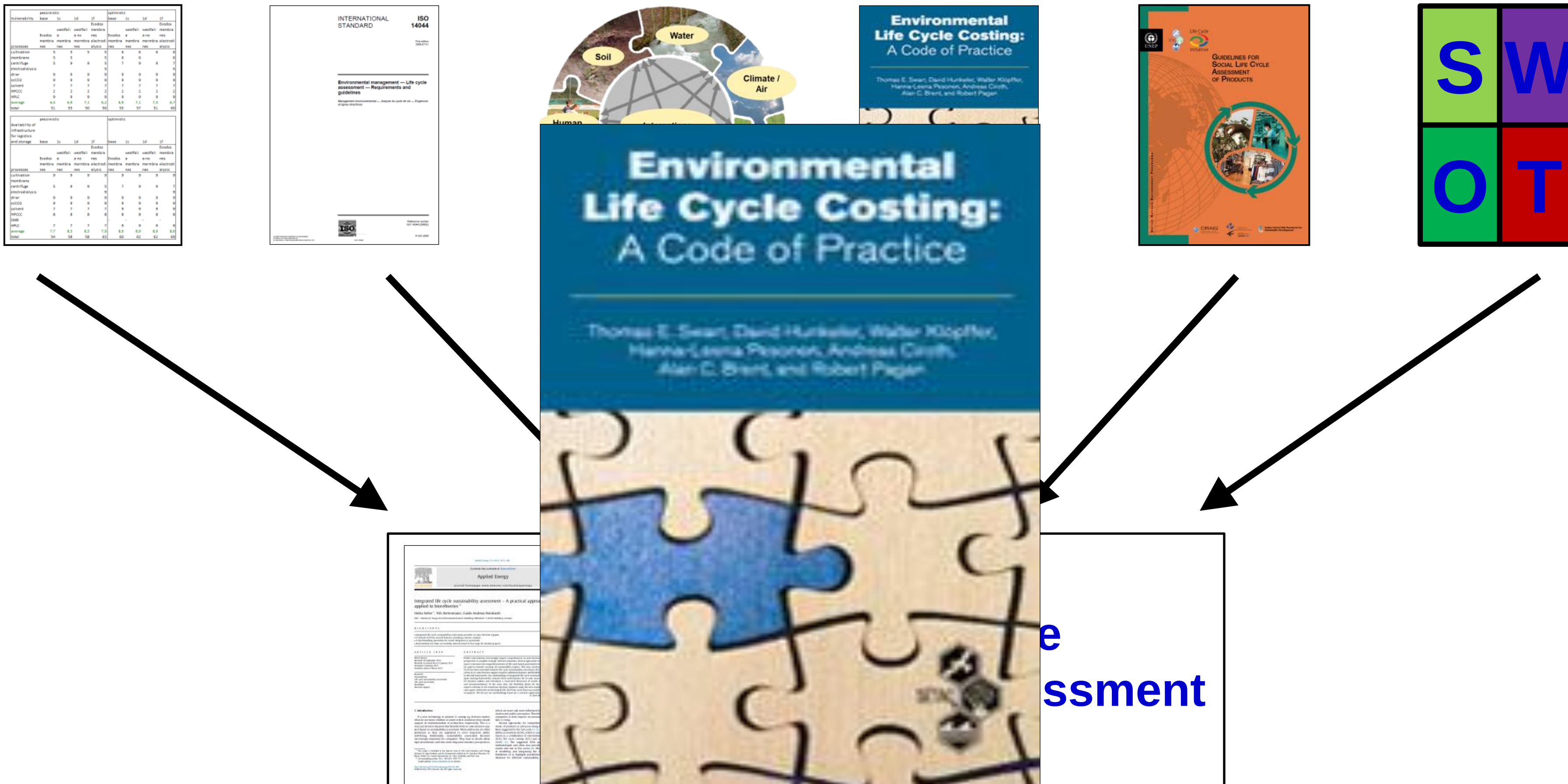
- **Overall environmental advantages for camelina or crambe pathways cannot be stated for all options.**
- **Chance for considerable savings of greenhouse gases and rain forests with benefits for local biodiversity.**
- **The results are dominated by the use of the press cake. The substitution of palm / coconut / castor oil is of minor relevance.**
- **Promising results for double cropping of camelina.**

Environmental Assessment

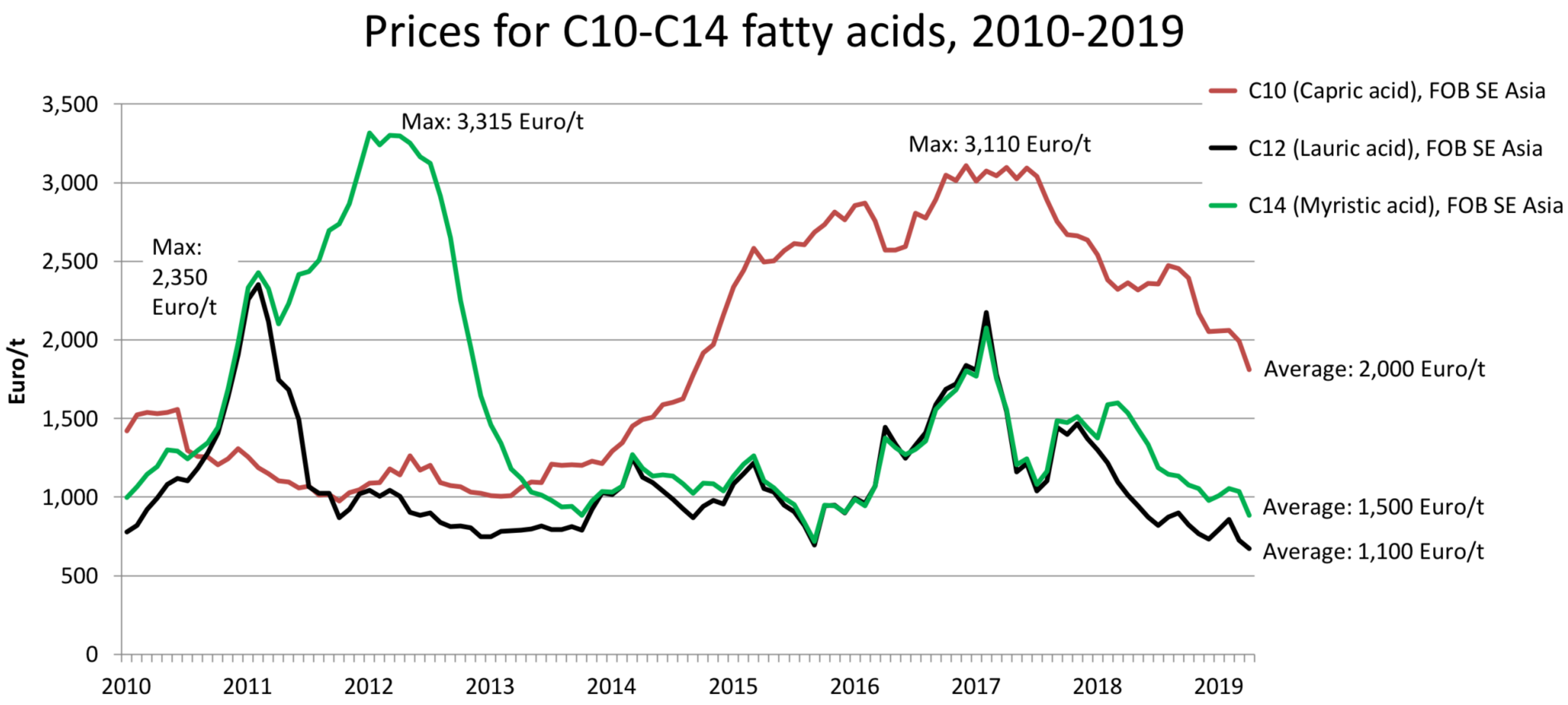
Recommendations

- The numerous co-products should each undergo their best use options.
- A displacement of other crops should be avoided.
- Double cropping of camelina should be further developed, e.g. by testing adapted crop rotations and publishing concrete guidelines for farmers.

Life cycle costing (LCC)



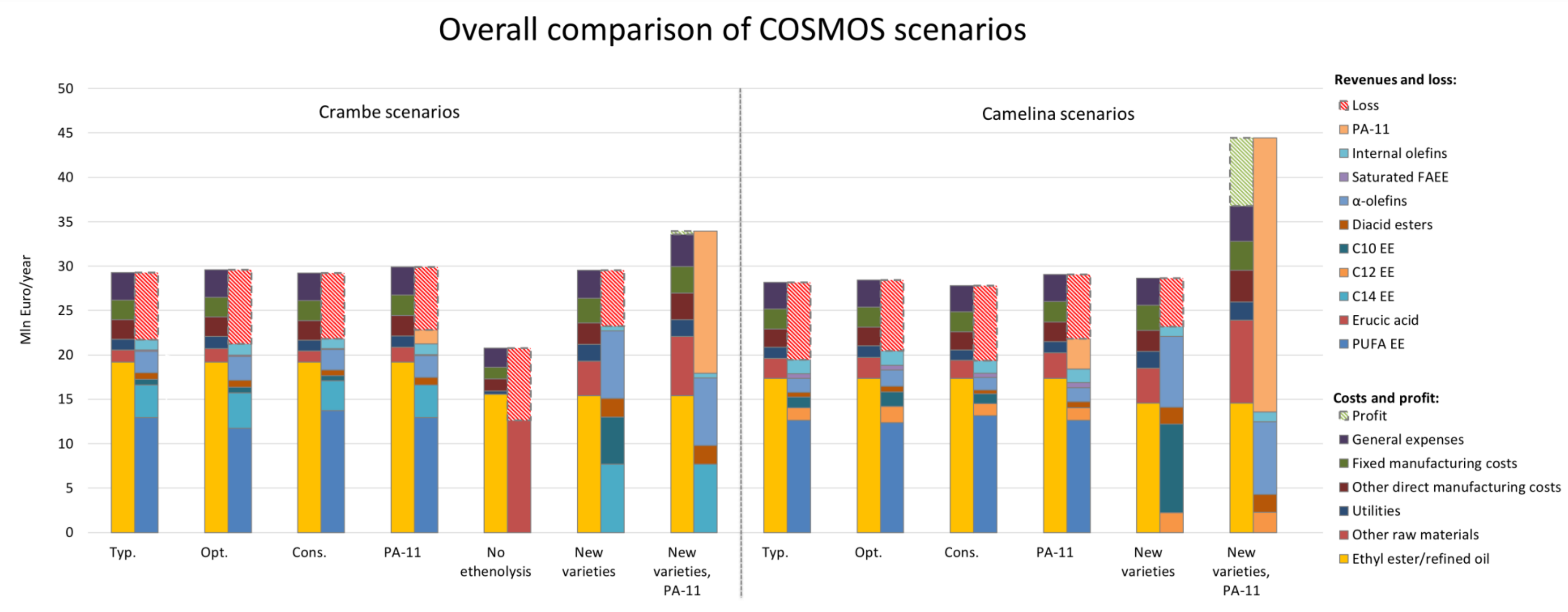
Selected results



Source: ICIS

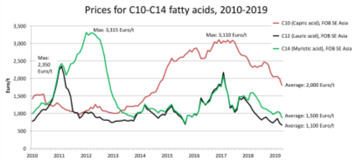
Economic Assessment

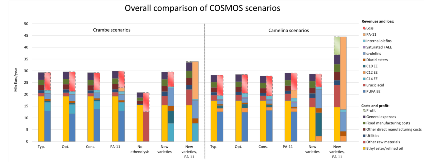
Selected results



Source: nova, Hürth, 2019

Economic Assessment





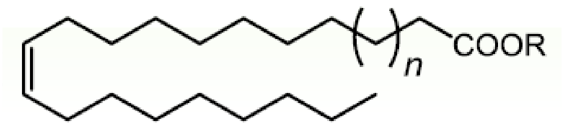
Selected results

- **Today, Camelina and Crambe, respectively, are not competitive for large scale cultivation and use.**
- **Main bottlenecks are**

  - comparably high costs for agricultural production

Crambe abyssinica

- **Seed yield 1.500 – 4.000 kg / ha**
- **Oil content > 38 %**
- **Oil yield 600 – 900 kg / ha**
- **Erucic acid (C22:1): 60 - 65 %**



n = 3: *erucic acid* (C22:1n9)

- Too much C18:2 + C18:3
- **Too much glucosinolates**

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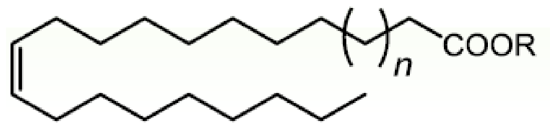
Camelina sativa

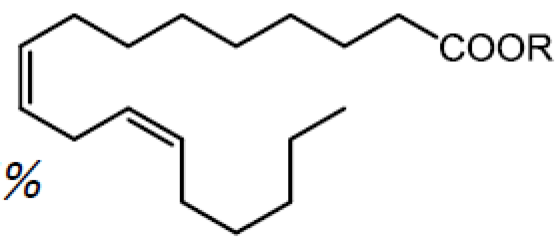
- **Seed yield 1.500 – 3.500 kg / ha**
- **Oil content > 40 %**
- **Oil yield 600 – 900 kg / ha**
- **Gondoic acid (C20:1): 15 %**

15%


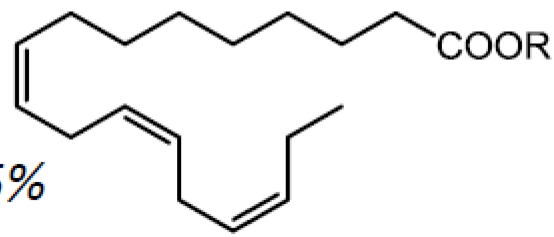
n = 1: *gondoic acid* (C20:1n9)

Source: www.cosmos-H2020.eu

- (Too) high in C18:2 + C18:3 (linoleic+ linolenic acid): 50 %

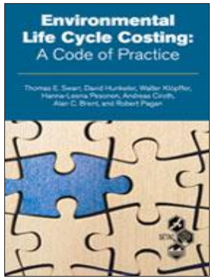
15%


Linoleic acid

35%


Linolenic acid

Economic Assessment



Selected results

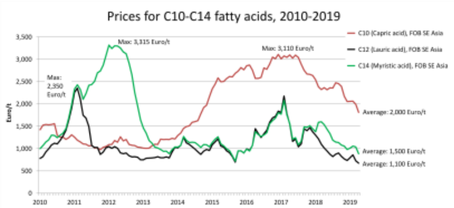
- **Today, Camelina and Crambe, respectively, are not competitive for large scale cultivation and use.**

- **Main bottlenecks are**

  - comparably high costs for agricultural production

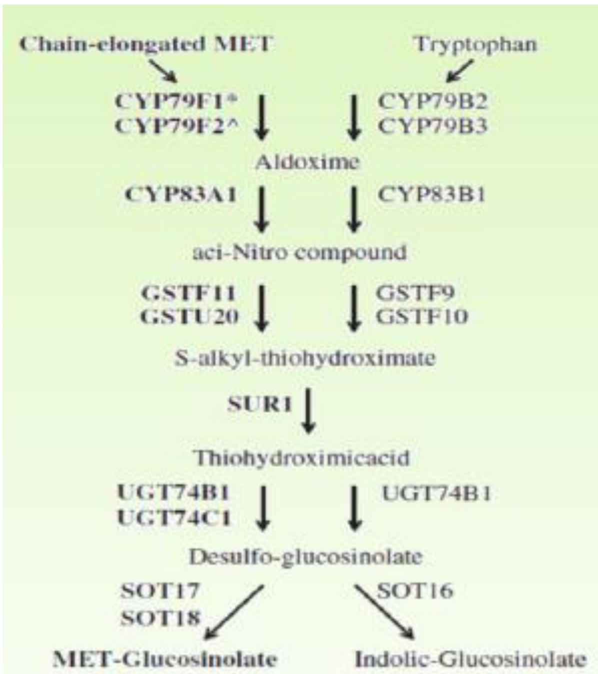
  - comparably low revenues for the oil cake

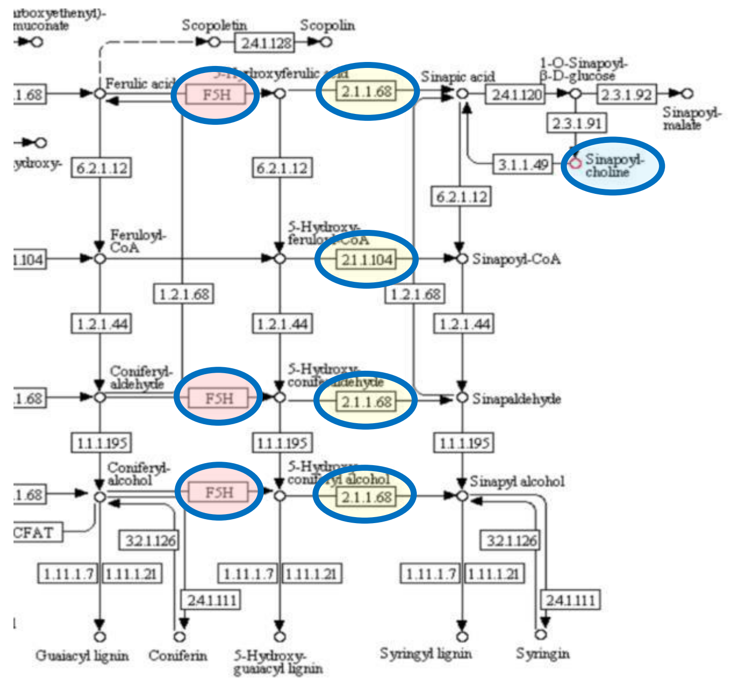
  - high fluctuation in revenues for the oil components

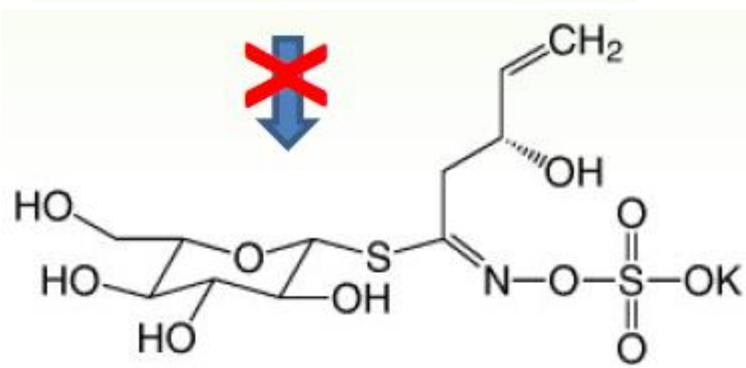


Plant breeding & genetics

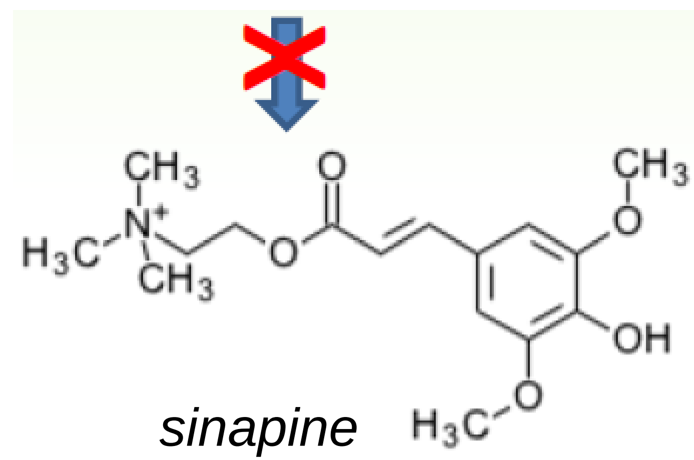
Knocking out glucosinolates in crambe, and sinapine in camelina







epi - progoitrin



sinapine

Different technologies to achieve the same

- **"Classical" breeding**
  - Find natural mutants (forward or reverse screens)
    - Look at the trait (forward screen) or find natural mutations in the gene itself
    - Often no such mutants present in nature
    - (Back)crossing, selection and selfing
- **Induce mutations**
  - Chemically (e.g. EMS to get single nucleotide changes rendering the target gene non-functional)
  - Radiation
  - All allowed without regulation although considered GM in EU, USA, Australia, Asia
  - In Canada: regulated through novel plant trait regulation
- **Transgenesis** (genetic modification) / **Cisgenesis**
  - Introduction of new DNA into the genomes of organisms
  - "trans" = from other species ('hardcore' genetic modification)
  - "cis" = from the same species (some people argue that less regulation is needed)
  - Process based regulation in EU, China, Australia, Brazil
  - Product-based (more case-by-case) regulation in USA, Canada, Argentina (mixed)
  - Knock-outs/downregulation e.g. using RNAi

Discussion on regulation issues

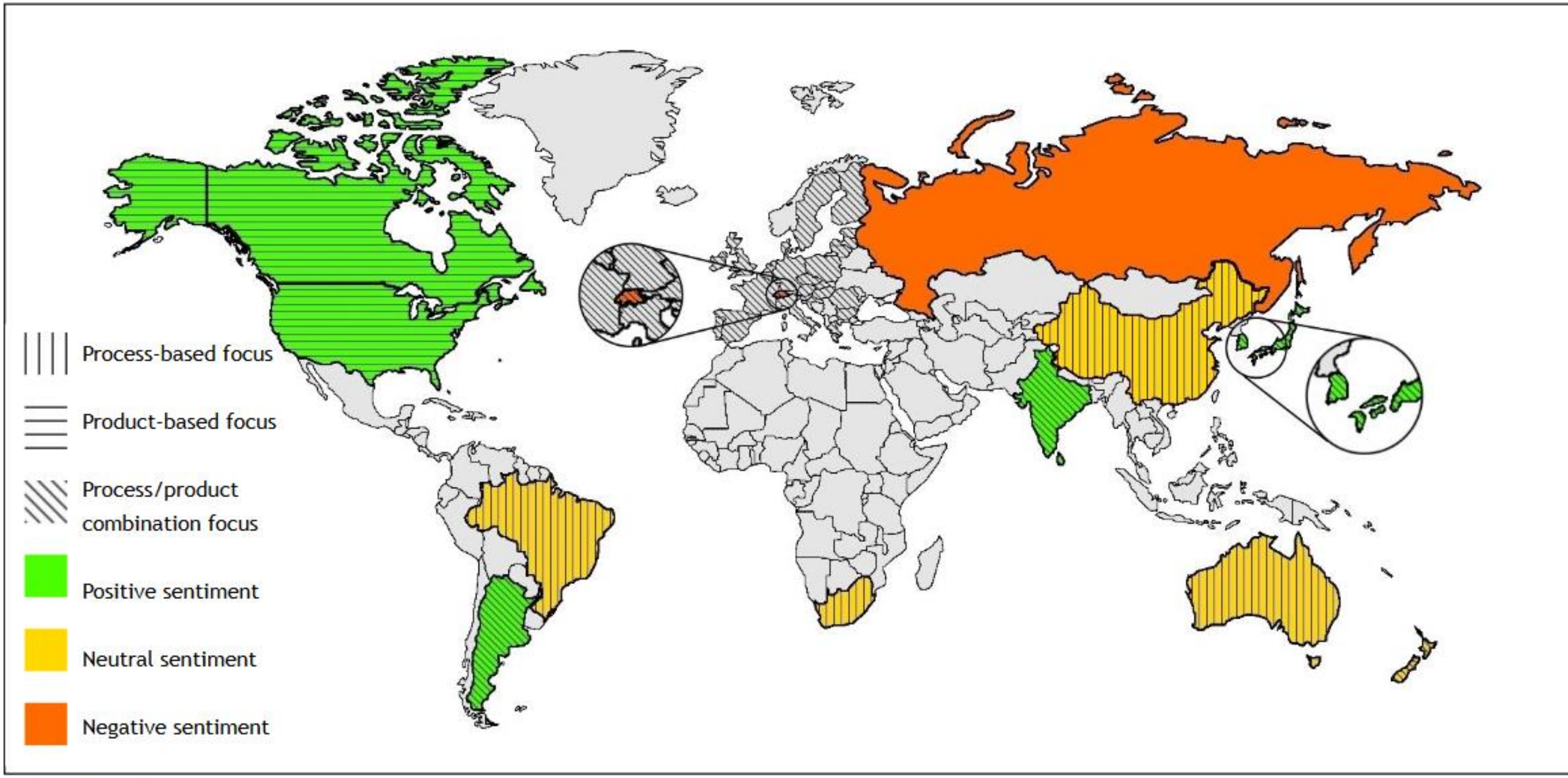
- **"Classical" (random) mutation breeding (e.g. EMS, radiation):**
  - **Europe and USA: no GMO regulation,**
  - **Canada: same regulation as GMOs; novel plant traits to be evaluated**

- **Gene-editing or targeted mutation breeding**
  - **Zinc fingers/TALENS, CRISPR mutants: safety same as EMS mutants, but regulated as GMO in EU**
  - **CRISPR without transformation (example in Sweden in potato) → some EU countries want to allow this using rules for non-GMO**

- **Oligonucleotide-directed mutagenesis: still regulated as GMO in EU**

Attitude towards gene editing / CRISPR

Annex E: Figure 'World map showing sentiment towards NBTs and regulatory focus, based on interviews and collected information' (updated May 2015)



Source: Annex D

https://www.nbtplatform.org/background-documents/rep-regulatory-status-of-nbts-oustide-the-eu-june-2015.pdf

Unclear rules for imports of gene edited products

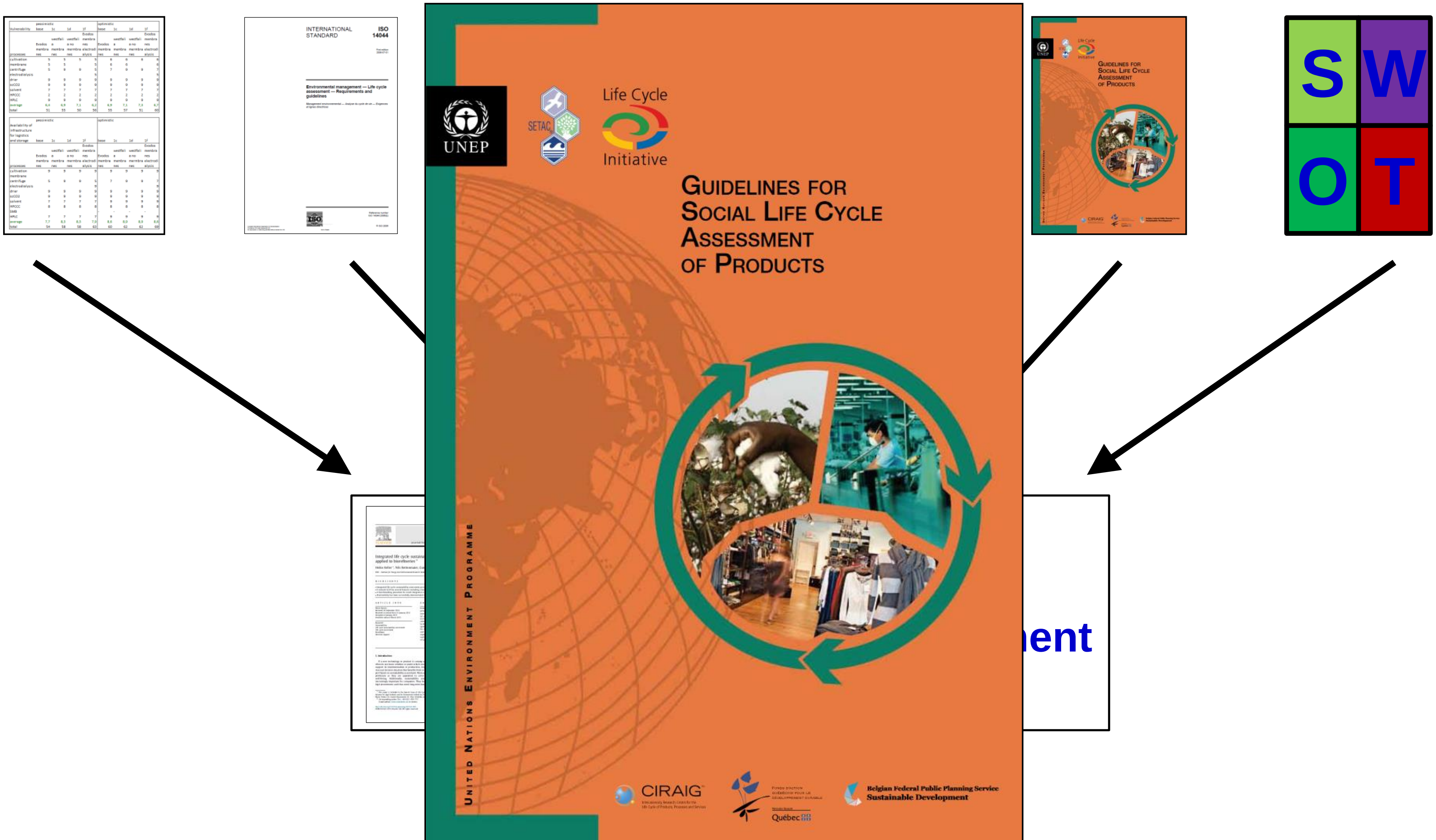
- What will happen if USA approves a CRISPR crop without labelling and extensive safety approval?
- Will EU block the import?
- How would the EU “see” a crop was “CRISPR-ed”?
  - Virtually impossible if target genes are not revealed
  - YIELD10 is an example of approved camelina with target genes not revealed!
- WTO may forbid EU to block the import!
  - Massive production of CRISPR crops in China and USA will flood EU markets?

Economic Assessment

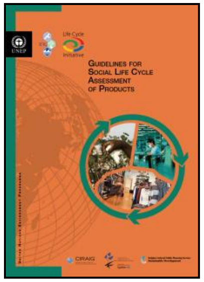
Conclusions

- **Camelina and Crambe not yet competitive**
- **Bottlenecks can be solved**
- **Transition phase necessary**

Social life cycle assessment (sLCA)



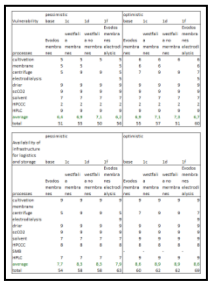
Social Assessment

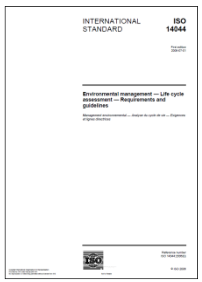


Key findings

- Main social impacts in Europe is expected on development of rural areas: big benefit.
- Also, diversification can lead to a more stable social security.

Integrated life cycle sustainability assessment (ILCSA)





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Integrated life cycle sustainability assessment – A practical approach applied to biorefineries ☆

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H I G H L I G H T S

- Integrated life cycle sustainability assessment provides ex-ante decision support.
- It extends LCSA by several features including a barrier analysis.
- A benchmarking procedure for result integration is presented.
- Practicability has been successfully demonstrated in five large EC-funded projects.

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A B S T R A C T

Politics and industry increasingly request comprehensive ex-ante decision support from a sustainability perspective in complex strategic decision situations. Several approaches have been introduced in the last years to increase the comprehensiveness of life cycle based assessments from covering only environmental aspects towards covering all sustainability aspects. This way, (environmental) life cycle assessment (LCA) has been extended towards life cycle sustainability assessment (LCSA). However, a practical application in ex-ante decision support requires additional features and flexibility that do not exist in the newly devised frameworks. Our methodology of integrated life cycle sustainability assessment (ILCSA) builds upon existing frameworks, extends them with features for ex-ante assessments that increase the value for decision makers and introduces a structured discussion of results to derive concrete conclusions and recommendations. At the same time, the flexibility allows for focussing on those sustainability aspects relevant in the respective decision situation using the best available methodology for assessing each aspect within the overarching ILCSA. ILCSA has so far been successfully applied in five large EC-funded projects. We discuss our methodology based on a concrete application example from these projects.

1. Introduction

If a new technology or product is coming up, decision makers often do not know whether or under which conditions they should support its implementation or production, respectively. This is a classical decision situation that benefits from ex-ante decision support based on sustainability assessment. Main addressees are often politicians as they are appointed to serve long-term public well-being. Additionally, sustainability assessment becomes increasingly important for companies. They have to decide about high investments and thus need long-term business perspectives, which are more and more influenced by sustainability-related legislation and public perception. Therefore, the proactive interest of companies in their impacts on sustainability and in potential pitfalls is rising.

Several approaches for comprehensive sustainability assessments of products or processes along their whole life cycles have been suggested in the last years [1–3]. The term life cycle sustainability assessment (LCSA), which is used in this context, was introduced as a combination of (environmental) life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (sLCA) [1]. The suggested LCSA approaches extend existing methodologies and often also provide options how to integrate results into one or few scores [4]. Heijungs et al. discuss options of modelling and integrating the assessment procedure and Finkbeiner et al. highlight possibilities of integrating the results obtained for different sustainability aspects [2,3]. The UNEP/

☆ This paper is included in the Special Issue of Life Cycle Analysis and Energy Balance for algal biofuels and for biomaterials edited by Dr. Kyriakos Maniatis, Dr. Mario Tredici, Dr. David Chiaramonti, Dr. Vitor Verdelho and Prof. Yan.

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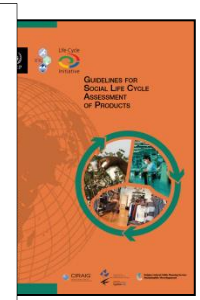
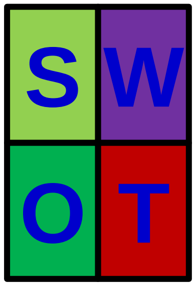
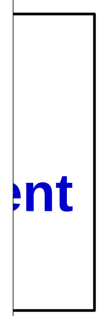






Integrated Assessment

ILCSA, exemplary results

Conservative performance – COSMOS scenarios

	Indicator	Unit	Scenario 1 Crambe main	Scenario 2 Camelina main	Scenario 3 Crambe hulls as fertiliser	Scenario 4 Crambe hulls to energy	Scenario 5 Crambe Cake as fertiliser	Scenario 6 Crambe cake for insects	Scenario 7 Crambe GSL extraction	Scenario 8 Camelina cake for insects	Scenario 9 Crambe PA 11	Scenario 10 Crambe erucic acid	Scenario 11 Camelina PA 11
Technology	Maturity	-	6,5	6,3	6,1	6,0	6,1	5,7	6,0	6,1	5,7	7,0	6,1
	Legislative framework and bureaucratic hurdles	-	5,6	5,5	5,3	5,2	5,3	4,9	5,2	5,3	4,9	6,1	5,3
	Availability of competent support systems	-	4,9	4,8	4,6	4,5	4,6	4,3	4,5	4,6	4,3	5,3	4,6
	Vulnerability	-	6,5	6,4	6,2	6,1	6,2	5,8	6,1	6,2	5,8	7,0	6,2
	Complexity	-	6,6	6,5	6,3	6,3	6,3	6,0	6,3	6,3	6,0	7,1	6,3
	Biological risk	-	5,6	6,2	5,4	5,3	5,4	5,0	5,3	5,4	5,0	6,1	5,4
	Technological risk: Hazardous substances	-	5,8	5,6	5,5	5,4	5,5	5,2	5,4	5,5	5,2	6,2	5,5
Environment	Global warming	t CO_2 eq. / ha/yr	-1	-1	-1	-1	1	1	7	1	-1	0	-1
	Energy resources	GJ / ha/yr	-2	-3	-4	-13	-2	-1	71	-2	-1	6	-1
	Terrestrial acidification	kg SO_2 eq. / ha/yr	13	7	12	12	12	12	26	7	13	1	8
	Marine eutrophication	kg N eq. / ha/yr	5	2	5	5	4	4	6	2	5	-1	2
	Freshwater eutrophication	g P eq. / ha/yr	522	290	511	523	556	555	966	317	521	9	288
	Photochemical smog	kg ethene eq. / ha/yr	-153	-166	-204	-413	-116	-117	1765	-117	-121	243	-113
	Ozone depletion	g CFC-11 eq. / ha/yr	29	10	29	30	22	23	25	5	28	-3	9
	Human toxicity (respiratory inorganics)	kg PM10 eq. / ha/yr	2	1	2	2	2	2	7	1	3	0	2
	Distance-to-Nature-Potential	m^2 artificial land eq. · yr / ha/yr	2239	638	2239	2241	3795	3685	3807	1949	2167	1404	517
	Water (local)	-	0	0	0	0	0	0	0	0	0	0	0
	Soil	-	0	-	-	0	-	0	-	-	-	0	0
	Fauna	-	-	-	0	0	0	0	0	0	-	0	0
	Flora	-	0	0	0	0	0	-	0	0	0	0	0
	Landscape	-	0	0	0	0	0	0	0	0	0	0	0
Economy	Target price for harvested seeds *1	€/t seeds	16	11	15	15	11	4	16	11	15	15	11
	Market price for harvested seeds	€/t seeds	11	11	14	14	12	2	11	11	14	14	12
	Target price for refined oil *2	€/t refined oil	0	0	0	0	0	-1	0	0	0	0	0
	Market price for refined oil		51	52	53	53	4	4	51	52	53	53	4
	Capital expenditure oleochemistry *3	Million €	100	20	30	20	40	20	30	30	40	20	10
	Net Present Value for oleochemistry *5	Million €	100	20	30	20	40	20	30	30	40	20	10
	Required investment / annual subsidies for oleochemistry	Million €/year oder Million €	110	22	33	22	44	22	51	52	53	53	4
Society & Policy	Unemployment	-	+	+	0	0	+	0	0	0	0	+	0
	Gender equity	-	0	0	0	0	0	0	0	0	0	0	0
	Governance (fragility of legal system)	-	+	+	+	+	+	+	+	+	+	+	+
	Health and Safety	-	+	+	+	+	+	+	+	+	+	+	+
	Labour rights (breach of NMW and excessive working time)	-	+	+	+	+	+	+	+	+	+	+	0
	Substituted (sub-)tropical oil products	-	0	0	0	0	-	-	0	0	0	0	0
	Policy issues	-	0	0	0	0	-	-	0	0	0	0	0

Optimistic performance – COSMOS scenarios

	Indicator	Unit	Scenario 1 Crambe main	Scenario 2 Camelina main	Scenario 3 Crambe hulls as fertiliser	Scenario 4 Crambe hulls to energy	Scenario 5 Crambe Cake as fertiliser	Scenario 6 Crambe cake for insects	Scenario 7 Crambe GSL extraction	Scenario 8 Camelina cake for insects	Scenario 9 Crambe PA 11	Scenario 10 Crambe erucic acid	Scenario 11 Camelina PA 11
Technology	Maturity	-	7,4	7,3	7,0	6,9	7,0	6,5	6,9	7,0	6,5	8,1	7,0
	Legislative framework and bureaucratic hurdles	-	6,5	6,3	6,1	6,0	6,1	5,7	6,0	6,1	5,7	7,0	6,1
	Availability of competent support systems	-	5,6	5,5	5,3	5,2	5,3	4,9	5,2	5,3	4,9	6,1	5,3
	Vulnerability	-	7,5	7,3	7,1	7,0	7,1	6,7	7,0	7,1	6,7	8,0	7,1
	Complexity	-	7,6	7,5	7,3	7,2	7,3	6,9	7,2	7,3	6,9	8,1	7,3
	Biological risk	-	6,5	6,4	6,2	6,1	6,2	5,8	6,1	6,2	5,8	7,0	6,2
	Technological risk: Hazardous substances	-	6,6	6,5	6,3	6,2	6,3	5,9	6,2	6,3	5,9	7,1	6,3
Environment	Global warming	t CO_2 eq. / ha/yr	-9	-7	-9	-10	-4	-5	-3	-3	-8	-2	-6
	Energy resources	GJ / ha/yr	4	-8	1	-22	6	6	34	-5	5	2	-5
	Terrestrial acidification	kg SO_2 eq. / ha/yr	32	24	31	30	28	28	33	21	32	-3	25
	Marine eutrophication	kg N eq. / ha/yr	13	9	13	13	12	12	12	7	13	0	8
	Freshwater eutrophication	g P eq. / ha/yr	1194	819	1165	1196	1286	1260	1419	884	1186	-219	798
	Photochemical smog	kg ethene eq. / ha/yr	-363	-833	-482	-1009	-239	-291	407	-730	-407	-29	-943
	Ozone depletion	g CFC-11 eq. / ha/yr	69	34	68	72	47	47	50	16	67	-12	29
	Human toxicity (respiratory inorganics)	kg PM10 eq. / ha/yr	7	5	6	6	6	6	8	4	7	0	5
	Distance-to-Nature-Potential	m^2 artificial land eq. · yr / ha/yr	-830	-6075	-828	-823	3854	3083	3136	-2316	-1124	-3284	-6812
	Water (local)	-	0	0	0	0	0	0	-	0	0	0	+
	Soil	-	+	+	0	0	0	+	0	0	+	0	+
	Fauna	-	+	+	+	+	0	++	-	0	0	+	0
	Flora	-	0	0	0	0	0	0	0	0	+	0	0
	Landscape	-	0	0	0	0	+	0	0	0	0	0	0
Economy	Target price for harvested seeds *1	€/t seeds	16	11	15	15	11	4	16	11	15	15	11
	Market price for harvested seeds	€/t seeds	11	11	14	14	12	2	11	11	14	14	12
	Target price for refined oil *2	€/t refined oil	0	0	0	0	0	-1	0	0	0	0	0
	Market price for refined oil		51	52	53	53	4	4	51	52	53	53	4
	Capital expenditure oleochemistry *3	Million €	100	40	50	40	60	40	50	50	60	40	30
	Net Present Value for oleochemistry *5	Million €	100	40	50	40	60	40	50	50	60	40	30
	Required investment / annual subsidies for oleochemistry	Million €/year oder Million €	100	40	50	40	60	40	50	50	60	40	30
Society & Policy	Unemployment	-	+	+	0	0	+	0	0	0	0	+	0
	Gender equity	-	0	0	0	0	0	0	0	0	0	0	0
	Governance (fragility of legal system)	-	+	+	+	+	+	+	+	+	+	+	+
	Health and Safety	-	+	+	+	+	+	+	+	+	+	+	+
	Labour rights (breach of NMW and excessive working time)	-	+	+	+	+	+	+	+	+	+	+	0
	Substituted (sub-)tropical oil products	-	0	0	0	0	0	0	0	0	0	0	0
	Policy issues	-	0	0	0	0	0	0	0	-	-	0	0

Integrated Assessment

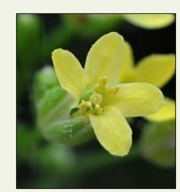
ILCSA, exemplary results

	Conservative performance										
	COSMOS scenarios										
	Scenario 1 Crambe main	Scenario 2 Camelina main	Scenario 3 Crambe hulls as fertiliser	Scenario 4 Crambe hulls to energy	Scenario 5 Crambe Cake as fertiliser	Scenario 6 Crambe cake for insects	Scenario 7 Crambe GSL extraction	Scenario 8 Camelina cake for insects	Scenario 9 Crambe PA 11	Scenario 10 Crambe erucic acid	Scenario 11 Camelina PA 11

	Optimistic performance										
	COSMOS scenarios										
	Scenario 1 Crambe main	Scenario 2 Camelina main	Scenario 3 Crambe hulls as fertiliser	Scenario 4 Crambe hulls to energy	Scenario 5 Crambe Cake as fertiliser	Scenario 6 Crambe cake for insects	Scenario 7 Crambe GSL extraction	Scenario 8 Camelina cake for insects	Scenario 9 Crambe PA 11	Scenario 10 Crambe erucic acid	Scenario 11 Camelina PA 11

	Indicator	Unit
Technology	Maturity	-
	Legislative framework and bureaucratic hurdles	-
	Availability of competent support systems	-
	Vulnerability	-
	Complexity	-
	Biological risk	-
	Technological risk: Hazardous substances	-
Environment	Global warming	t CO_2 eq. / ha/yr
	Energy resources	GJ / ha/yr
	Terrestrial acidification	kg SO_2 eq. / ha/yr
	Marine eutrophication	kg N eq. / ha/yr
	Freshwater eutrophication	g P eq. / ha/yr
	Photochemical smog	kg ethene eq. / ha/yr
	Ozone depletion	g CFC-11 eq. / ha/yr
	Human toxicity (respiratory inorganics)	kg PM10 eq. / ha/yr
	Distance-to-Nature-Potential	m^2 artificial land eq. · yr / ha/yr
	Water (local)	-
	Soil	-
	Fauna	-
	Flora	-
	Landscape	-
Economy	Target price for harvested seeds *1	€/t seeds
	Market price for harvested seeds	€/t seeds
	Target price for refined oil *2	€/t refined oil
	Market price for refined oil	
	Capital expenditure oleochemistry *3	Million €
	Net Present Value for oleochemistry *5	Million €
	Required investment / annual subsidies for oleochemistry	Million €/year oder Million €
Society & Policy	Unemployment	-
	Gender equity	-
	Governance (fragility of legal system)	-
	Health and Safety	-
	Labour rights (breach of NMW and excessive working time)	-
	Substituted (sub-)tropical oil products	-
	Policy issues	-

- Partly conflicting results across pillars of sustainability
- Suitable tool to identify
  - best performing pathways
  - important trade-offs
  - major aspects for decision support



Outline

- Background
- Sustainability of cramelina and crambe
- Summary and conclusions

Summary 1/2

Promising benefits for camelina and crambe:

- ➔ **Next to greenhouse gas savings, overall biodiversity conservation is possible with some pathways, especially with crambe, though also with camelina to a lesser extent.**
- ➔ **Especially, savings of tropical forests are possible.**
- ➔ **Very promising benefits for double cropping of camelina.**
- ➔ **Socio-economic impacts tend to be positive, e.g. rural development, diversification in several sectors in Europe, and reduced import dependancy.**


Summary 2/2

Hurdles exist, but can be overcome:

- ➔ **Financial hurdles quite dominant: Actions needed also on long term.**
- ➔ **Harvest technology especially for Crambe seeds needs further development.**
- ➔ **Separation technology for hulls not yet mature.**
- ➔ **Crop rotations scheme including double cropping have still to be optimized for different soil and climatic conditions.**
- ➔ **Breeding issues (especially CRISPR/Cas) have to be solved.**

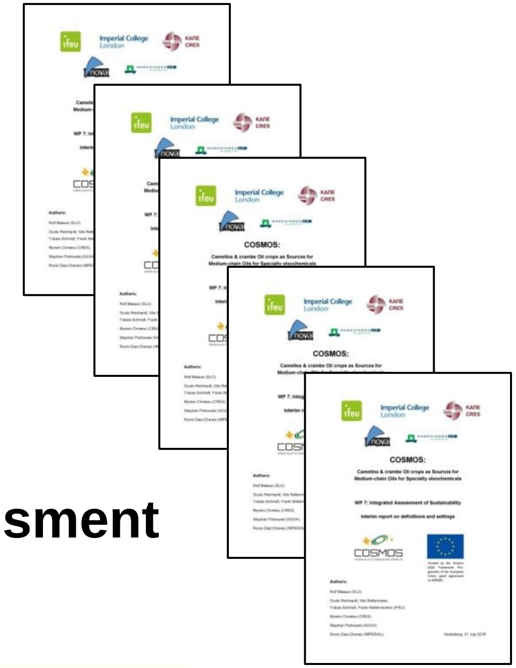
Conclusions and recommendations

- Camelina and crambe are very promising oil crops for Europe to meet sustainability goals especially in the environmental and socio-economic sector.
- Not yet mature for full implementation.
- Needs some support for the transition phase if society / policy decides to realize the opportunity.
- Use the transition phase efficient and parallel in all sectors: technology development, legal aspects etc.
- For identification the most efficient optimization options and steer policy, integrated life cycle sustainability assessment (ILCSA) needs to be applied.


Publications

Further reading:

- Final report on technological assessment
- Final report on economic assessment
- Final report on environmental assessment
- Final report on policy and social assessment
- Final report on integrated sustainability assessment



→ All reports are public !

→ Download from: www.cosmos-H2020.eu

→ Available in about 2 months.

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COSMOS
ADDING VALUE TO CAMELINA AND CRAMBE OIL

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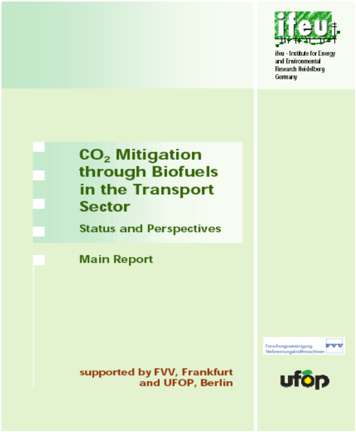

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