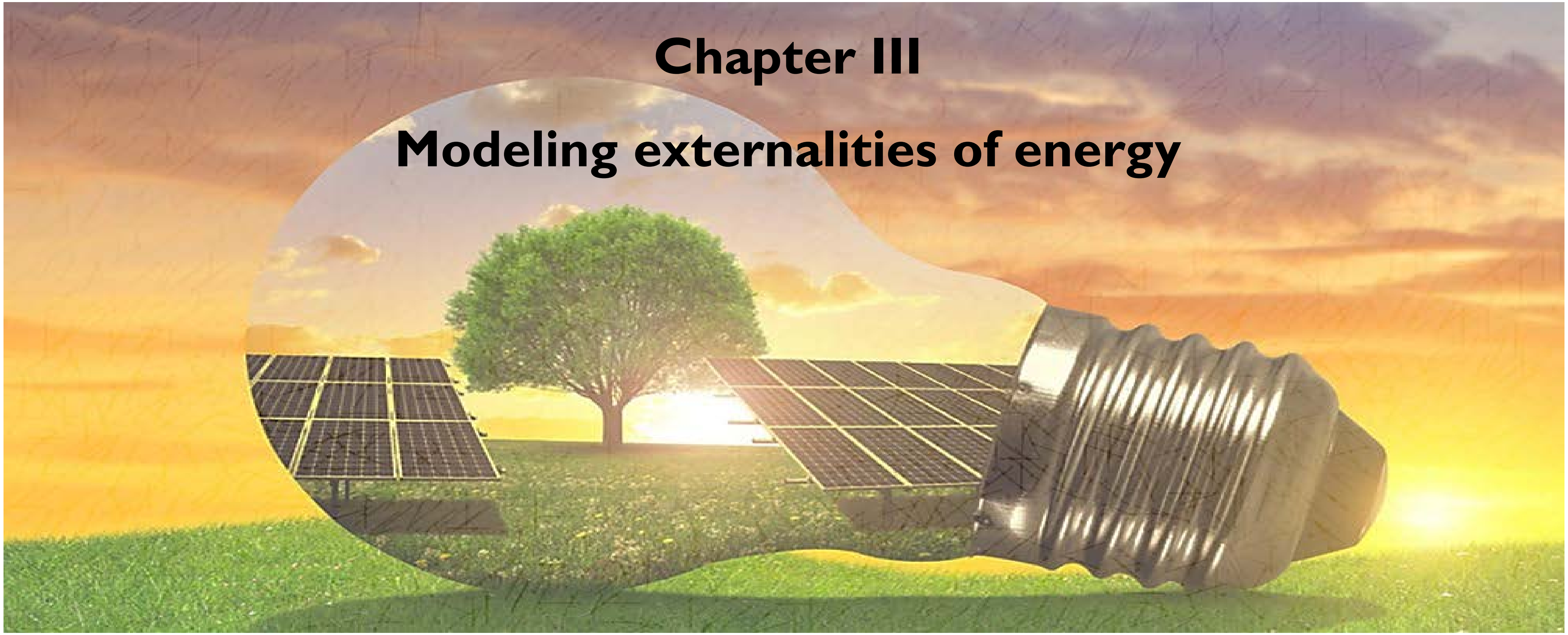
ENERGY PLANNING : MODELLING AND DECISION SUPPORT



Chapter III

Modeling externalities of energy

-CONTENT-

3.1 The issue of externality

3.2 Selected valuation methods

3.3 ExternE: Externalities of Energy

3.4 The concept of LCA and its application to biofuels

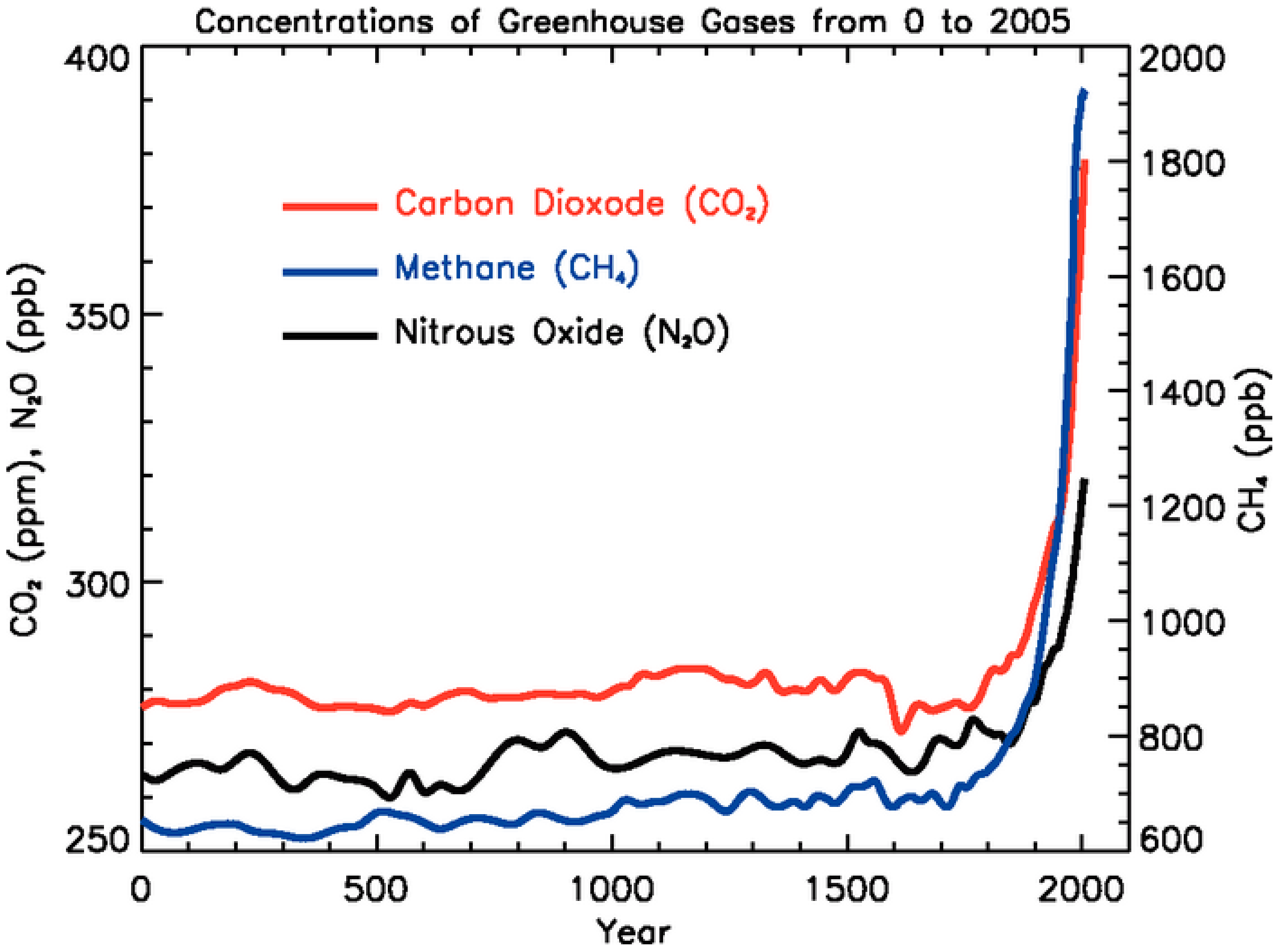
3.1 THE ISSUE OF EXTERNALITY

- In the orthodox economy, the production cost of a good is the sum of the costs of the production factors: labor, capital, materials and energy. Costs that only consider the production system within its boundaries are internal or private costs.

- The production of goods may harm the environment, the costs of which will not be in charge of the producer. These costs are considered as external to the production system.

- One difficulty to impute «external costs» to a producer is the cumulative cause of the damage to the environment

- Climate Change is a consequence of the concentration of greenhouse gases in the atmosphere. The emission of GHG by a particular producer would have more or less damages to the environment depending of the previous state of concentration



- Market (or private) goods have two main properties: excludability (anyone who will not be able to pay the price of a good will be excluded from its consumption) and rivalness (goods that are consumed by someone cannot be consumed by another agent)
- Some goods such as the landscape or the environment are not excludable nor rival they are common goods
- They are not divisible and if public, no one can be excluded from their use
- Difficulty of «free market» to price common goods is a «market failure»

3.2 SELECTED VALUATION METHODS

The dose-response method links physiological response of living organisms to pollution stress

In some cases, increasing the dose can change the production output which can be valued using market price, e.g. loss of crops due to increasing pollution

Regarding effects on human health, valuation using price may be considered as a reductionism!

e.g. the cost of bank renaturation can be considered as the external cost of anthropologic denaturation actions

Replacement cost method estimates the cost of restoring the damaged asset and uses that cost as the external cost of the damage

However estimating replacement costs means that it is possible to define a reference state after restoring. Theoretically, it may be the state of the asset before the damage e.g. acoustic insulation of a building in order to reduce noises to a required level

Mitigation cost methods estimate the cost to prevent damages (avertive expenditures)

However mitigation works on the effects not on the source

Revealed preference methods relate a quantitative variable to a value of an environmental asset

e.g. the value of a recreation site can be evaluated using visitors' travel cost (number of visitors per year, average distance, price of fuel)

Travel cost method (TCM) is an example of revealed preference methods

Expressed preference methods are used to value (through a questionnaire) what individuals are willing to pay (Willingness to pay – WTP) in order to get benefit to an environmental asset

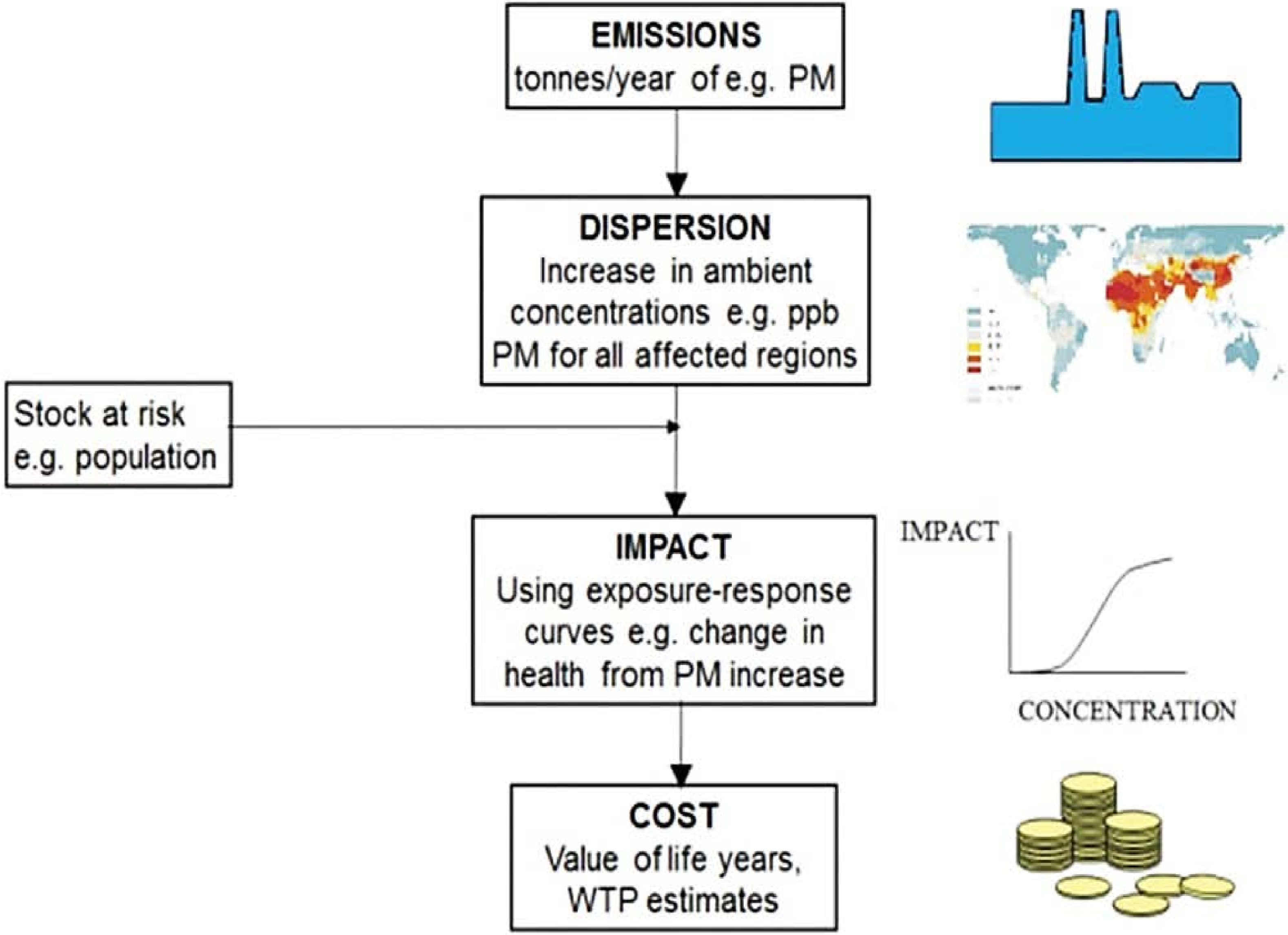
This method is also called «Contingent valuation method (CVM)»

What are individuals willing to accept (in terms of money) in compensation for the loss of the environmental asset (Willingness to accept (WTA)

Experiments show that WTA is often higher compared to WTP

3.3 EXTERNE: EXTERNALITIES OF ENERGY

ExternE methodology was developed in the framework of the Joule EC project (EC, 2005) and applies an «Impact Pathway Approach» from the source to the monetary valuation. The approach consists in four steps.



The four steps of the ExternE approach

Emission:

specification of the emission factor of a given technonology : e.g. kg of oxides of nitrogen (NOx) per GWh

Dispersion:

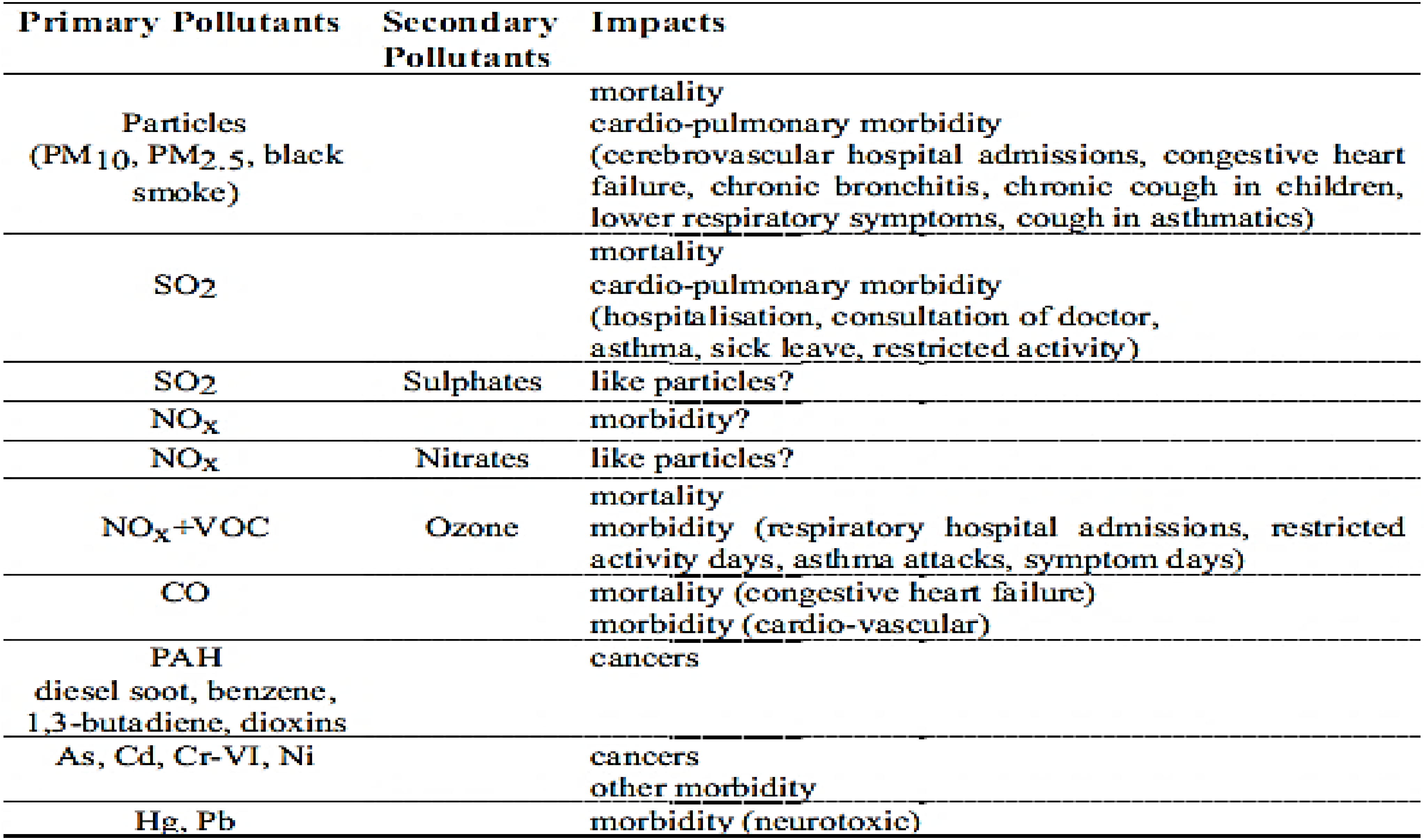
estimated increased concentration of pollutants using atmospheric dispersion and chemistry of pollutants formation

Impacts:

calculate damages taking into account a cumulated exposure to pollutants' concentration and using exposure-response function (e.g. asthma caused by increase of ozone O_3)

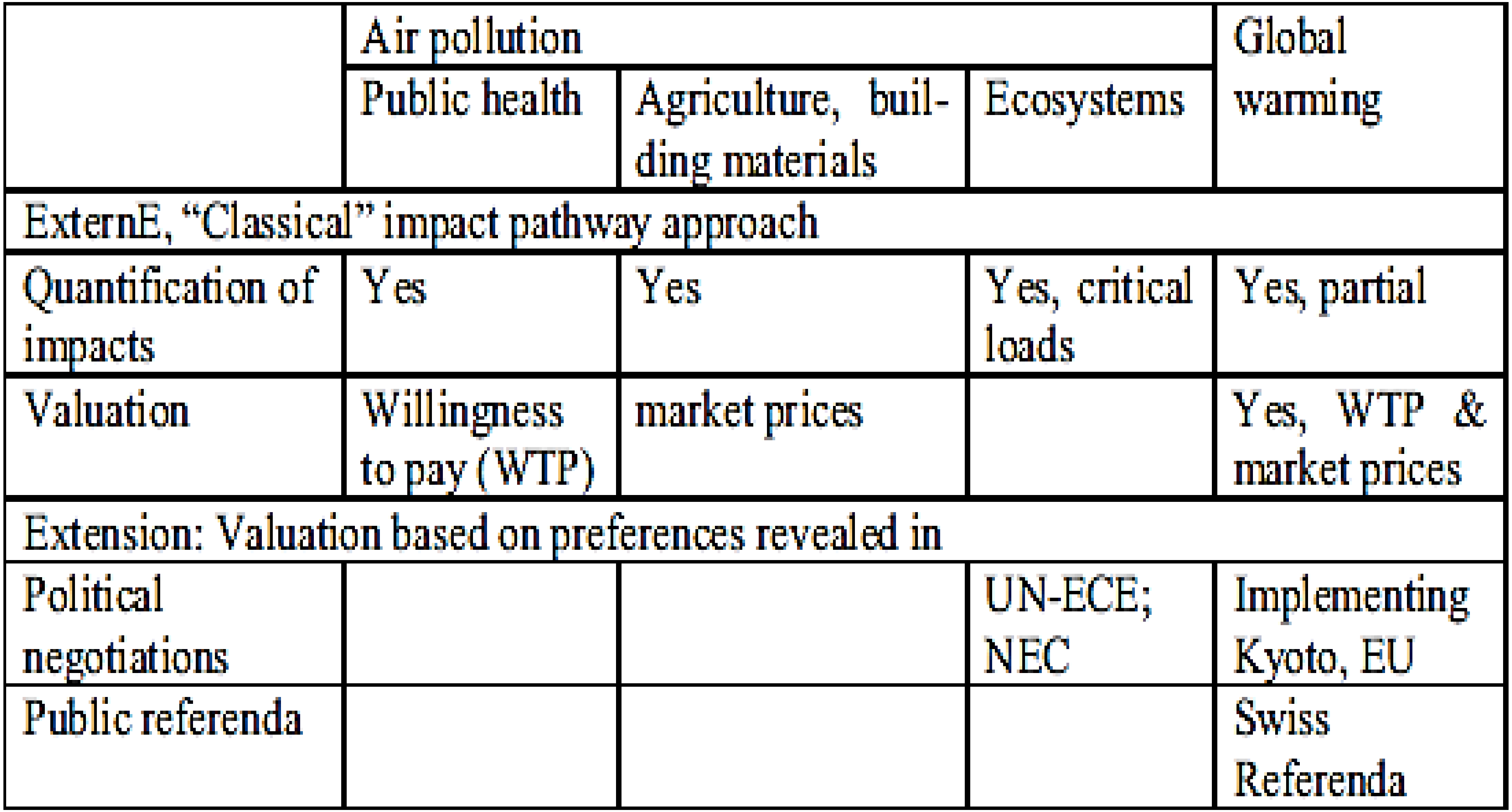
Monetary valuation:

e.g. using health cost related to asthma



Primary Pollutants	Secondary Pollutants	Impacts
Particles (PM_{10}, $PM_{2.5}$, black smoke)		mortality cardio-pulmonary morbidity (cerebrovascular hospital admissions, congestive heart failure, chronic bronchitis, chronic cough in children, lower respiratory symptoms, cough in asthmatics)
SO_2		mortality cardio-pulmonary morbidity (hospitalisation, consultation of doctor, asthma, sick leave, restricted activity)
SO_2	Sulphates	like particles?
NO_x		morbidity?
NO_x	Nitrates	like particles?
NO_x+VOC	Ozone	mortality morbidity (respiratory hospital admissions, restricted activity days, asthma attacks, symptom days)
CO		mortality (congestive heart failure) morbidity (cardio-vascular)
PAH diesel soot, benzene, 1,3-butadiene, dioxins		cancers
As, Cd, Cr-VI, Ni		cancers other morbidity
Hg, Pb		morbidity (neurotoxic)

Source: EC, 2005



	Air pollution			Global warming
	Public health	Agriculture, building materials	Ecosystems	
ExternE, "Classical" impact pathway approach				
Quantification of impacts	Yes	Yes	Yes, critical loads	Yes, partial
Valuation	Willingness to pay (WTP)	market prices		Yes, WTP & market prices
Extension: Valuation based on preferences revealed in				
Political negotiations			UN-ECE; NEC	Implementing Kyoto, EU
Public referenda				Swiss Referenda

Source: EC, 2005

Discussion: Internalization of externalities

Externalities can be internalized through policy measures such as:

- Taxation of pollutants emissions (Group 1)
- Regulation of pollution (Group 2)
- Normalization (Group 3)
- Technology choice (Group 4)

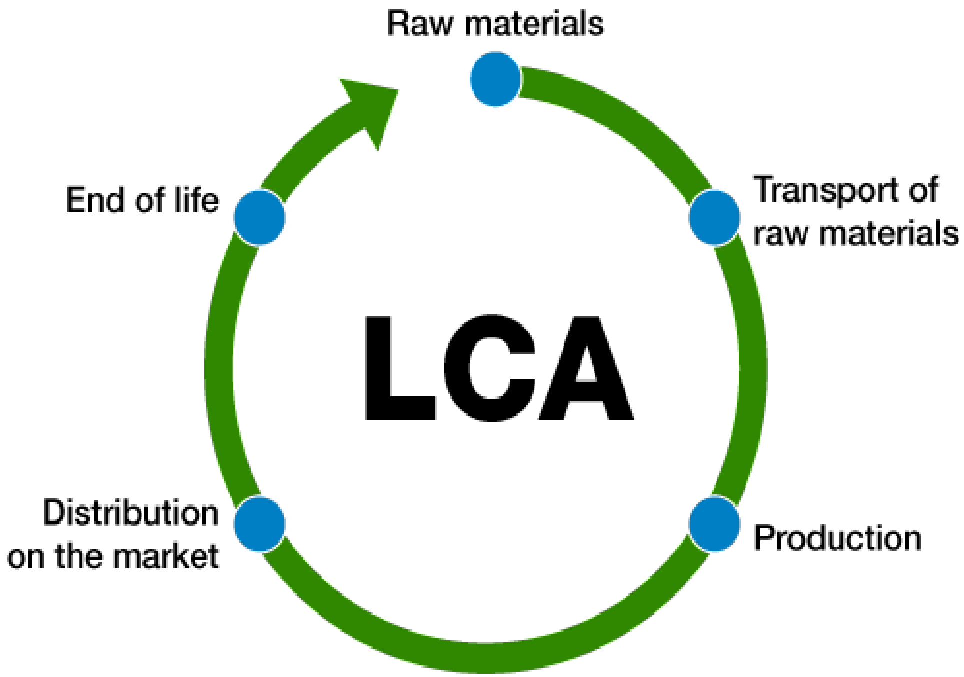
1) Give an example of each measure in regard to planning of the electrical generating system
2) How can that be considered with Planelec-Pro?

3.4 THE CONCEPT OF LCA

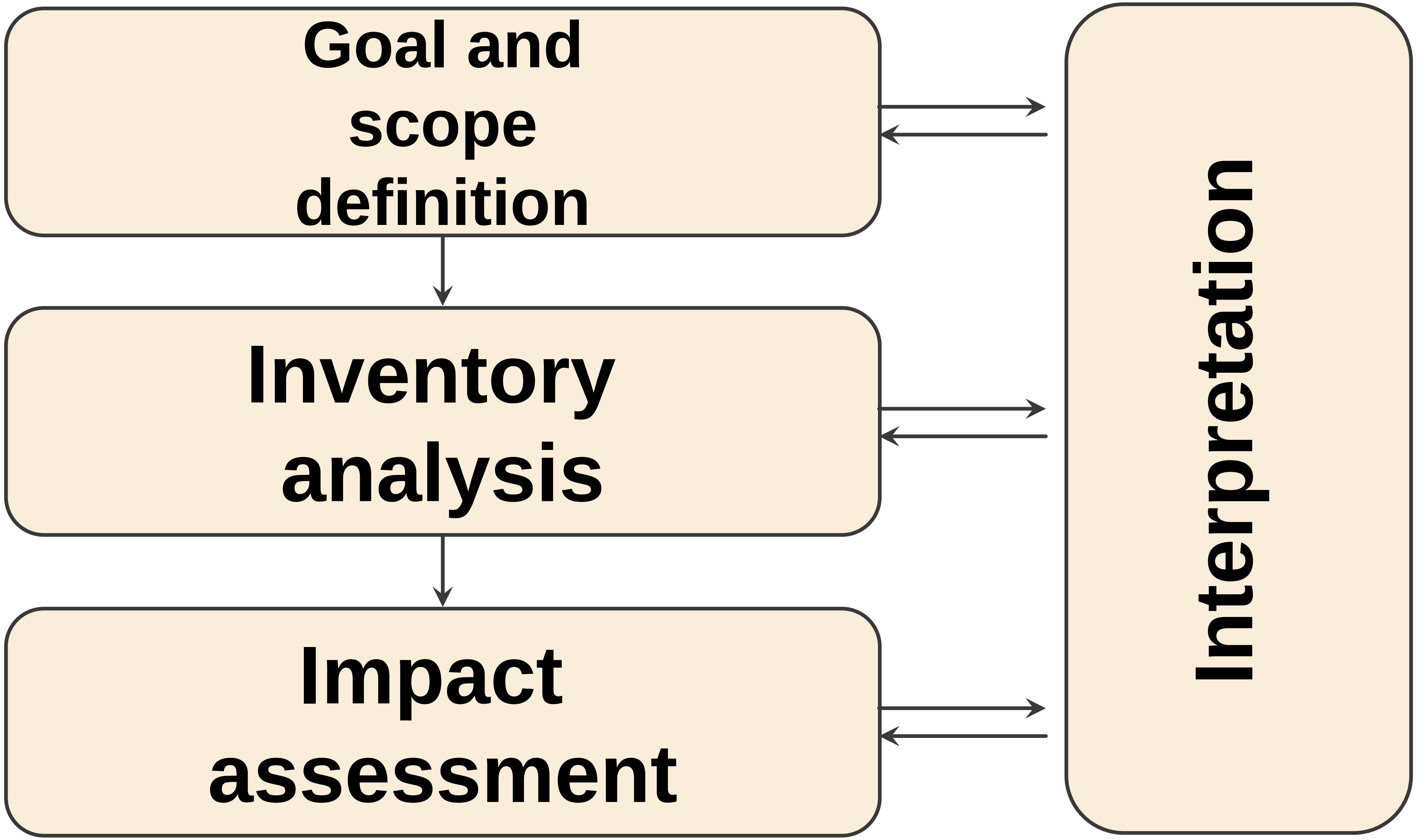
and its application to biofuels

Definition of LCA

«LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)»



ISO 14040:2006



Goal and scope definition

Inventory analysis

Impact assessment

Interpretation

Fundamentals of LCA

Goal definition

- Why is the LCA study carried out ?
- Which audience is it addressed to ?
- Does it aim at designing or improving a product ?
- Does it intend to support comparative assertions ?

Depending on the goal, the LCA study will be more or less broad, deep and detailed

Fundamentals of LCA

Goal and scope definition

As far as the policy framework is concerned, comparative life cycle must be used with the purpose to compare the biofuel with the fossil substituted fuel.

The system boundaries must be a Well-to-Wheel (WtW) instead of Well-to-Tank (WtT).

Fundamentals of LCA

Scope definition & choices

- The product system
- The function(s) of the systems
- The functional unit
- The system boundaries
- Allocation procedure(s)

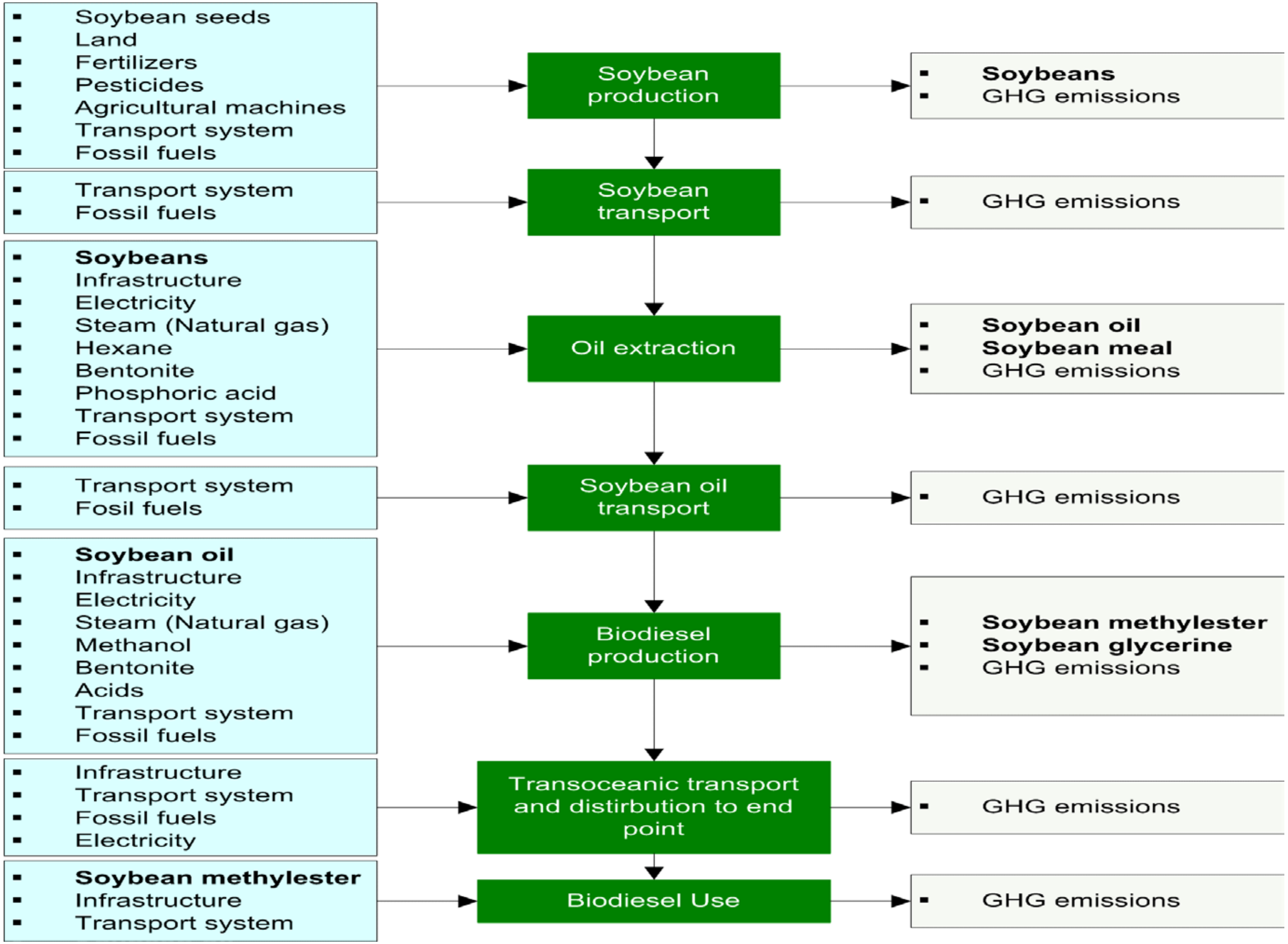
Scope requirements

- Impact categories selected and methodology of impact assessment
- Issues related to interpretation
- Data requirements
- Limitations
- Initial data quality requirements

Fundamentals of LCA

Inventory analysis

It involves data collection and evaluation procedures to estimate inputs and outputs of each step of the product system. Existing inventory databases are very helpful: e.g. the Swiss life cycle inventory database ecoinvent; the European Union and the United States are also implementing their own database.



- Soybean seeds
- Land
- Fertilizers
- Pesticides
- Agricultural machines
- Transport system
- Fossil fuels

Soybean production

- **Soybeans**
- GHG emissions

- Transport system
- Fossil fuels

Soybean transport

- GHG emissions

- **Soybeans**
- Infrastructure
- Electricity
- Steam (Natural gas)
- Hexane
- Bentonite
- Phosphoric acid
- Transport system
- Fossil fuels

Oil extraction

- **Soybean oil**
- **Soybean meal**
- GHG emissions

- Transport system
- Fosil fuels

Soybean oil transport

- GHG emissions

- **Soybean oil**
- Infrastructure
- Electricity
- Steam (Natural gas)
- Methanol
- Bentonite
- Acids
- Transport system
- Fossil fuels

Biodiesel production

- **Soybean methylester**
- **Soybean glycerine**
- GHG emissions

- Infrastructure
- Transport system
- Fossil fuels
- Electricity

Transoceanic transport and distirbution to end point

- GHG emissions

- **Soybean methylester**
- Infrastructure
- Transport system

Biodiesel Use

- GHG emissions

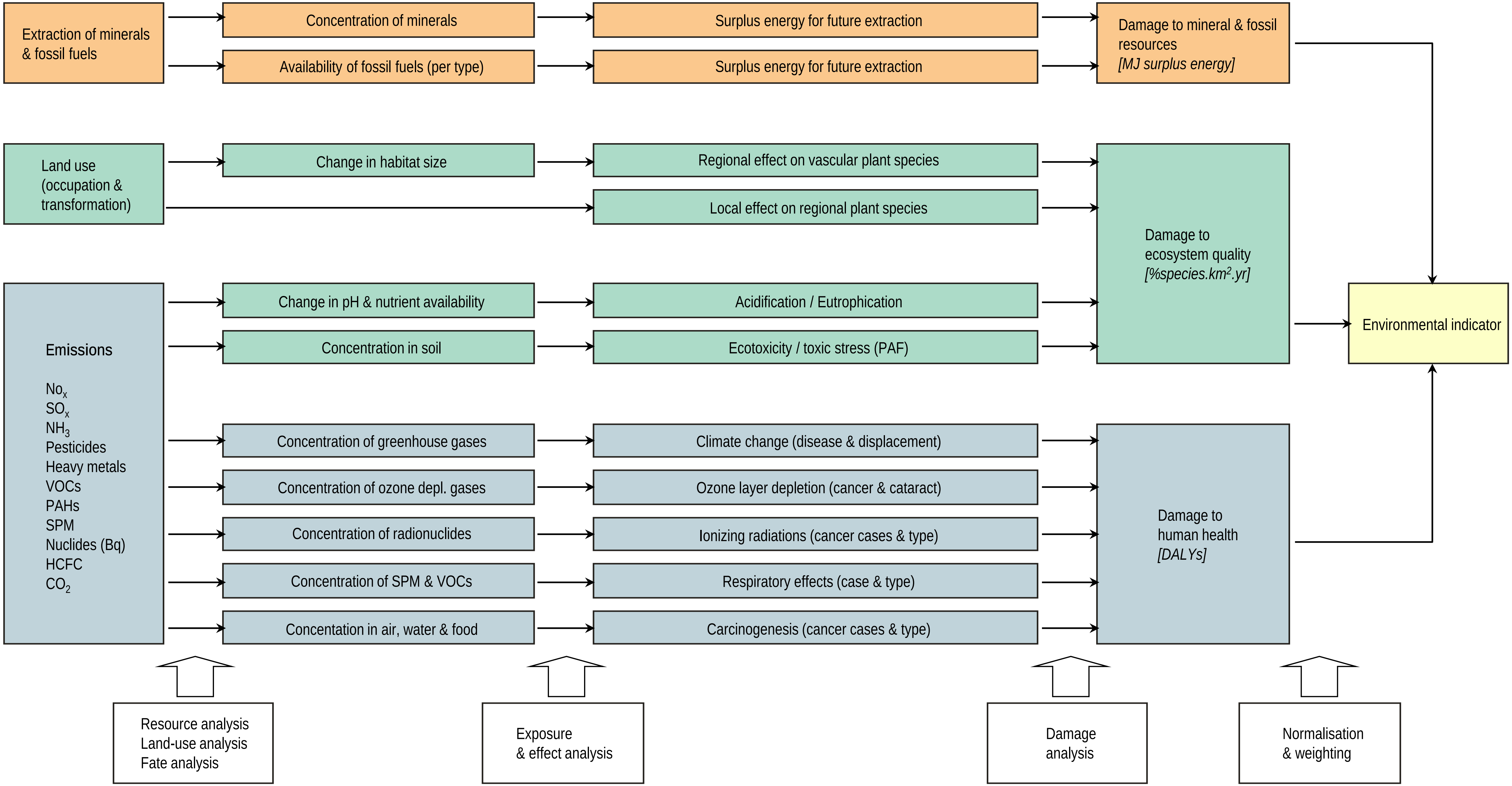
Example of the system definition and inventory analysis in the case of biodiesel production and export from Argentina to Switzerland

(Panichelli and Gnansounou)

Fundamentals of LCA

Impact assessment (LCIA)

At this step, the inputs (incl. resources, processes, products, etc.) and outputs (emissions, wastes, etc.) through the life cycle inventory are converted into environmental categories and indicators.



Extraction of minerals & fossil fuels

Concentration of minerals

Availability of fossil fuels (per type)

Surplus energy for future extraction

Surplus energy for future extraction

Damage to mineral & fossil resources *[MJ surplus energy]*

Land use (occupation & transformation)

Change in habitat size

Regional effect on vascular plant species

Local effect on regional plant species

Damage to ecosystem quality *[%species.km^2.yr]*

Emissions

No$_x$
SO$_x$
NH$_3$
Pesticides
Heavy metals
VOCs
PAHs
SPM
Nuclides (Bq)
HCFC
CO$_2$

Change in pH & nutrient availability

Acidification / Eutrophication

Concentration in soil

Ecotoxicity / toxic stress (PAF)

Environmental indicator

Concentration of greenhouse gases

Climate change (disease & displacement)

Concentration of ozone depl. gases

Ozone layer depletion (cancer & cataract)

Concentration of radionuclides

Ionizing radiations (cancer cases & type)

Concentration of SPM & VOCs

Respiratory effects (case & type)

Concentation in air, water & food

Carcinogenesis (cancer cases & type)

Damage to human health *[DALYs]*

Resource analysis
Land-use analysis
Fate analysis

Exposure & effect analysis

Damage analysis

Normalisation & weighting

Fundamentals of LCA

Life cycle interpretation

- To what extent does the LCI and/or the LCIA contribute to the goal achievement ?
- What are the major findings ?
- Are the scope of the LCA relevant in regards to the goal achievement ?
- In which extent the results are sensitive to the assumptions and to the quality of inputs ?
- What recommendations can be made to the decision makers ?

According to the answers, iterations may be performed with the other steps

Goal and scope definition

- The functional unit must be 1km instead of 1 MJth because the fuels are not considered for thermal production rather then for mechanical energy. Thus the combustion performance must be accounted for.

Proposed methodology

- To define a baseline, as complete and relevant as possible, that considers not only the substituted fossil fuel but all other initial use or product replaced by the co-products of the biofuel.
- As a consequence, the previous land uses must be accounted for in the baseline.
- Although the ISO 14040-series recommends avoiding allocation whenever possible, the so called system expansion or substitution may induce inconsistencies.
- The performance of the biofuel must be evaluated in the same way as the one of its co-products.

ILLUSTRATION

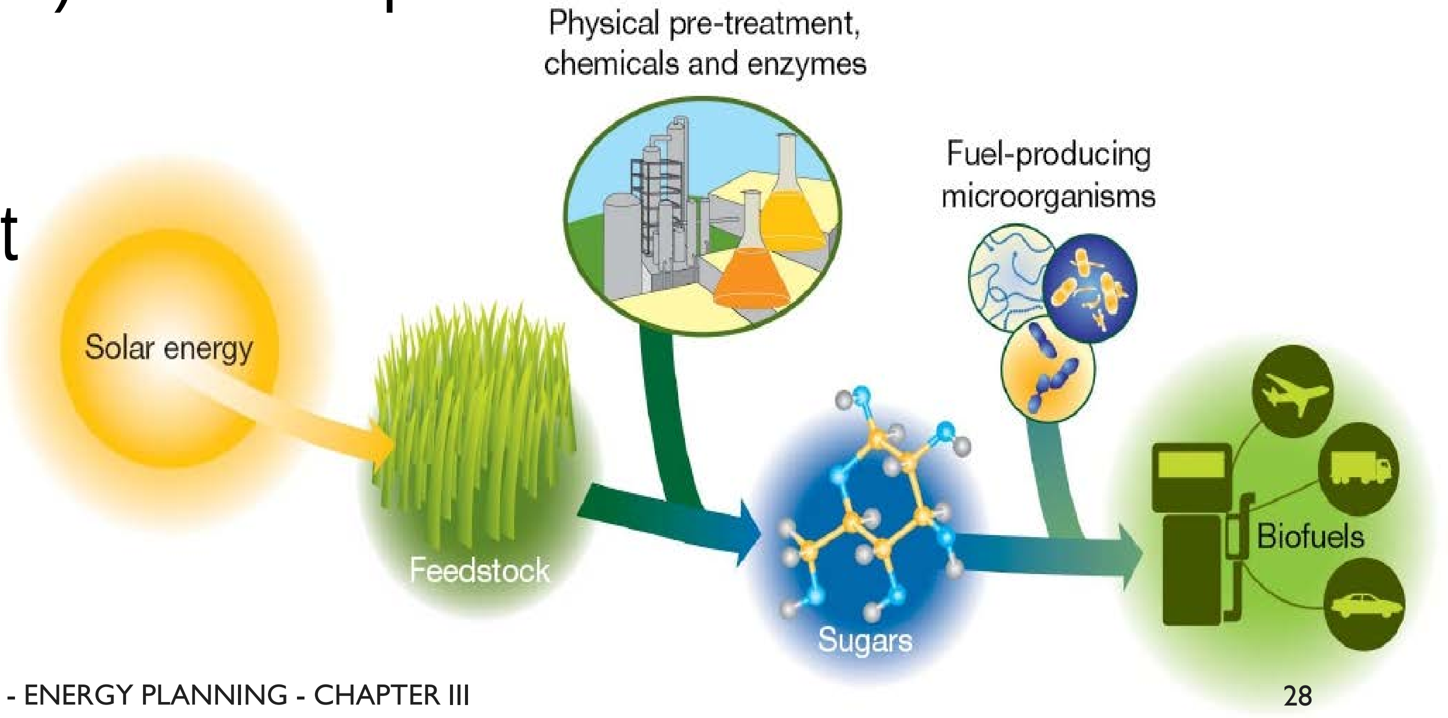
BIOETHANOL PRODUCTION AND USE IN SWITZERLAND

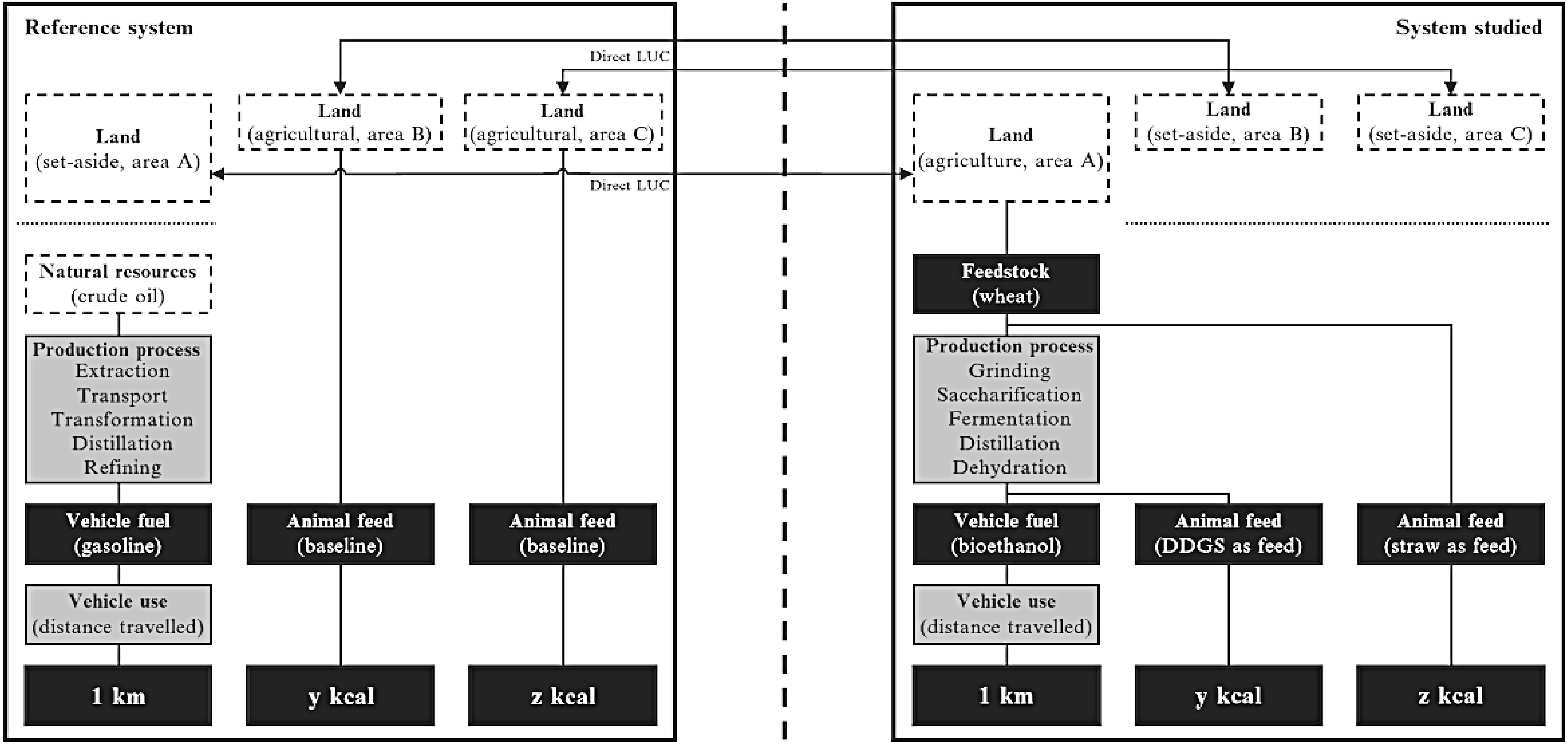
The case study is concerned with a production, distribution and use of anhydrous fuel-bioethanol (99.7wt%) as a transportation fuel in Switzerland (CH)

Bioethanol is produced from wheat

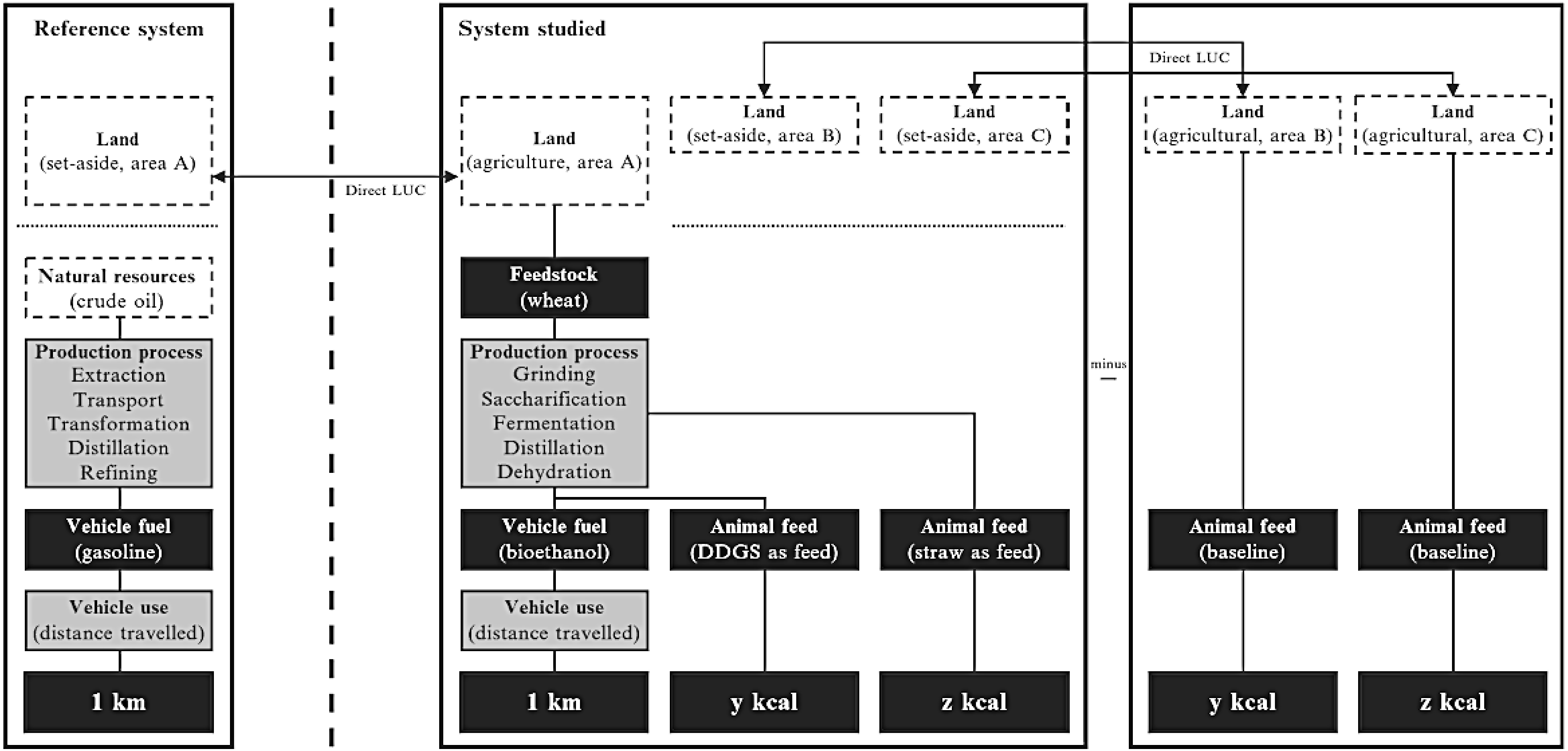
The functional unit is 1km

Source: Gnansounou et al. 2009

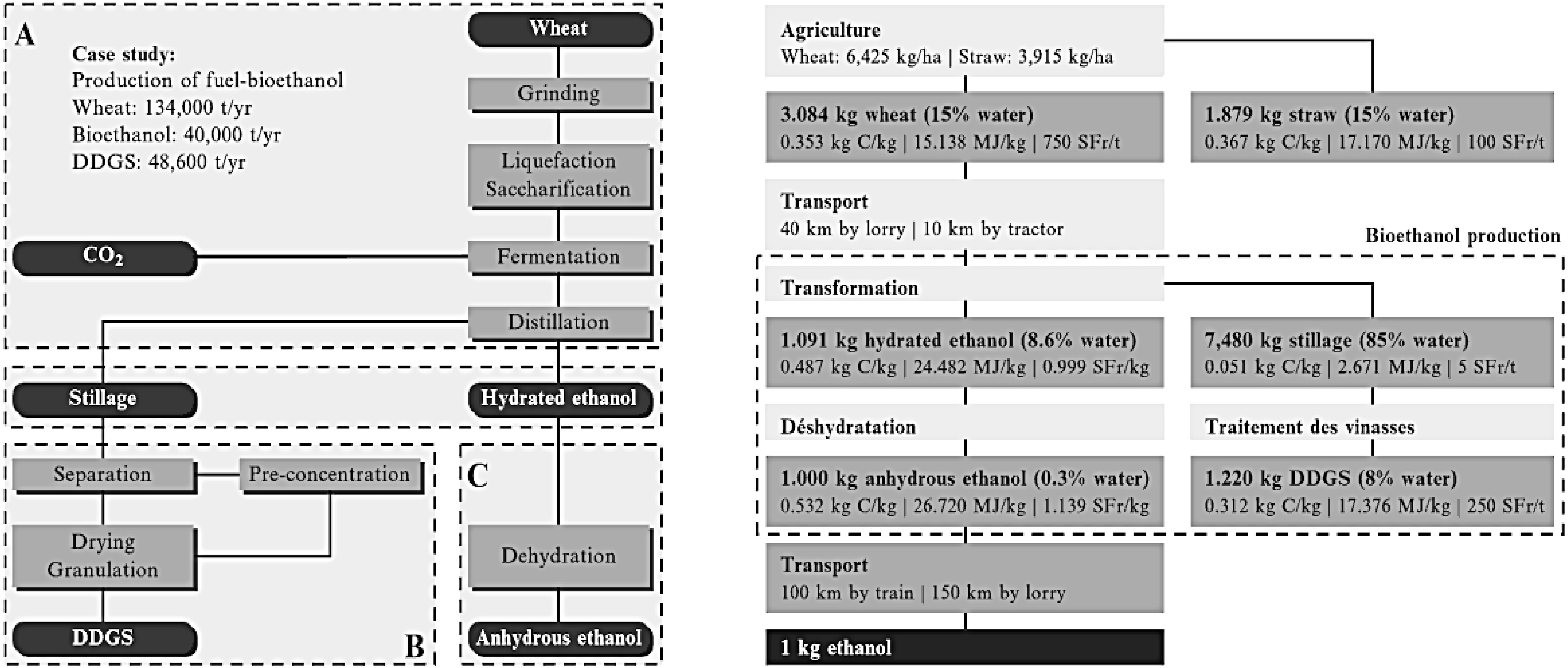




System definition and boundaries (from reference system to system studied)



System definition and boundaries (in case of allocation by substitution, case of S-1, that is, DDGS and straw animal feed



A

Case study:
Production of fuel-bioethanol
Wheat: 134,000 t/yr
Bioethanol: 40,000 t/yr
DDGS: 48,600 t/yr

Wheat
Grinding
Liquefaction
Saccharification
Fermentation
CO_2
Distillation
Stillage
Hydrated ethanol

B

Separation
Pre-concentration
Drying
Granulation
DDGS

C

Dehydration
Anhydrous ethanol

Agriculture
Wheat: 6,425 kg/ha | Straw: 3,915 kg/ha

3.084 kg wheat (15% water)
0.353 kg C/kg | 15.138 MJ/kg | 750 SFr/t

1.879 kg straw (15% water)
0.367 kg C/kg | 17.170 MJ/kg | 100 SFr/t

Transport
40 km by lorry | 10 km by tractor

Bioethanol production

Transformation

1.091 kg hydrated ethanol (8.6% water)
0.487 kg C/kg | 24.482 MJ/kg | 0.999 SFr/kg

7,480 kg stillage (85% water)
0.051 kg C/kg | 2.671 MJ/kg | 5 SFr/t

Déshydratation

Traitement des vinasses

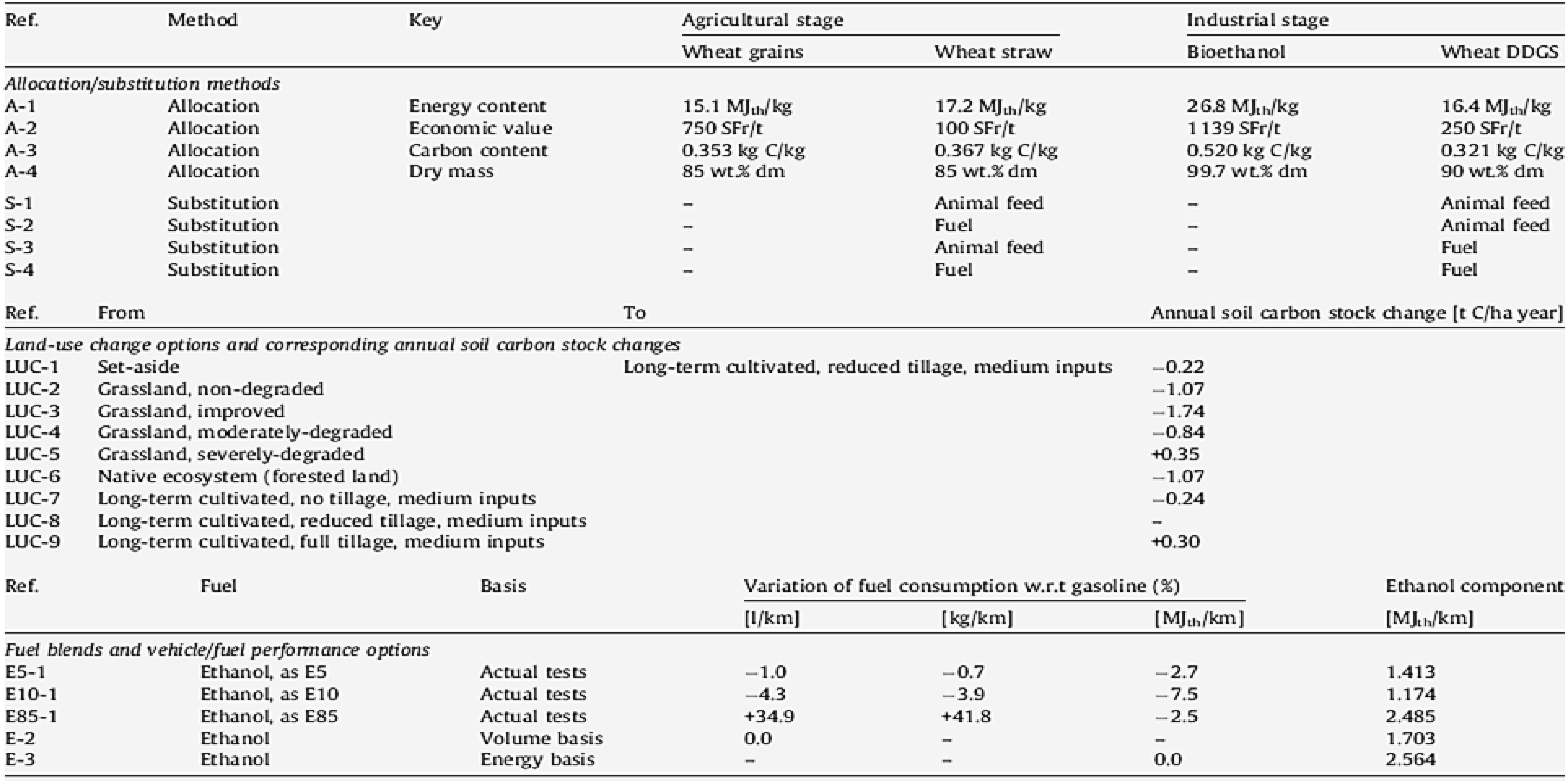
1.000 kg anhydrous ethanol (0.3% water)
0.532 kg C/kg | 26.720 MJ/kg | 1.139 SFr/kg

1.220 kg DDGS (8% water)
0.312 kg C/kg | 17.376 MJ/kg | 250 SFr/t

Transport
100 km by train | 150 km by lorry

1 kg ethanol

Simplified diagram of bioethanol production from wheat

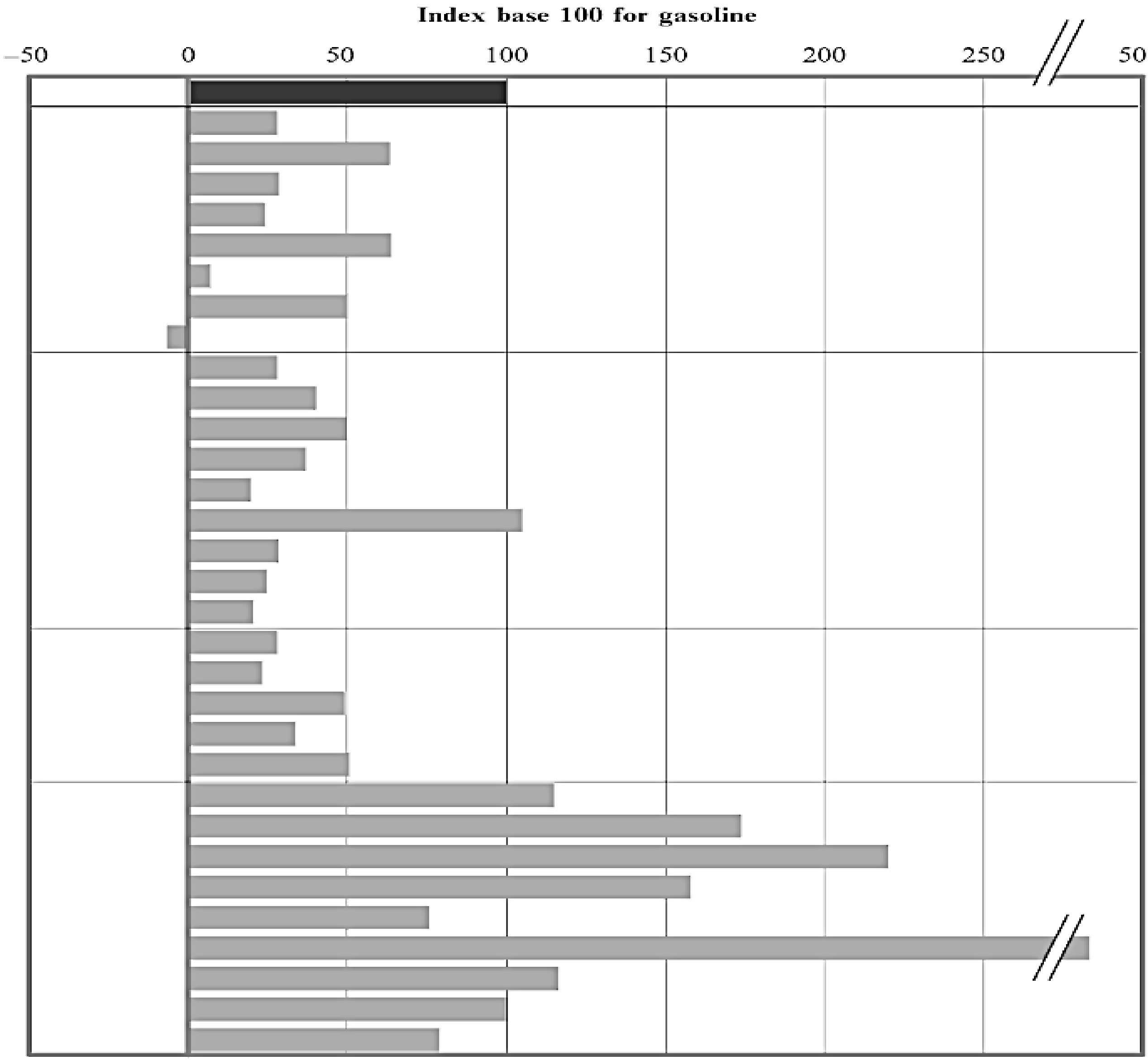


Ref.	Method	Key	Agricultural stage		Industrial stage	
			Wheat grains	Wheat straw	Bioethanol	Wheat DDGS
Allocation/substitution methods						
A-1	Allocation	Energy content	15.1 MJ_{th}/kg	17.2 MJ_{th}/kg	26.8 MJ_{th}/kg	16.4 MJ_{th}/kg
A-2	Allocation	Economic value	750 SFr/t	100 SFr/t	1139 SFr/t	250 SFr/t
A-3	Allocation	Carbon content	0.353 kg C/kg	0.367 kg C/kg	0.520 kg C/kg	0.321 kg C/kg
A-4	Allocation	Dry mass	85 wt.% dm	85 wt.% dm	99.7 wt.% dm	90 wt.% dm
S-1	Substitution		–	Animal feed	–	Animal feed
S-2	Substitution		–	Fuel	–	Animal feed
S-3	Substitution		–	Animal feed	–	Fuel
S-4	Substitution		–	Fuel	–	Fuel

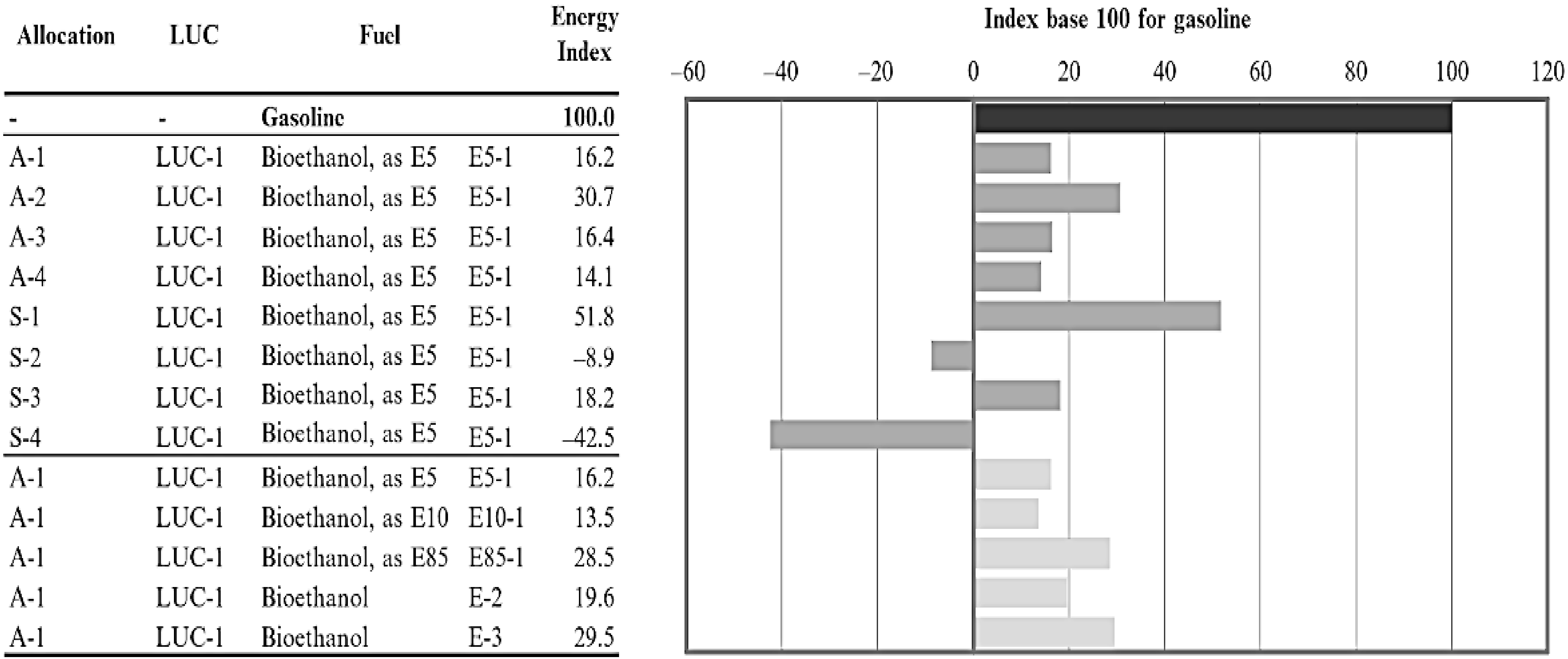
Ref.	From	To	Annual soil carbon stock change [t C/ha year]
Land-use change options and corresponding annual soil carbon stock changes			
LUC-1	Set-aside	Long-term cultivated, reduced tillage, medium inputs	−0.22
LUC-2	Grassland, non-degraded		−1.07
LUC-3	Grassland, improved		−1.74
LUC-4	Grassland, moderately-degraded		−0.84
LUC-5	Grassland, severely-degraded		+0.35
LUC-6	Native ecosystem (forested land)		−1.07
LUC-7	Long-term cultivated, no tillage, medium inputs		−0.24
LUC-8	Long-term cultivated, reduced tillage, medium inputs		–
LUC-9	Long-term cultivated, full tillage, medium inputs		+0.30

Ref.	Fuel	Basis	Variation of fuel consumption w.r.t gasoline (%)			Ethanol component
			[l/km]	[kg/km]	[MJ_{th}/km]	[MJ_{th}/km]
Fuel blends and vehicle/fuel performance options						
E5-1	Ethanol, as E5	Actual tests	−1.0	−0.7	−2.7	1.413
E10-1	Ethanol, as E10	Actual tests	−4.3	−3.9	−7.5	1.174
E85-1	Ethanol, as E85	Actual tests	+34.9	+41.8	−2.5	2.485
E-2	Ethanol	Volume basis	0.0	–	–	1.703
E-3	Ethanol	Energy basis	–	–	0.0	2.564

Allocation	LUC	Fuel		IPCC Index
-	-	Gasoline		100.0
A-1	LUC-1	Bioethanol, as E5	E5-1	27.9
A-2	LUC-1	Bioethanol, as E5	E5-1	63.4
A-3	LUC-1	Bioethanol, as E5	E5-1	28.5
A-4	LUC-1	Bioethanol, as E5	E5-1	24.2
S-1	LUC-1	Bioethanol, as E5	E5-1	63.8
S-2	LUC-1	Bioethanol, as E5	E5-1	7.0
S-3	LUC-1	Bioethanol, as E5	E5-1	50.1
S-4	LUC-1	Bioethanol, as E5	E5-1	–6.7
A-1	LUC-1	Bioethanol, as E5	E5-1	27.9
A-1	LUC-2	Bioethanol, as E5	E5-1	40.2
A-1	LUC-3	Bioethanol, as E5	E5-1	49.9
A-1	LUC-4	Bioethanol, as E5	E5-1	36.9
A-1	LUC-5	Bioethanol, as E5	E5-1	19.7
A-1	LUC-6	Bioethanol, as E5	E5-1	104.9
A-1	LUC-7	Bioethanol, as E5	E5-1	28.2
A-1	LUC-8	Bioethanol, as E5	E5-1	24.7
A-1	LUC-9	Bioethanol, as E5	E5-1	20.4
A-1	LUC-1	Bioethanol, as E5	E5-1	27.9
A-1	LUC-1	Bioethanol, as E10	E10-1	23.2
A-1	LUC-1	Bioethanol, as E85	E85-1	49.1
A-1	LUC-1	Bioethanol	E-2	33.7
A-1	LUC-1	Bioethanol	E-3	50.7
A-2	LUC-1	Bioethanol	E-3	115.0
A-2	LUC-2	Bioethanol	E-3	173.7
A-2	LUC-3	Bioethanol	E-3	220.1
A-2	LUC-4	Bioethanol	E-3	157.8
A-2	LUC-5	Bioethanol	E-3	75.6
A-2	LUC-6	Bioethanol	E-3	483.2
A-2	LUC-7	Bioethanol	E-3	116.4
A-2	LUC-8	Bioethanol	E-3	99.8
A-2	LUC-9	Bioethanol	E-3	79.0

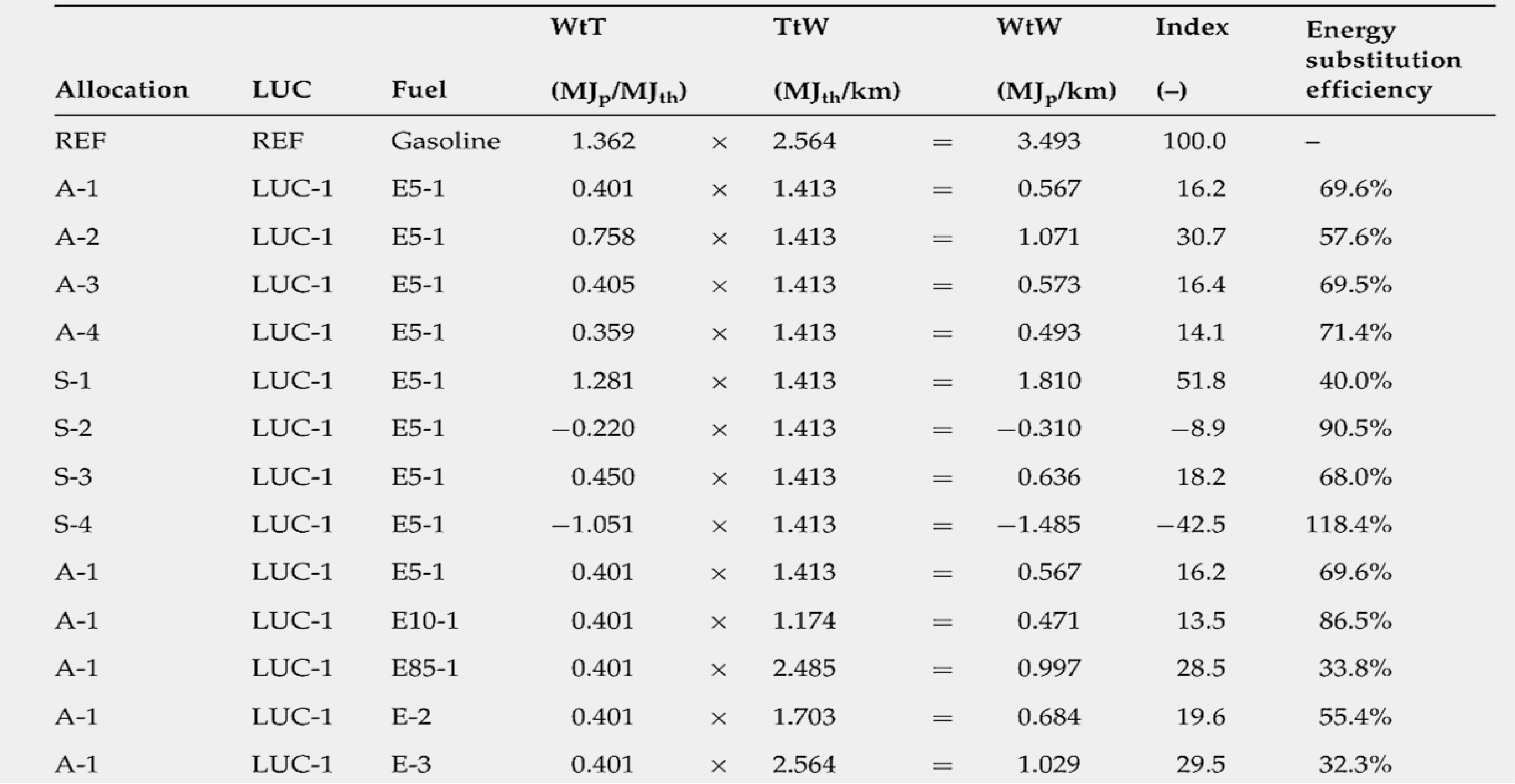


WtW net emissions of GHG of ethanol according to selected options



Allocation	LUC	Fuel		Energy Index
-	-	Gasoline		100.0
A-1	LUC-1	Bioethanol, as E5	E5-1	16.2
A-2	LUC-1	Bioethanol, as E5	E5-1	30.7
A-3	LUC-1	Bioethanol, as E5	E5-1	16.4
A-4	LUC-1	Bioethanol, as E5	E5-1	14.1
S-1	LUC-1	Bioethanol, as E5	E5-1	51.8
S-2	LUC-1	Bioethanol, as E5	E5-1	–8.9
S-3	LUC-1	Bioethanol, as E5	E5-1	18.2
S-4	LUC-1	Bioethanol, as E5	E5-1	–42.5
A-1	LUC-1	Bioethanol, as E5	E5-1	16.2
A-1	LUC-1	Bioethanol, as E10	E10-1	13.5
A-1	LUC-1	Bioethanol, as E85	E85-1	28.5
A-1	LUC-1	Bioethanol	E-2	19.6
A-1	LUC-1	Bioethanol	E-3	29.5

WtW net non-renewable primary energy use of ethanol according to selected options



Allocation	LUC	Fuel	WtT (MJ_p/MJ_{th})		TtW (MJ_{th}/km)		WtW (MJ_p/km)	Index (–)	Energy substitution efficiency
REF	REF	Gasoline	1.362	×	2.564	=	3.493	100.0	–
A-1	LUC-1	E5-1	0.401	×	1.413	=	0.567	16.2	69.6%
A-2	LUC-1	E5-1	0.758	×	1.413	=	1.071	30.7	57.6%
A-3	LUC-1	E5-1	0.405	×	1.413	=	0.573	16.4	69.5%
A-4	LUC-1	E5-1	0.359	×	1.413	=	0.493	14.1	71.4%
S-1	LUC-1	E5-1	1.281	×	1.413	=	1.810	51.8	40.0%
S-2	LUC-1	E5-1	−0.220	×	1.413	=	−0.310	−8.9	90.5%
S-3	LUC-1	E5-1	0.450	×	1.413	=	0.636	18.2	68.0%
S-4	LUC-1	E5-1	−1.051	×	1.413	=	−1.485	−42.5	118.4%
A-1	LUC-1	E5-1	0.401	×	1.413	=	0.567	16.2	69.6%
A-1	LUC-1	E10-1	0.401	×	1.174	=	0.471	13.5	86.5%
A-1	LUC-1	E85-1	0.401	×	2.485	=	0.997	28.5	33.8%
A-1	LUC-1	E-2	0.401	×	1.703	=	0.684	19.6	55.4%
A-1	LUC-1	E-3	0.401	×	2.564	=	1.029	29.5	32.3%

WtW net non-renewable primary energy use and energy substitution efficiency of ethanol according to selected options

ILLUSTRATION

DISCUSSION OF RESULTS

Effect of allocation

- Strong influence of the choice of allocation

Depending of the allocation method, the net GHG emissions ranges from (-107% to -36% with respect to gasoline)

Effect of LUC

- Strong influence of the land use change

Depending of the case of LUC, the net GHG emissions ranges from (- 80% to +5% with respect to gasoline)

ILLUSTRATION

FUEL BLENDS AND VEHICLE/ FUEL PERFORMANCES

- Strong influence of these variables
- Depending of the cases, the net GHG emissions ranges from (-77% to -49% with respect to gasoline)
- For a given volume of bioethanol, E10 results in the best way to blend with gasoline with respect to net GHG emission reduction

ILLUSTRATION

NET ENERGY USE AND ENERGY SUBSTITUTION EFFICIENCY

- Strong influence of allocation methods, fuel blends and vehicle/fuel performance on the energy use and energy substitution efficiency