Comparative Evaluation of the ecological and economic performance of new renewable fuels and e-mobility

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Presentation on the 16th of February 2012
12th Symposium Energieinnovation

Energieinstitut an der
Johannes Kepler Universität Linz

INTRODUCTION

- **the world economy is strongly depending on fossil resources**
- **EU aim is 20% of energy from renewable sources by 2020 – the energy sector has a lot of options as source**
- **biomass as key resource in area of biofuels and chemical industry**
  - Negative ecological effects (land use, eutrophication, impact of pesticide application, …)
  - Negative economic effects (rising food price, rising energy price..)

→ what is a sustainable and eco-efficient development of biomass utilisation & How to measure it?

SYSTEM BOUNDARIES FOR ECOLOGICAL AND ECONOMIC EVALUATION

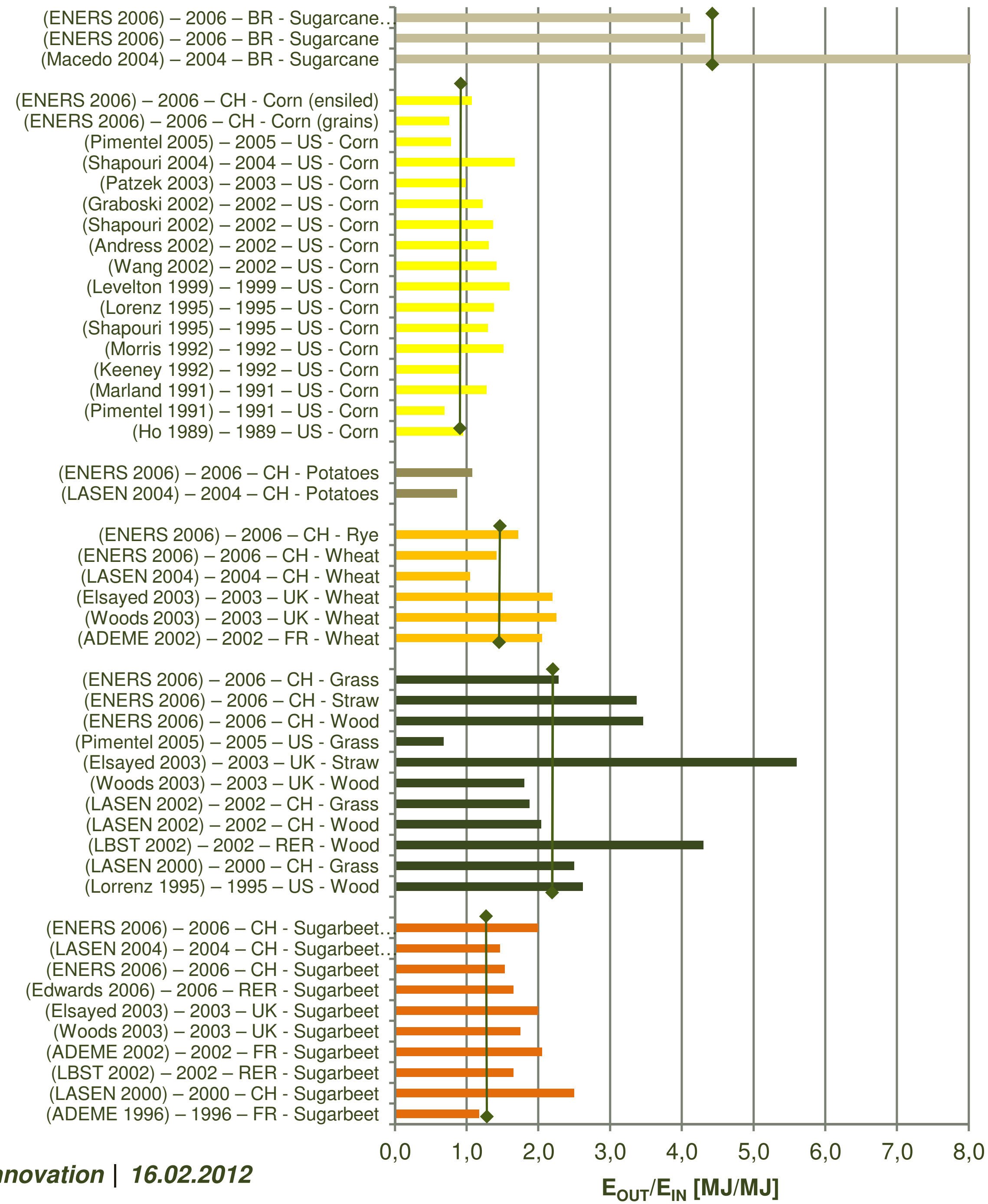
- Considered reference systems
  - Bioethanol from wheat (1st G. with natural gas as process energy source)
  - Bioethanol from wheat (1st G. with straw combustion and process energy source)
  - Bioethanol from wheat straw (2nd G. enzymatically; natural gas or lignin combustion as process energy source)
  - Petrol according to DIN EN 228
  - Diesel according to DIN EN 590
  - BTL - fuels from wheat straw / poplar
  - SNG - Synthetic Natural Gas (from organic wastes)
  - Electric Mobility (EE mix, PV, wind, ...)

RESULTS OF LITERATURE ANALYSIS ON BIOFUEL-LCAS

Comparison of **67** individual results in the assessment of biofuel production technologies (in particular concerning bioethanol production) show high inhomogeneity due to differences in:

- system boundaries (usually only fermentation / down-stream processing included)
- data used for agricultural production
- Intensity of the use of fossil fuels along the process chain
- Dealing with emissions from land use changes

ANALYSIS OF LITERATURE ON THE ECOLOGICAL ASSESSMENT OF BIOETHANOL PRODUCTION



Source: own representation based on Swiss Centre for Life Cycle Inventories [Ed.] (2007) „Life Cycle Inventories of Bioenergy", ecoinvent report No. 17

ENERGIE INSTITUT an der Johannes Kepler Universität Linz

Investigation of Framework Conditions

direct & indirect land use change (dLUC & idLUC)

Table: Emission factors of typical land-use changes for biofuel production

Land use change	„carbon dept“ – CO_2 released [t CO_2/ha]	allocation to biofuel [%]	„payback time“ [a]
Palm oil biodiesel on tropical rain forest in Indonesia / Malaysia	702	87	86
Palm oil biodiesel on peat bogs in Indonesia / Malyasia	3.452	87	423
Soy biodiesel on tropical rain forest in Brazil	737	39	319
Sugarcane ethanol on forested Cerrado in Brazil	165	100	17
Soy biodiesel on Cerrado grassland Brazil	85	39	37
Corn-ethanol on grassland in the U.S.	134	83	93
Corn-ethanol on set-aside agricultural land in the U.S.	69	38	48

Quelle: eigene Darstellung auf Basis von Fragione, L. et al Science 319 (2008) 1235-1238

➡ **Results from different models show intense variability**

INVESTIGATION OF FRAMEWORK CONDITIONS

- **scientific literature does not provide clear consensus about the influence on food prices through the production of biofuels[1,2,3,4,5,6,7]**

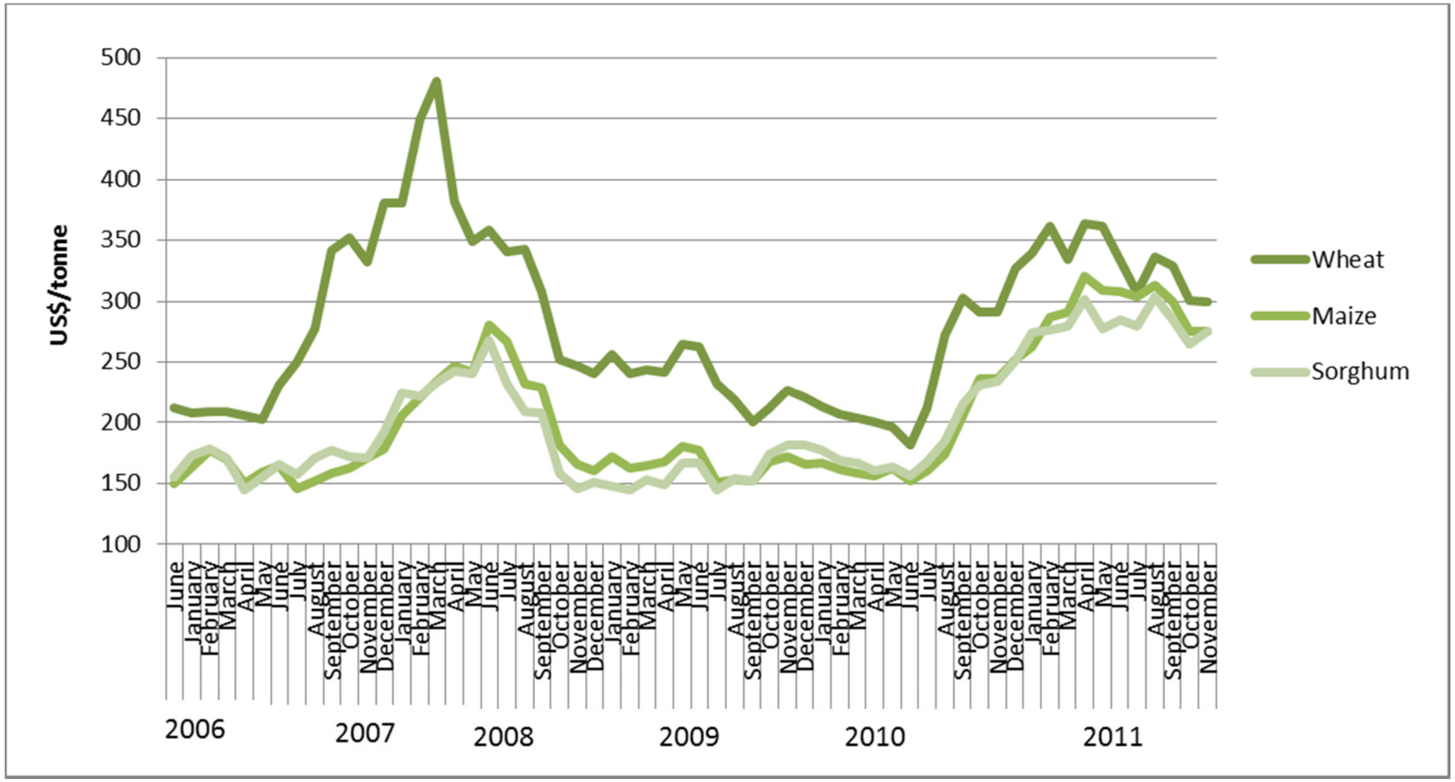
[1] *Ajanovic, A. Energy 36 (2011) 2070-2076*
[2] *Zhang, Z. et al Energy Policy 38 (2010) 445-451*
[3] *Goldemberg, J. et al Energy Policy 36 (2008) 2086-2097*
[4] *Kerckow, B. Quaterly Journal of International Agriculture 4 (2007)*
[5] *Pimentel D. et al Natural resources Research 16 (2007)*
[6] *Turpin, N. et al Land Use Policy 26 (2009) 273-283*
[7] *Sumathi S. et al Renewable & Sustainable Energy Reviews 12 (2008) 2404-2421*

⇩

- **in the short term ⇨ competition of land**
- **long term ⇨ direct and indirect land use change**

Biofuel production – diversification of feedstock required...

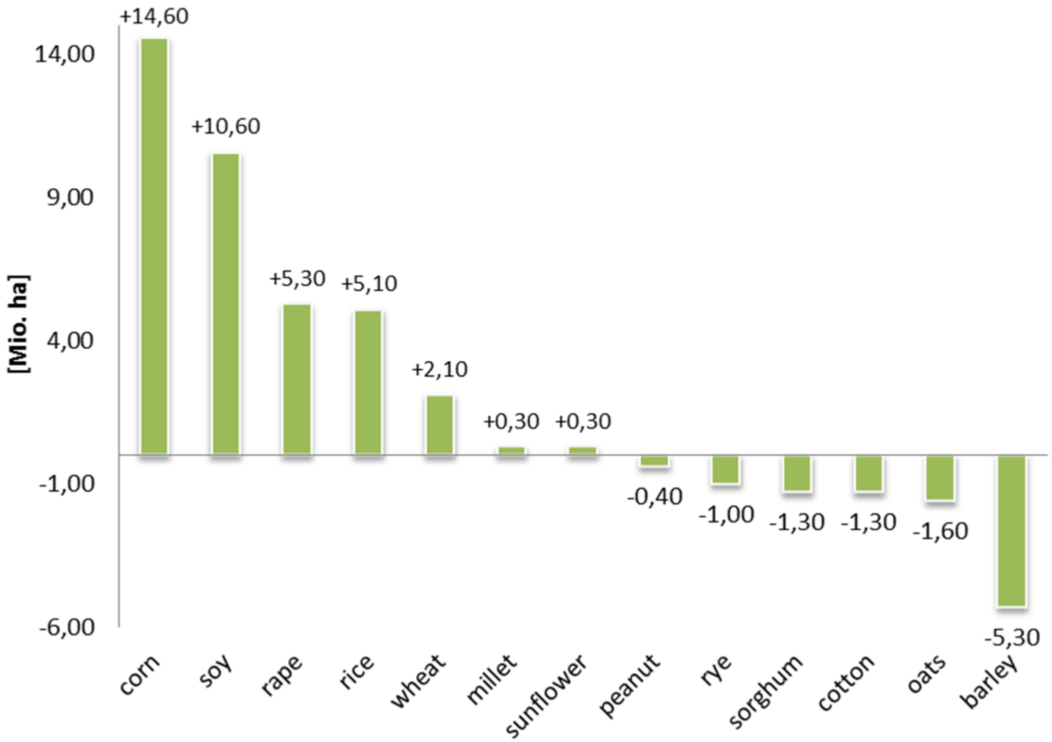
Figure: International development of selected grain prices



Wheat: US No.2 Hard Red Winter Prd. Prot.1
Maize: US No.2 Yellow
Sorghum: US No.2 Yellow
Source: own representation, based on FAO (2011) ‚Crop Prospects and Food Situation', No.4 Dezember 2011

INVESTIGATION OF FRAMEWORK CONDITIONS

- **Figure: Change in the global crop area of 13 major crops (reference year 2010/11 versus 2005/06)**



Source: onw representation based on FAS (2011) USDA PS & D online database

INVESTIGATION OF FRAMEWORK CONDITIONS

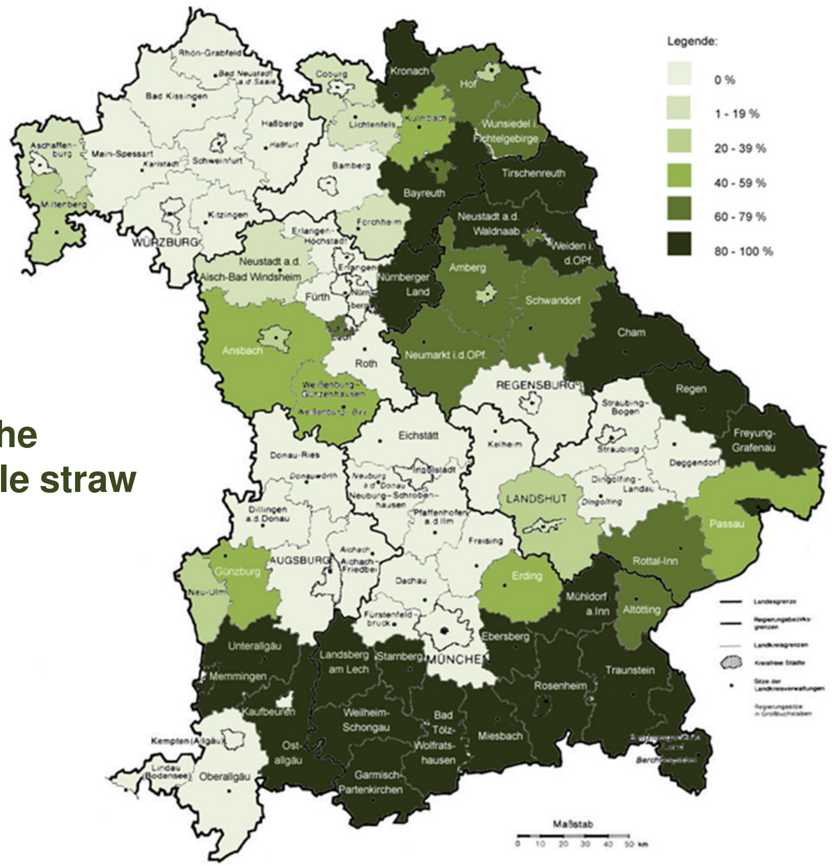
- **Carbon balance for the quantification of available wheat straw for energetic use**

Table: available amount of wheat straw in Germany according to different accounting methods

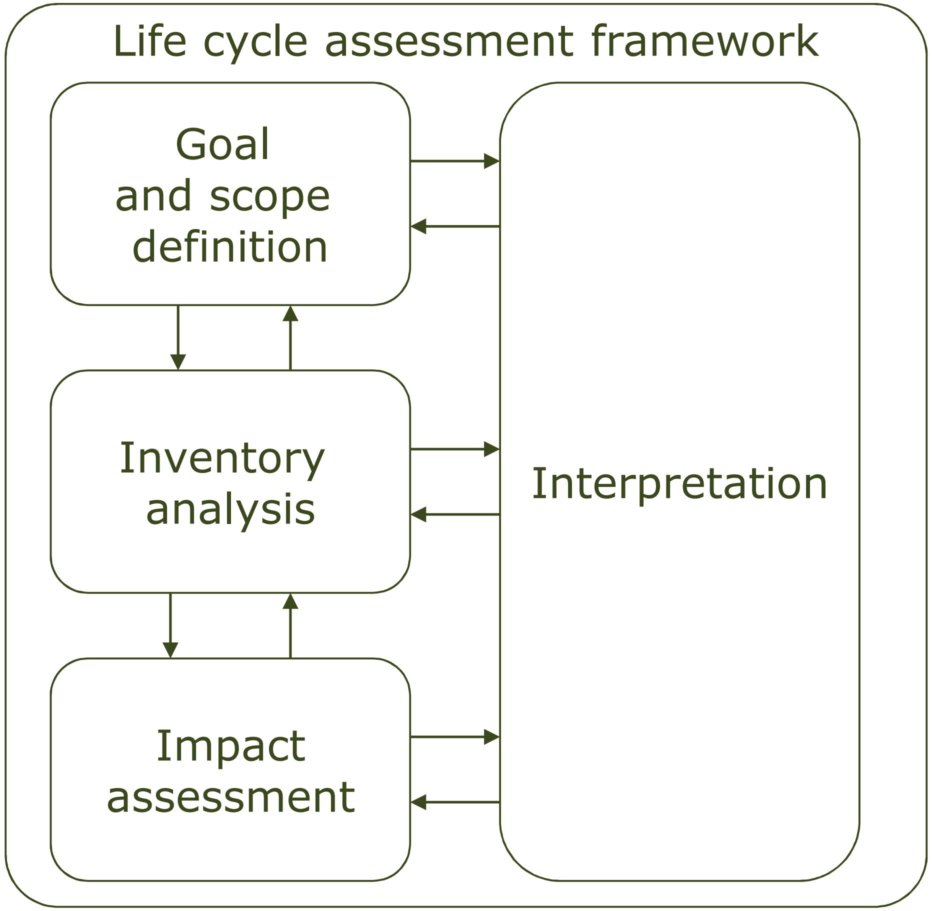
Cross Compliance	VDLUFA (upper value)	REPRO
available amount of wheat straw [Mio. t]		
13,8	10,2	7,7

Source: own illustration based on Vetter/Weiser (2011)

Figure: Cartographic representation of the proportion of the total energy recoverable straw straw fit for Bavarian counties



The method of choice – Life Cycle Assessment (LCA)



Source: own representation according ISO 14000 ff

according ISO 14040/14044

Goal and scope definition:
- aim & scope of the study
- process units
- system boundaries
- assessed flows

Inventory analysis:
- data collection
- data validation
- assignment to processes
- allokation

Impact assessment:
- effect model
- impact categories

Interpretation:
- Evaluation of results
- Analysis of results

SYSTEM BOUNDARIES FOR ECOLOGICAL EVALUATION

Basic framework

- Cradle to grave as system boundary
- Process of construction of buildings and machinery

  not included

- Allocation based on net calorific value
- Germany as regional system boundary
- Main inventory data source: GaBi 4.0 professional, ecoinvent v2, BIOGRACE default values

Impact Assessment methodology

Centrum voor Millieukunden Leiden (CML) 2001

Impact categories:

- **Ozone layer Depletion Potential (ODP)**
- **Abiotic Depletion (ADP)**
- **Global Warming Potential 100 years ($GWP_{100years}$)**
- **Photochemical Oxidant Creation Potential (POCP)**
- **Acidification Potential (AP)**
- **Eutrophication Potential (EP)**
- **Radioactive Radiation (RAD)**

LIFE CYCLE ASSESSMENT – TOOLS & METHOD

BIOGRACE
Harmonised Calculations of Biofuel Greenhouse Gas Emissions in Europe

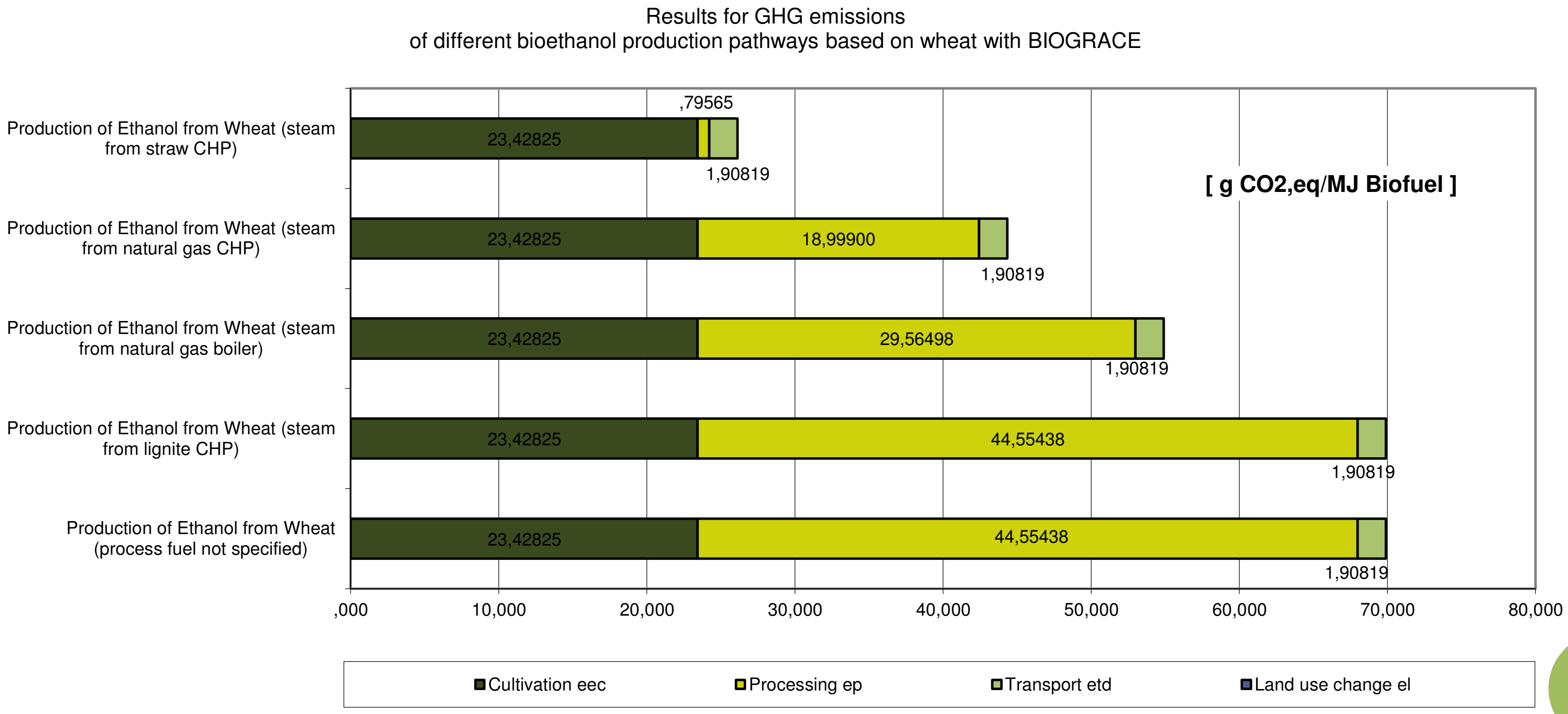
BIOGRACE

- **standardized calculations of Greenhouse Gas Emissions of biofuels in Europe**
- **Annex V of the Directive on Renewable Energy defines default values for greenhouse gas savings of 22 production routes for biofuels**
- **raw material cultivation, biofuel production & distrubition**

Source: http://www.biograce.net/

Life Cycle Assessment – GHG Results - Biograce

Calculation of greenhouse gas emissions for bioethanol production from wheat with different process energy sources

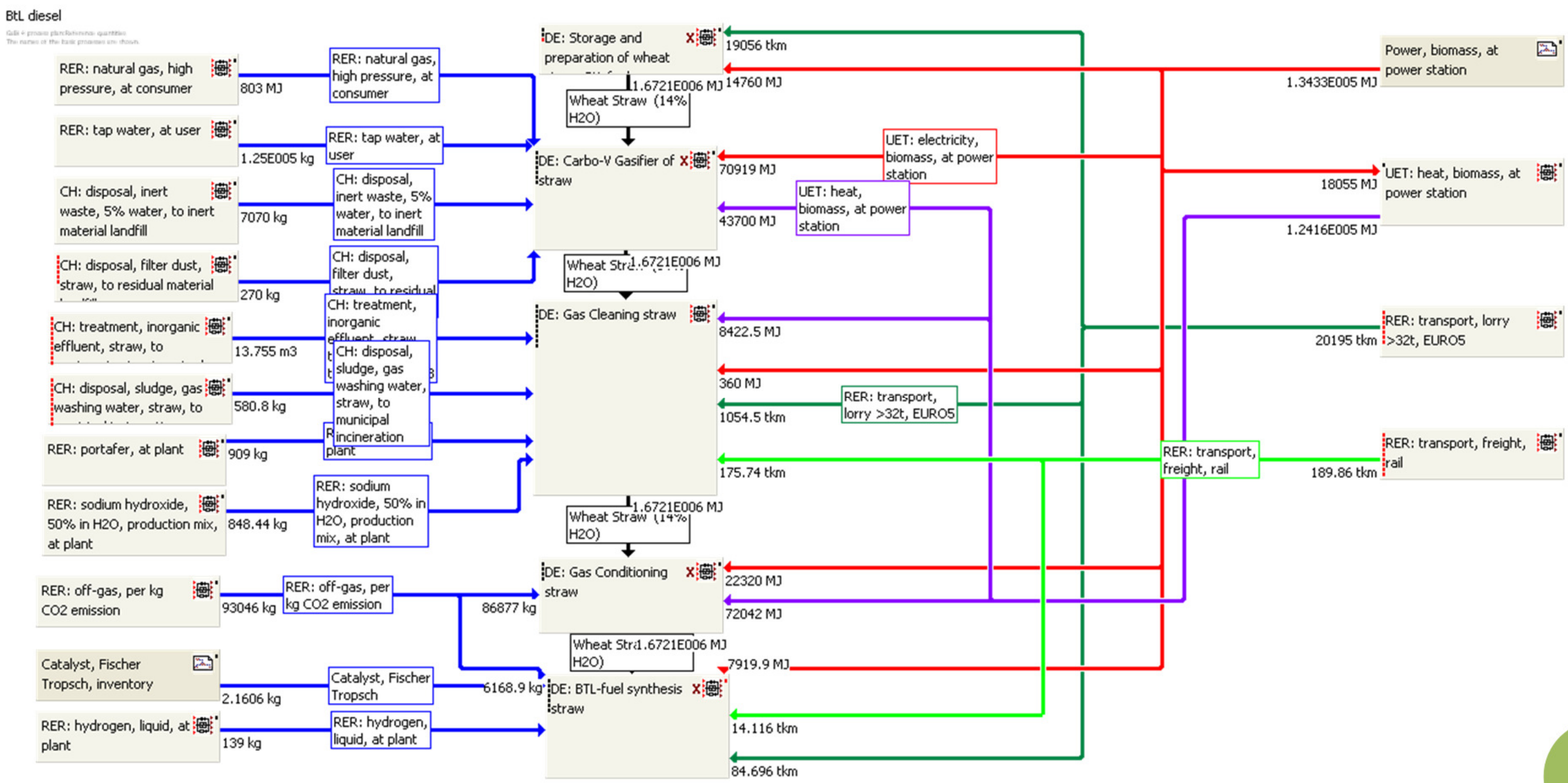


Source: own illustration based on values from BioGrace

Life Cycle Assessment – Inventory Data

- **Conversion of wheat straw to BtL-Syndiesel**
- **(Carbo-V-Process) with cogeneration for internal use & - feed in**

[calculated for the output of 1TJ EtOH]



Source: own modell in the software GaBi 4.0

LIFE CYCLE ASSESSMENT – SENSITIVITY ANALYSIS

Evaluation of LCA results for Ethanol production from wheat straw with different allocation scenarios

allocation scenarios

- mass balance

1.000	[kg]	wheat straw (fresh mass)
162	[kg]	ethanol
184	[kg]	lignin
47	[%]	ethanol
53	[%]	lignin

- Energy balance

15,49	[MJ/kg]	wheat straw (fresh mass
32,3	[MJ/kg]	ethanol
22	[MJ/kg]	lignin
5.234	[MJ]	ethanol
4.043	[MJ]	lignin
56	[%]	ethanol
44	[%]	lignin

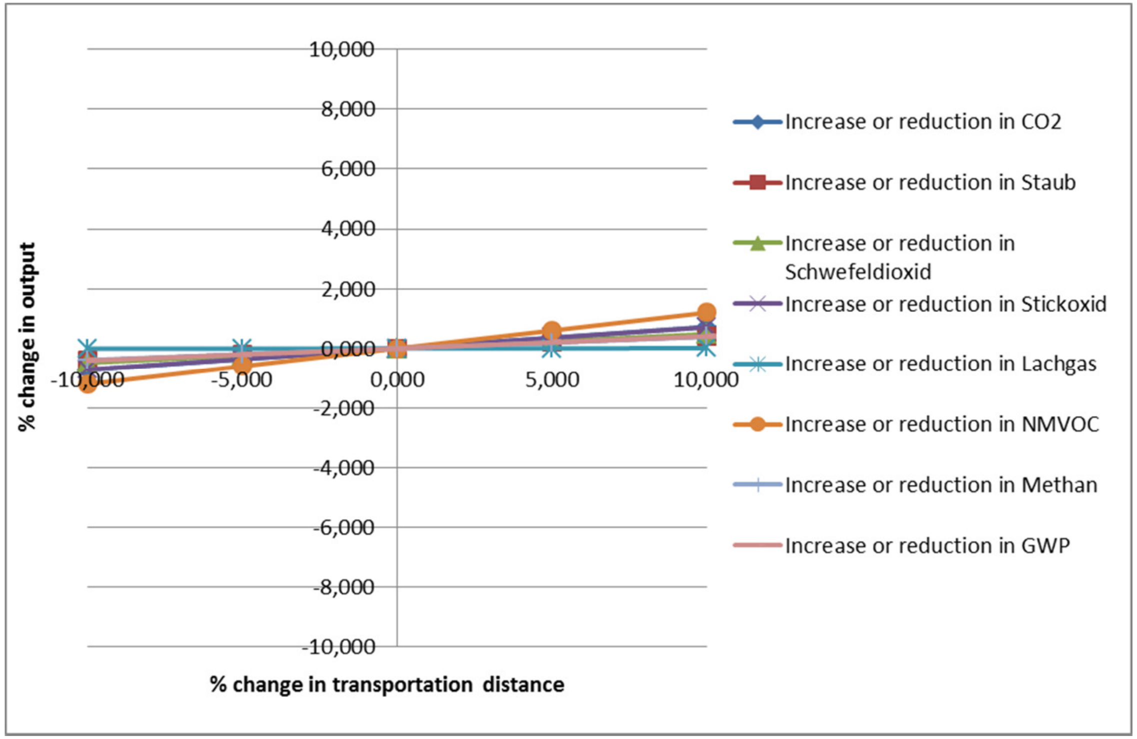
- Economic balance

55,54	[€/t]	wheat straw (fresh mass)
75,94	[ct/kg]	ethanol
24,44	[ct/kg]	lignin
123,04	[€]	ethanol
44,92	[€]	lignin
73	[%]	ethanol
27	[%]	lignin

LIFE CYCLE ASSESSMENT – SENSITIVITY ANALYSIS

Figure: For example, ethanol production from wheat straw

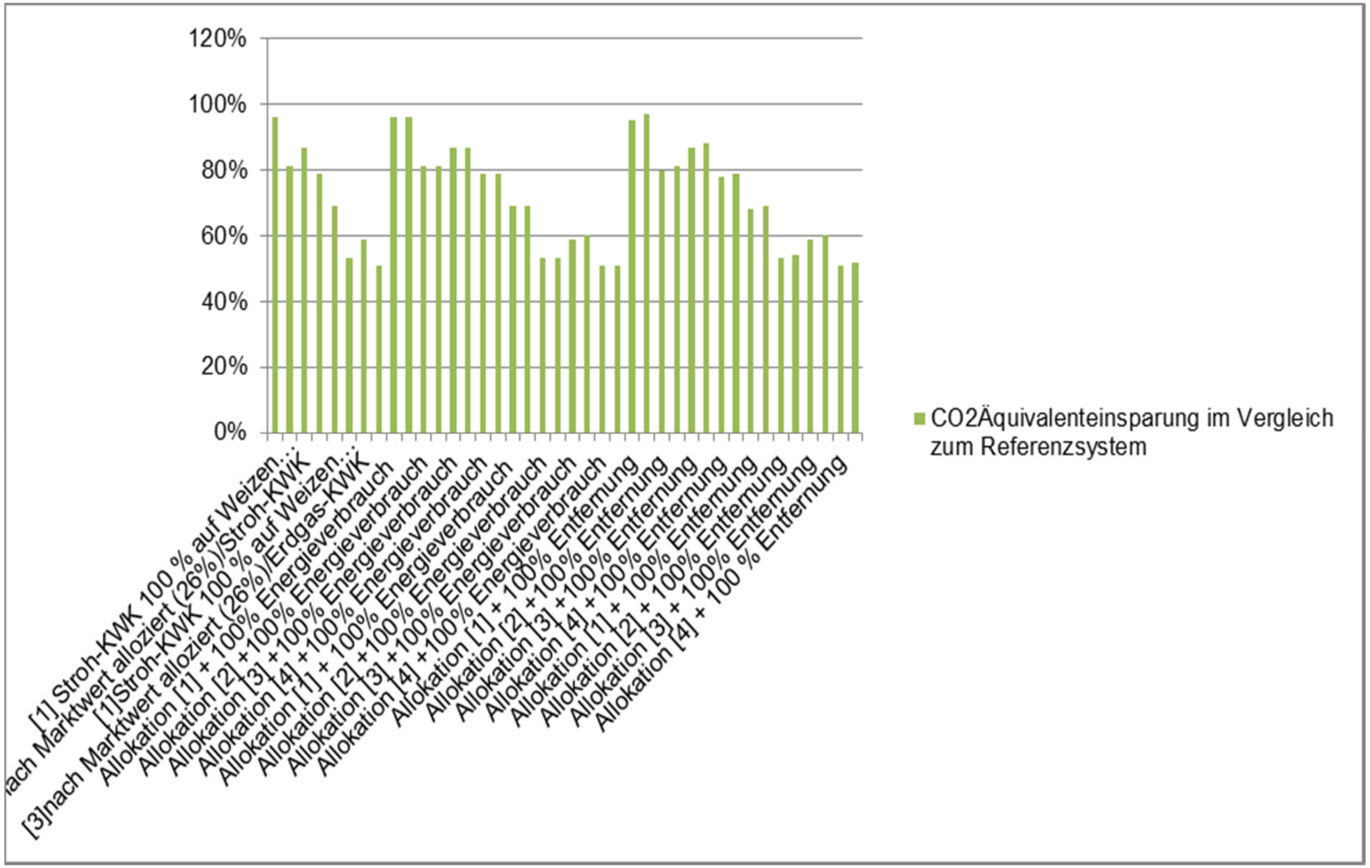
Sensitivity of emissions concerning changes in the transportation distance of agricultural operations to conversion plant



Source: own representation

LIFE CYCLE ASSESSMENT – SENSITIVITY ANALYSIS

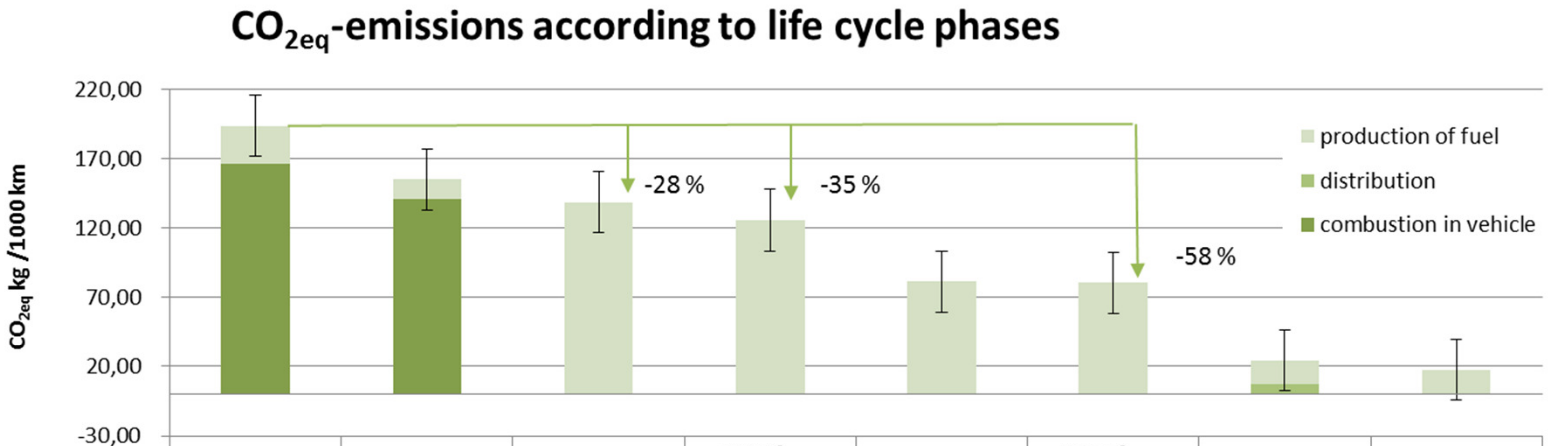
Figure: Sensitivity of CO_2 equivalent savings compared to the reference system with respect to the chosen allocation methods and energy use in the treatment and storage of straw



Source: own representation

LIFE CYCLE ASSESSMENT – GHG RESULTS - GABI

Figure: CO_2 equivalent emissions of biofuel pathways compared to the reference system (modeled with the software system GaBi 4.0)



	fossil petrol	fossil diesel	EtOH from wheat (NG as process fuel)	EtOH from wheat (straw as process fuel)	BtL-Syndiesel (without CHP)	EtOH from wheat straw (NG as process fuel)	Bio-SNG	BtL-Syndiesel (with CHP)
production of fuel	26,93	13,96	137,59	124,80	80,91	79,67	16,88	16,96
distribution	0,55	0,46	0,89	0,90	0,56	0,90	7,43	0,56
combustion in vehicle	166,00	140,70	-	-	-	-	-	-

Source: own representation

LIFE CYCLE ASSESSMENT – GHG RESULTS - GABI

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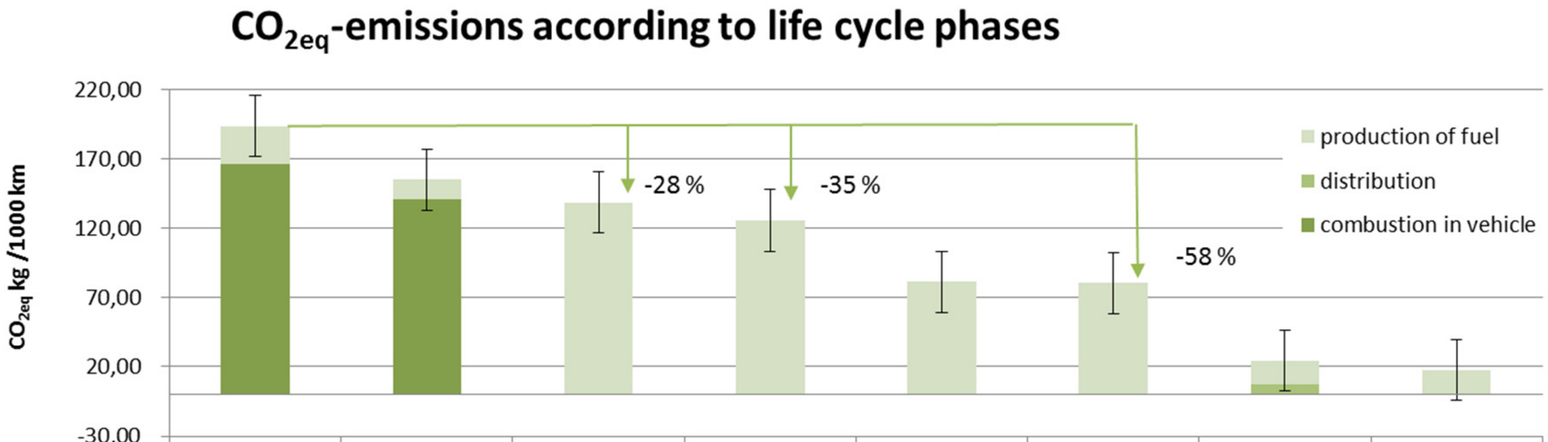

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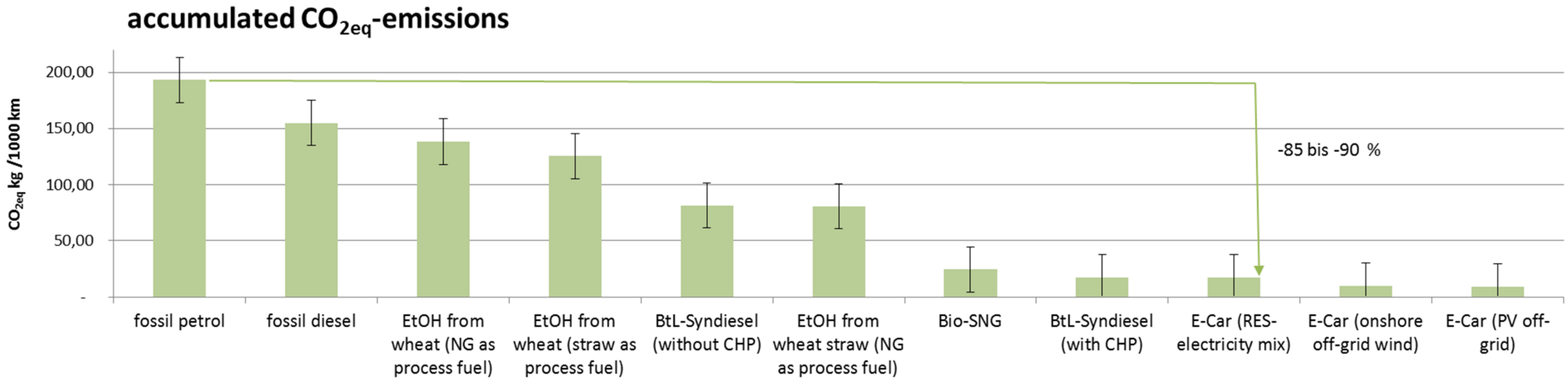
combustion in vehicle	166,00	140,70	-	-	-	-	-	-

Source: own representation

LIFE CYCLE ASSESSMENT – GHG RESULTS - GABI

Figure: CO_2 equivalent emissions of biofuel and e-mobiliy pathways based on renewable electricity compared to the reference system (modeled with the software system GaBi 4.0)



Source: own representation

Process of construction of buildings

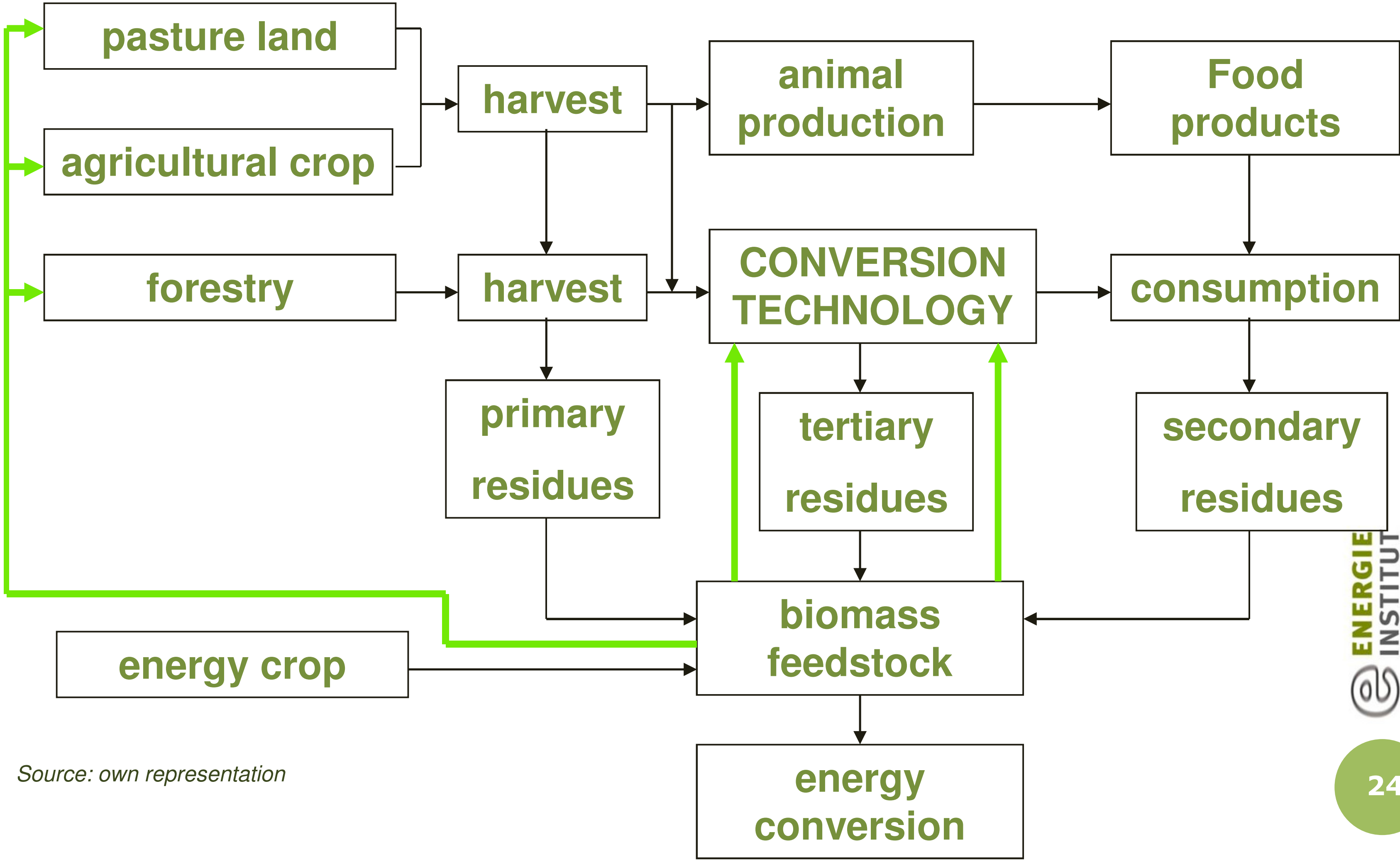
and machinery

not included !

Life Cycle Assessment - Conclusions

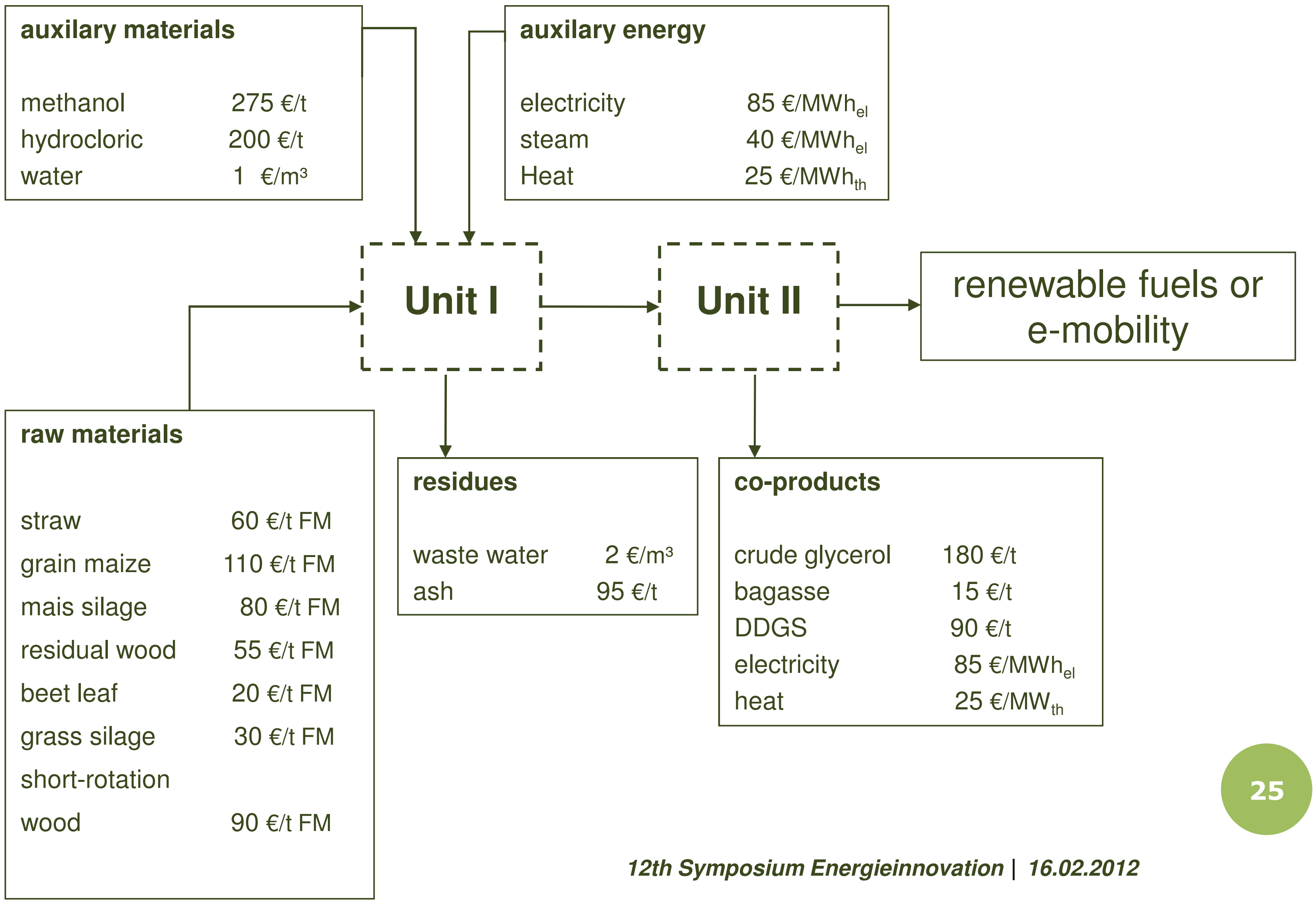
- Changes in energy use in the process step transport of feedstock tend to have less impact on the final result
- The main environmental impacts of biofuels in general result from the agricultural processes (upstream)
- The provision of process energy (heat) and in some cases auxiliary materials have the highest contribution to environmental effects from the production
- The efficiency of the vehicle motor determines fuel consumption and affects in a well-to-wheel analysis the environmental assessment

BIOMASS UTILISATION – POTENTIAL FOR IMPROVEMENT



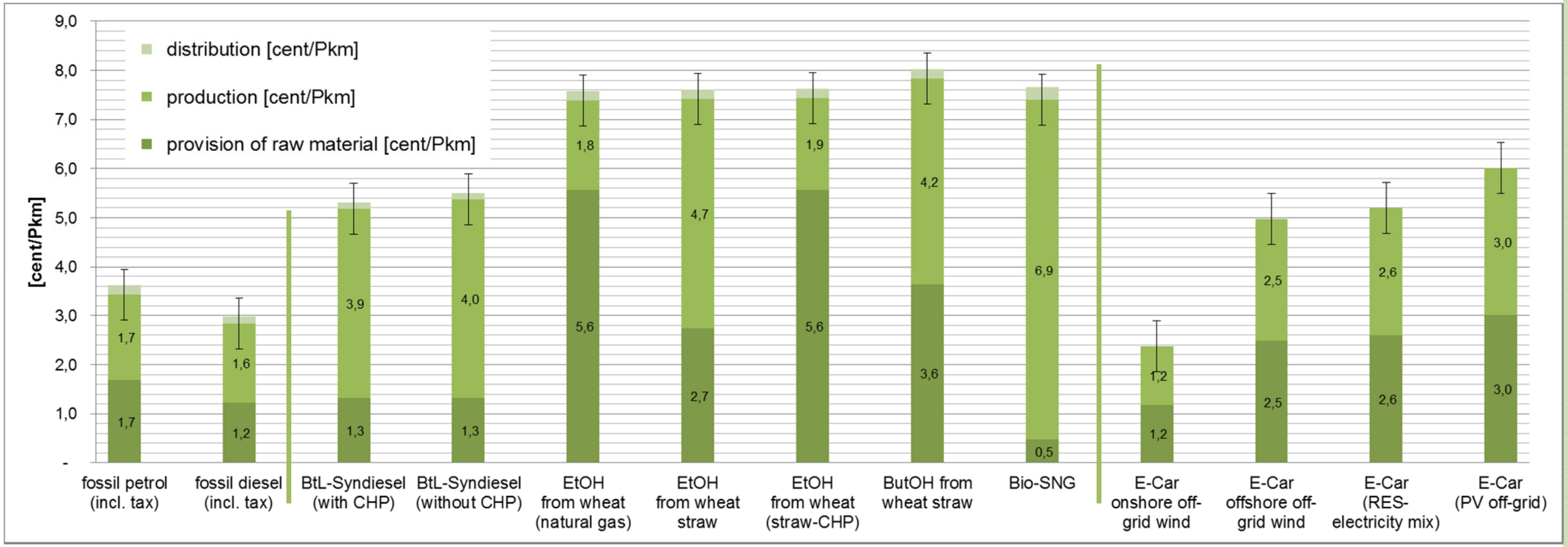
Source: own representation

ECONOMIC ASSESSMENT – DETERMINATION OF SPECIFIC COSTS



ECONOMIC ASSESSMENT – RESULTS

- **Overview of the total specific cost per service unit [Pkm]**
  - **excl. PKW**



Source: own calculation & representation

ECONOMIC ASSESSMENT – RESULTS

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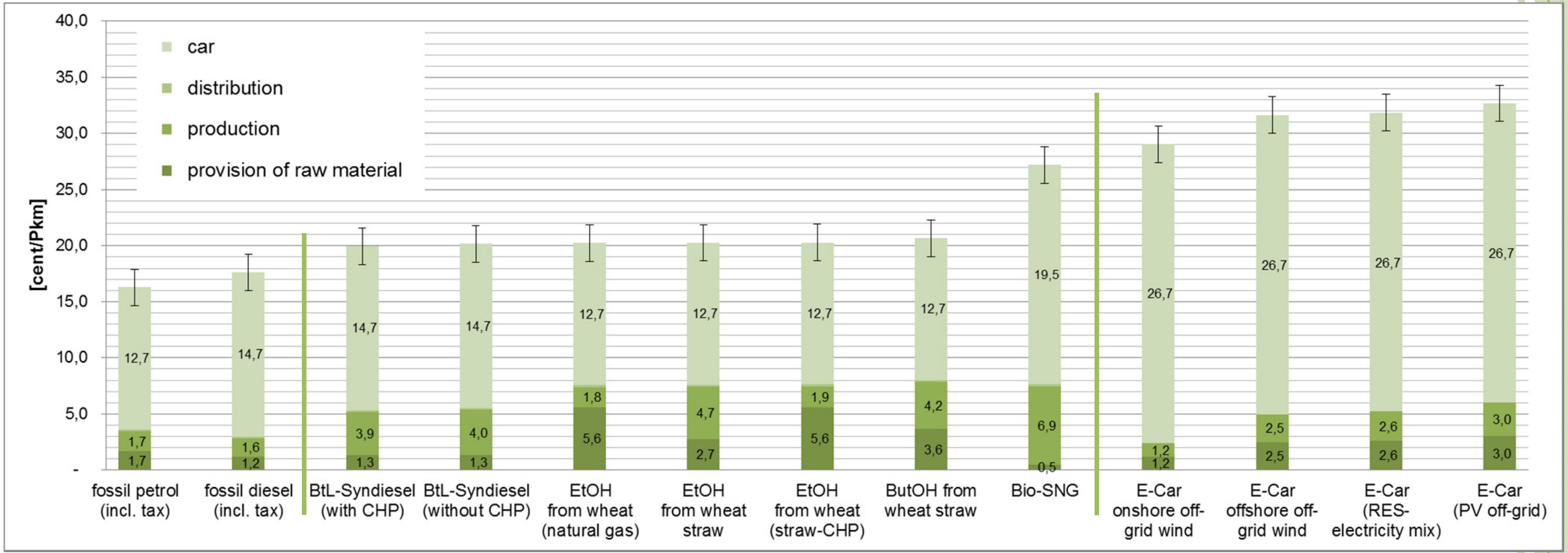
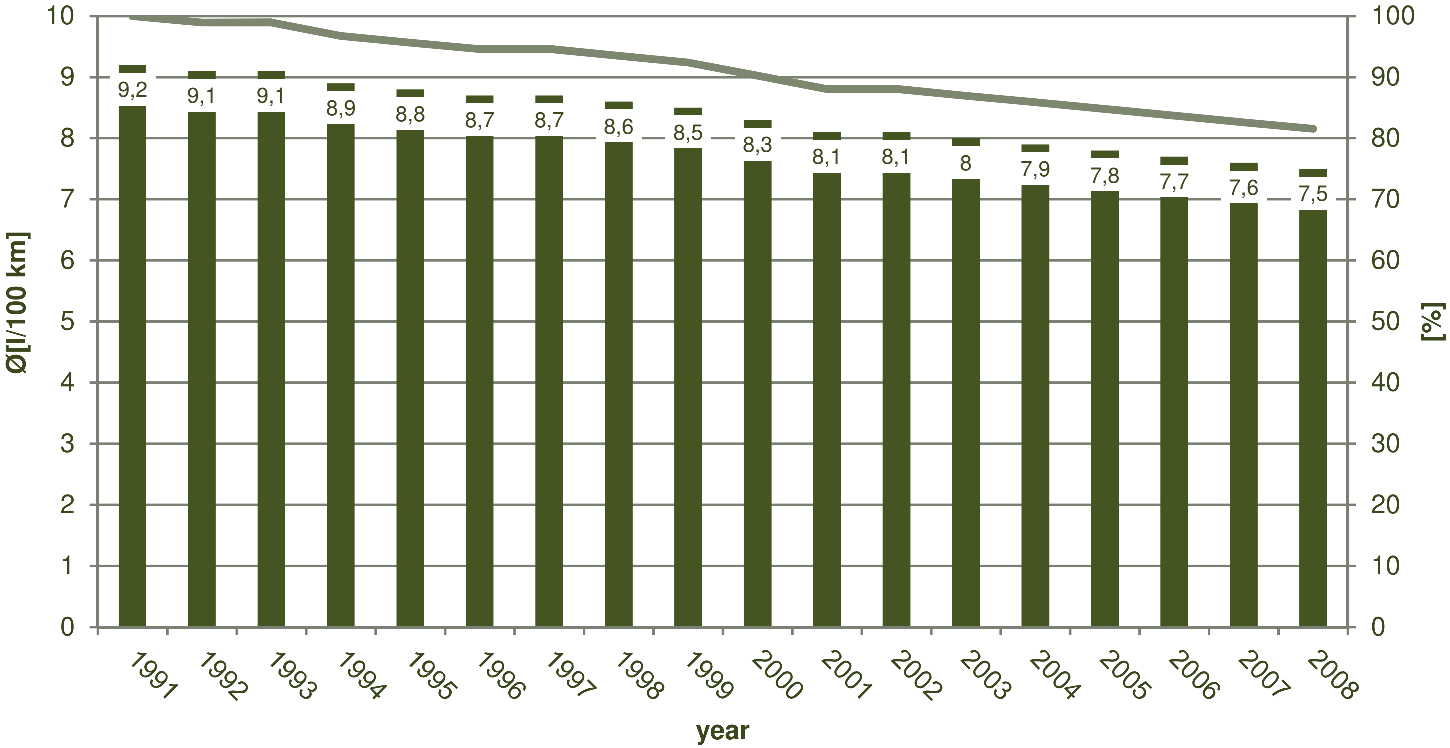
– incl. PKW



Source: own calculation & representation

Economic Assessment – Results

- **Development of Ø-fuel consumption in D**



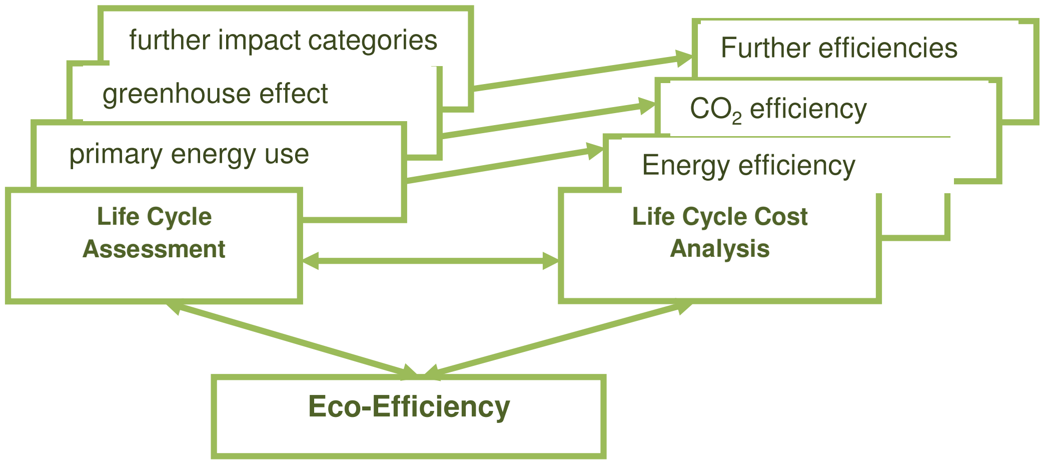
calculated on the basis of kilometers traveled (including international routes German automotive and domestic routes without foreign car)

Source: Federal Ministry of Transport, Building and Urban Development [ed] Transport in Figures 2009/2010

LCA + LCCA = EcoEfficiency

- **Combined life cycle oriented ecological and economic assessment as future task**

  ➡ **development of eco-efficiency indicators**



Source: own illustration based on
http://www.oeko.de/files/publikationen/broschueren/application/pdf/leitfaden_prosa.pdf

Thank you for your attention!

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