Life Cycle Assessment and Cost Analysis of Bioenergy Systems

22-26.11.2010
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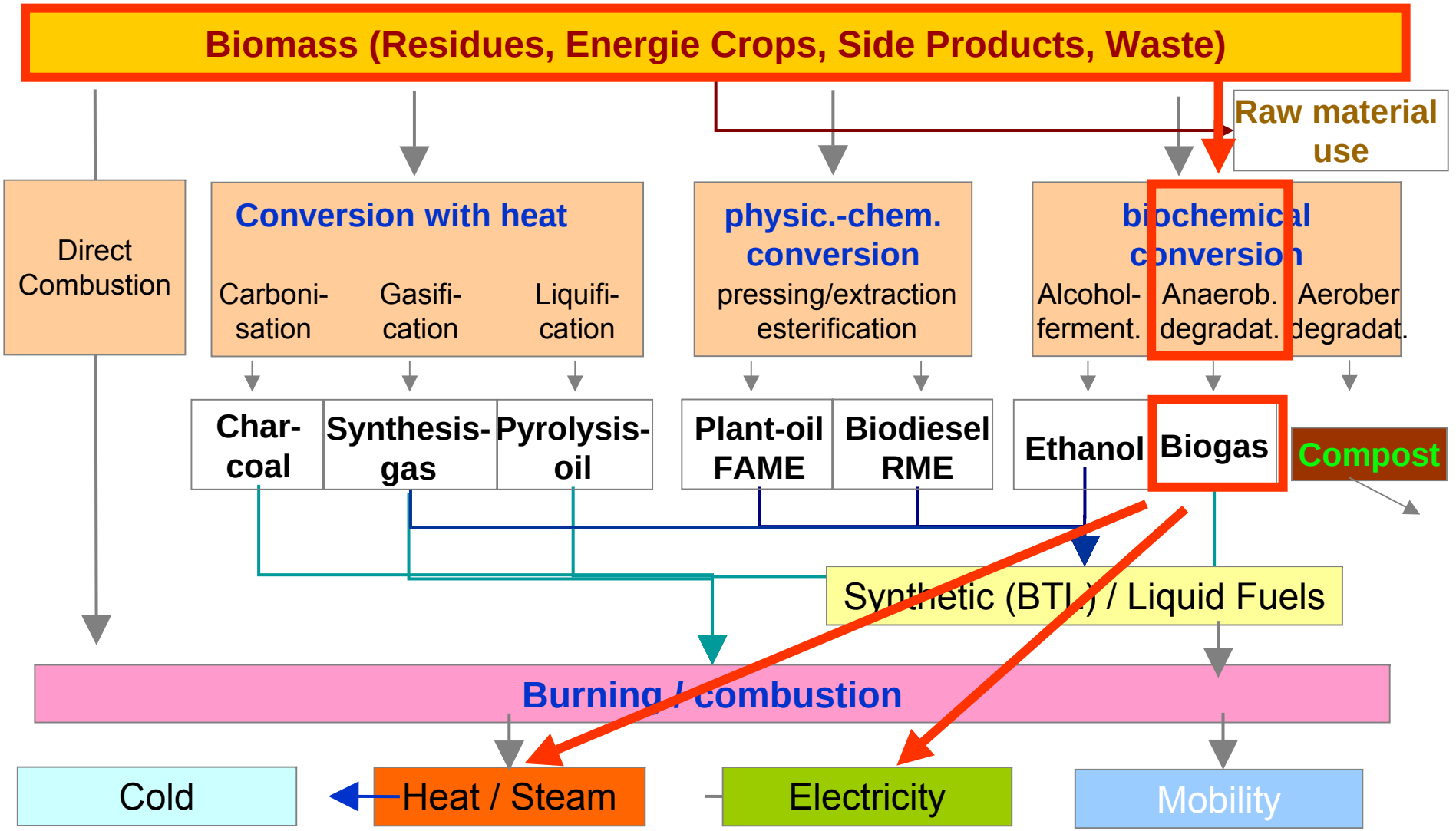
Agenda

- **Life Cycle Assessment (LCA) of Bioenergy Process Chains – General Overview**
  - **LCA of Energy Crop and Wood Cultivation**
  - **LCA of Electricity Generation from Biogas**
  - **Cost Analysis**
  - **CO_2-Abatement Costs**
  - **Conclusions**

Many Technologies, Process Chains and Products!



Life cycle assessement of bioenergy process chains

Impact Assessment

Global Warming Potential, Ozone Depletion Potential, Acidification, Eutrophication, Cumulative Energy Demand, etc.

Life Cycle Inventory Analysis

Corn
Fertilizer
Pesticides
Machine Diesel

Machine Diesel

Machine Diesel

Machine Diesel

Process energy
Building Materials
Machine

Process energy

Raw material Production | Transport | Storage and Pre-processing | Production and Use | Recycling

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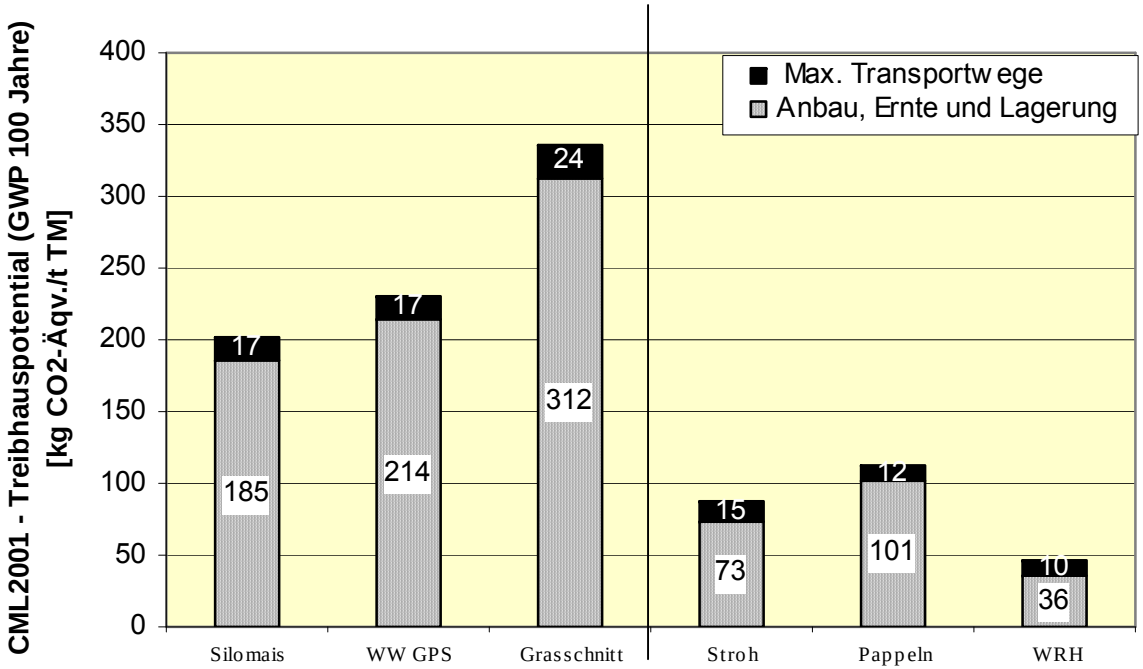
Life cycle assessment of bioenergy process chains- cultivation of short rotation coppice (SRC)

Pesticides	Cuttings Machine Diesel	Pesticides Machine Diesel	Fertilizer Machine Diesel	Machine Diesel	Process energy Building Materials	Machine Diesel	Machine Diesel

Global Warming Potential –Crop and Wood Cultivation

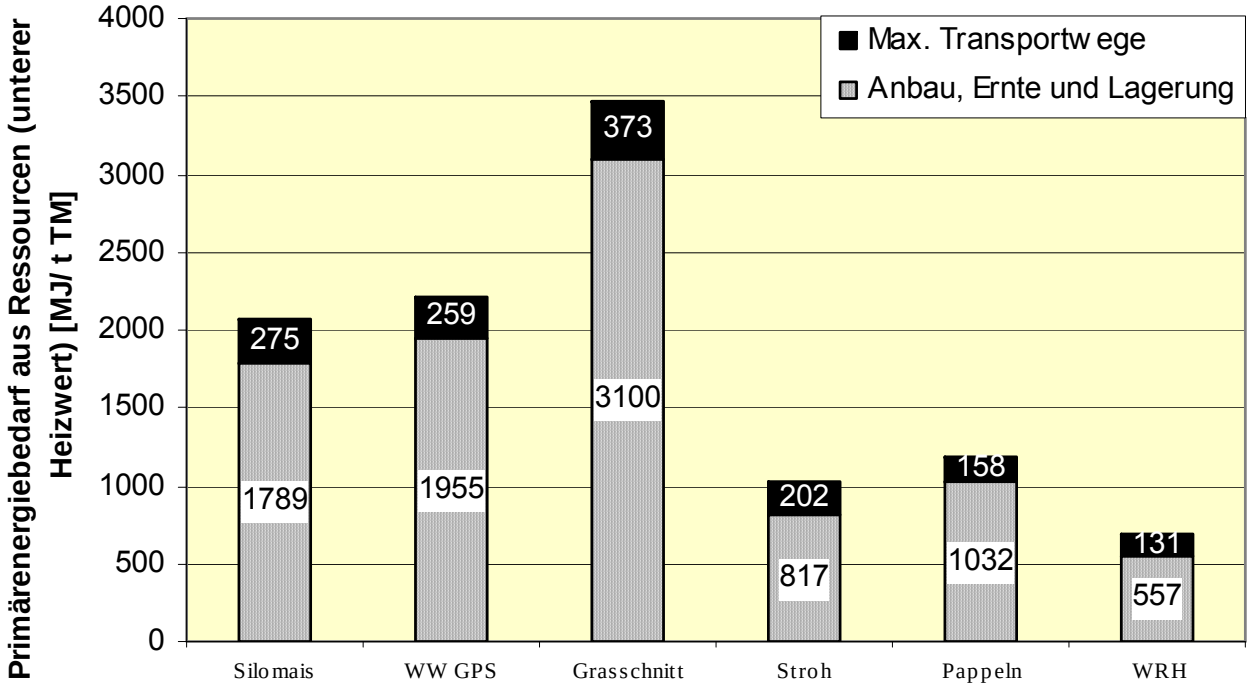


biogas plant feedstock
Transport: 10 km (Tractor)

gasification plant or wood-fired power plant feedstock
Transport: 80 km (Lorry)

Biogas plant feedstock: Grass silage production has the highest GHG-Emissions due to higher Nitrogen content
Gasification or wood-fired power plant feedstock: Short rotation coppice has the highest GHG emissions due to most demanding cultivation process

Primary Energy Demand –Crop and Wood Cultivation



biogas plant feedstock
Transport: 10 km Traktor

gasification plant or wood-fired power plant feedstock
Transport: 80 km Lorry

Primary Energy Demand shows similar characteristics as GHG-Emissions

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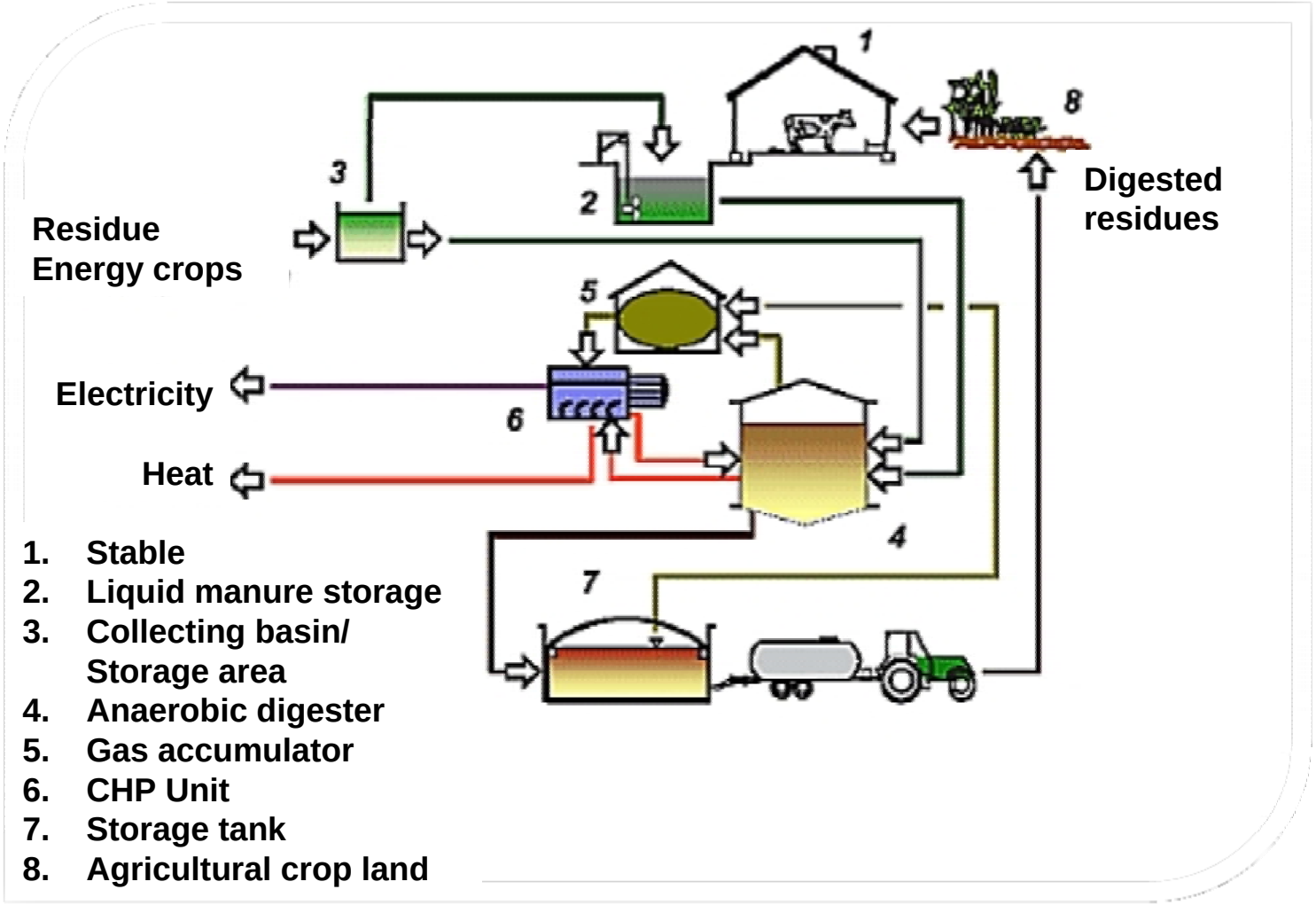
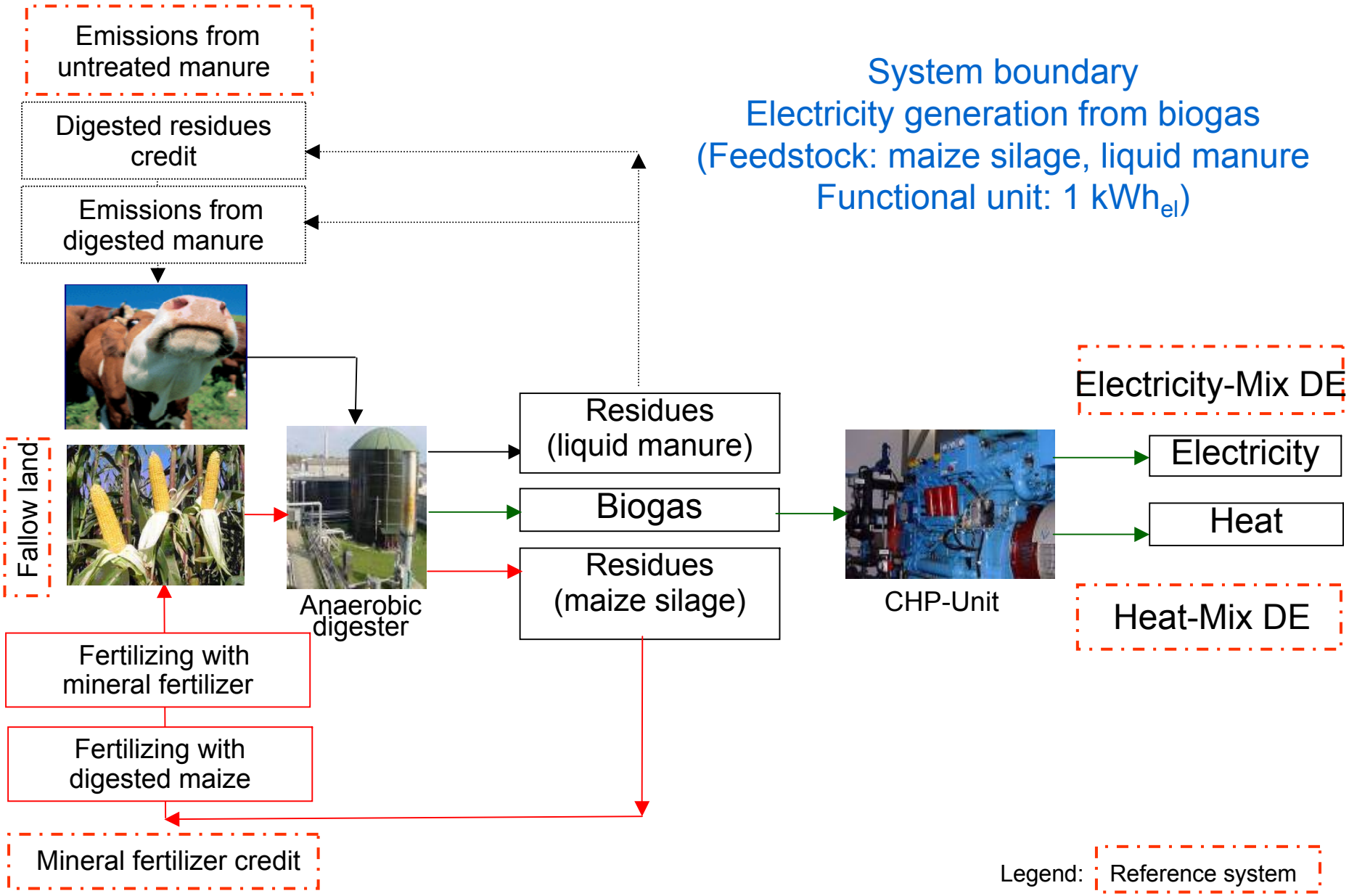
Biogas Plant Facility - general operating scheme

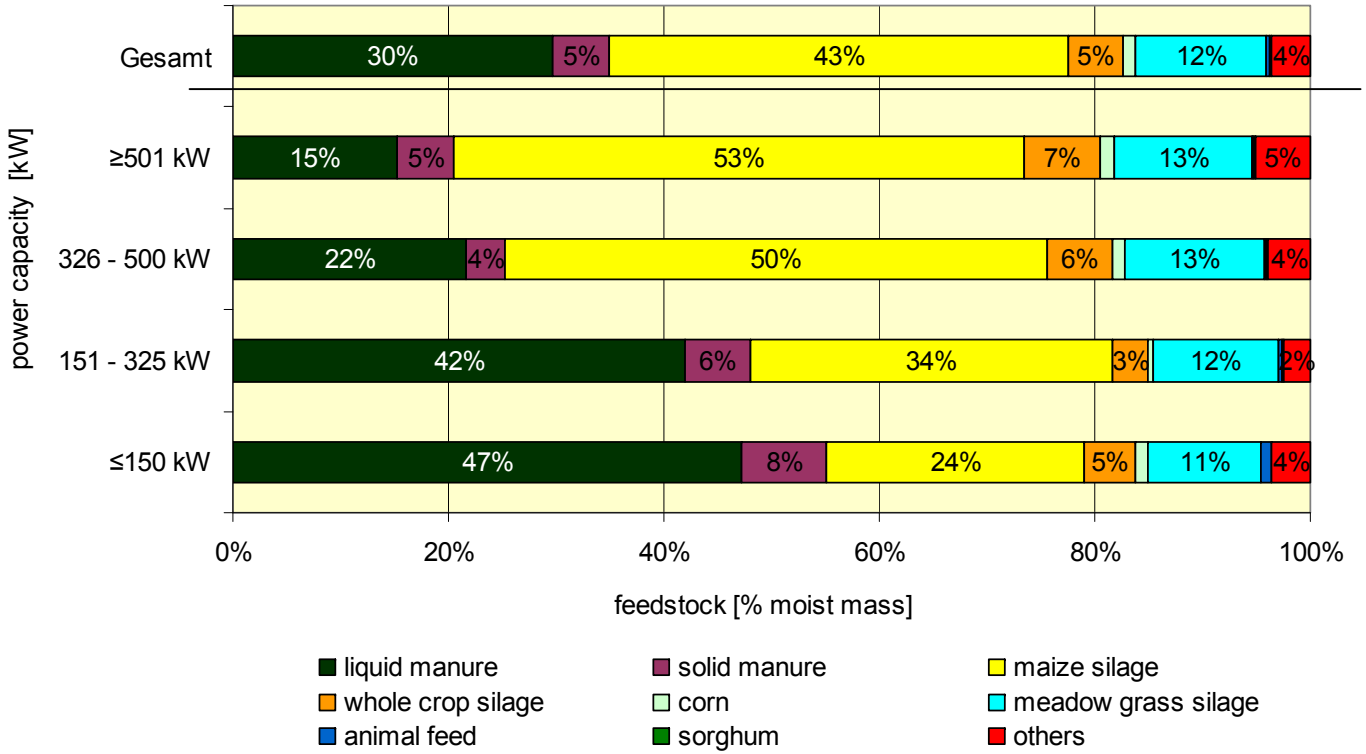


Source: http://www.ppm-biodiesel.com

System boundary
Electricity generation from biogas
(Feedstock: maize silage, liquid manure
Functional unit: 1 kWh_{el})



Average feedstock composition (in % moist mass) of biogas facilities in Baden-Wuerttemberg for 2009 by plant capacity



others: chicken manure, Sudan grass, fodder beet, rye, “corn-cob-mix”, feed rest, others

The more corn and whole crop silage is introduced, the larger the plant is.

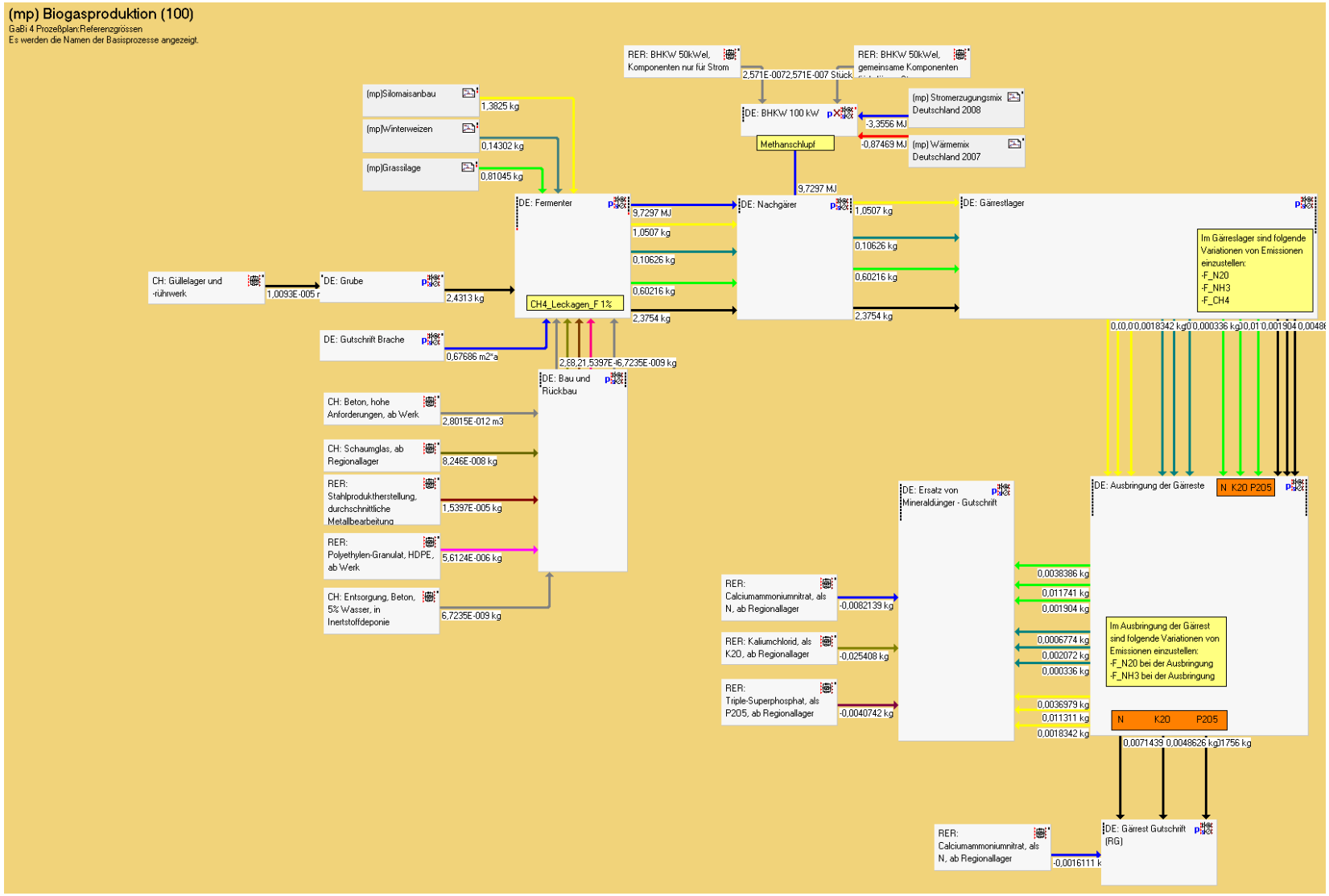
The smaller the plant is, the greater is the amount of manure used in the facility

Model plants for different capacity classes

Paramter	Unit	Modelfacilities				Source[1)]
Model Plant Number	-	1	2	3	4	
Power Capacity el	kWel	100	250	370	526	FB08
Power Capacity th	kWth	130	270	420	530	FB08
Lifetime of Biogas Facility	a	20	20	20	20	Annahme
Technical Specification						
Type of Engine	G-Gas	G	G	G	G	FB08
Engine Efficiency el	%	37%	38%	38%	40%	FB08
Engine Efficiency th	%	46%	47%	43%	43%	FB08
Operation						
Organic Loading Rate	kg oDM/m^3_{AD}	2,62	3,71	4,85	4,73	FB08
Full Load Hours	h/a	7779	7704	7760	7573	FB08
Covered Storage Tank for Digested Residues	yes/no	nein	nein	teils	ja	FB08
Heat Utiliziation (internal and external)	% Total Heat Generation	21%	16%	35%	39%	FB08
Electricity Purchase	% Total Electricity Generation	6,4%	5,6%	5,4%	6,2%	FB08
Emissions						
Methane leakage	% CH_4	1	1	1	1	Lit
Methane slip at CHP	% CH_4	1,45	1,45	1,45	1,45	Lit
Methane emissions from digested residues	Nm^3 CH_4/kg $oDM_{Digested\ Residue}$	10	10	5	2	Lit
Nitrous oxide emissions from digested residues	% N_2O-N	0,1	0,1	0,1	0,1	Lit
Nitrous oxide emissions from spreading of digested residues	% N_2O-N	1	1	1	1	Lit
Methane emissions from manure storage	kg $CH_4/m^3_{\ Manure}$	1,64	1,64	1,64	1,64	Lit
Nitrous oxide emissions from manure storage	% N_2O-N	0,1	0,1	0,1	0,1	Lit

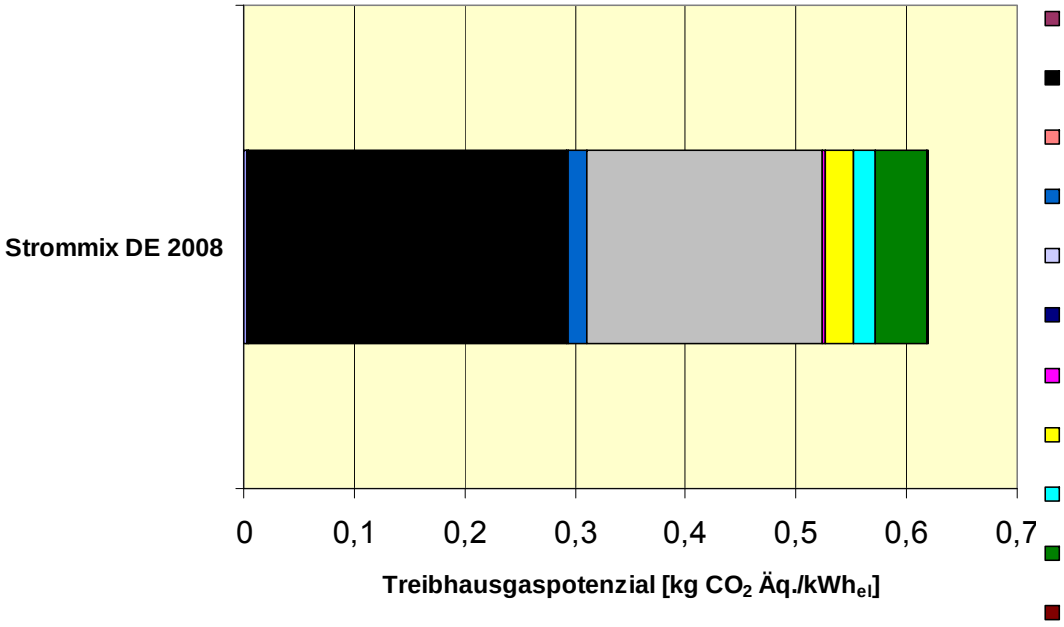
1) FB08 - Questionnaire 2008, Lit - Literature

Gabi Model – Electricity generation from biogas



Electricity-Mix DE

Reference System	Electricity Generation Costs [Cent/ kWhel]	GHG-Emissions [g CO2 Äq./kWhel]
Electricity-Mix DE 2008	**5,1**	**619**

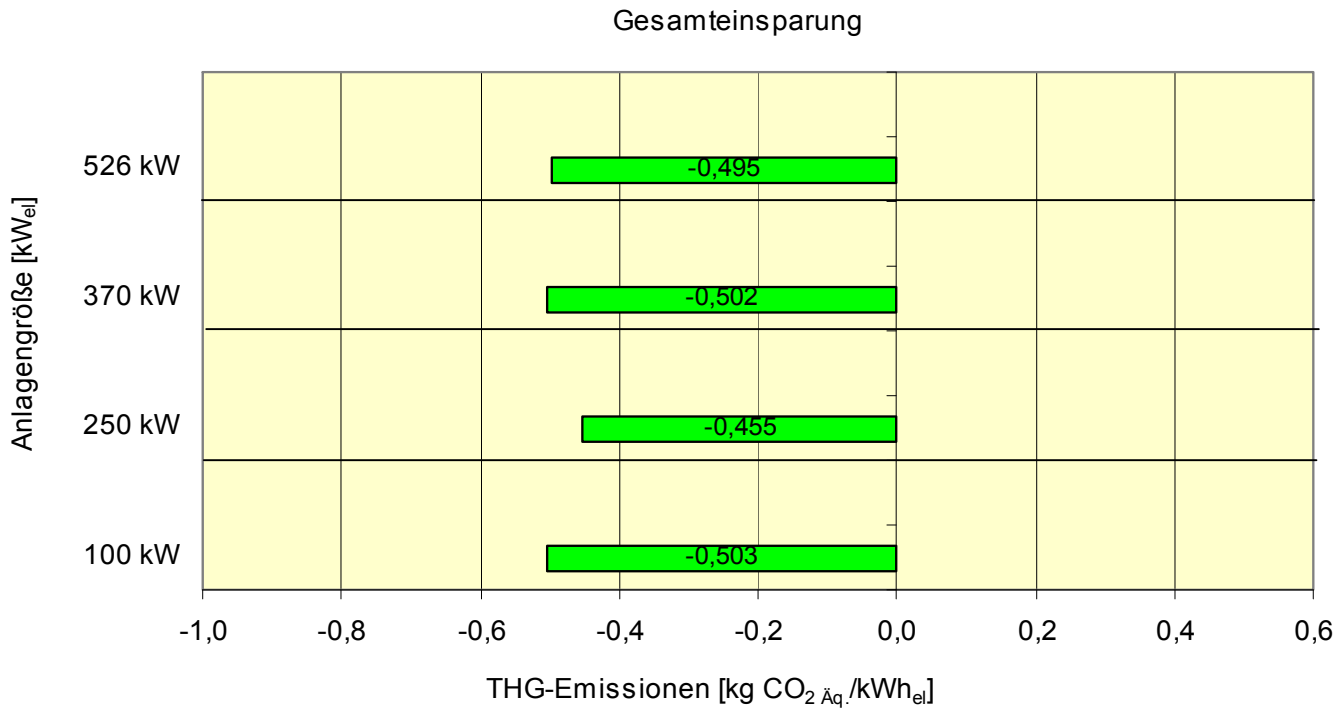


Energieträger	Strommix 2008 DE %
Braunkohle	24
Kernenergie	23
Steinkohle	20
Erdgas	14
Mineralölprodukte	1
Sonstige	4
Erneuerbare darunter	15
Wasserkraft	3
Windkraft	6
Biomasse	4
Photovoltaik	1
Geothermie	0
Müll	1
SUMME:	100

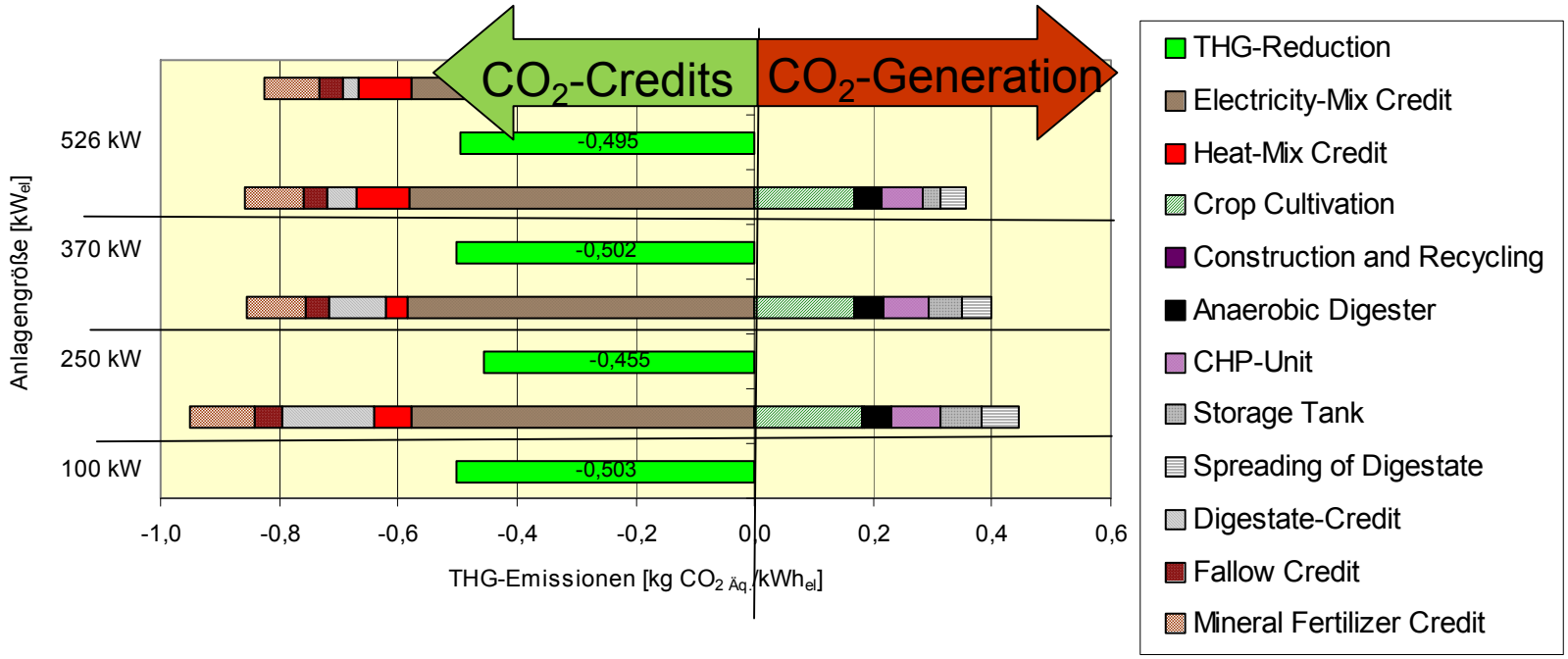
The GHG-Emissions of Electricity-Mix DE equal to 0,619 kg CO2 Äq./kWhel

Electricity from brown coal and hard coal power plants have highest contribution to the GHG-emissions

GHG-Reduction (Reference System Electricity-Mix DE)



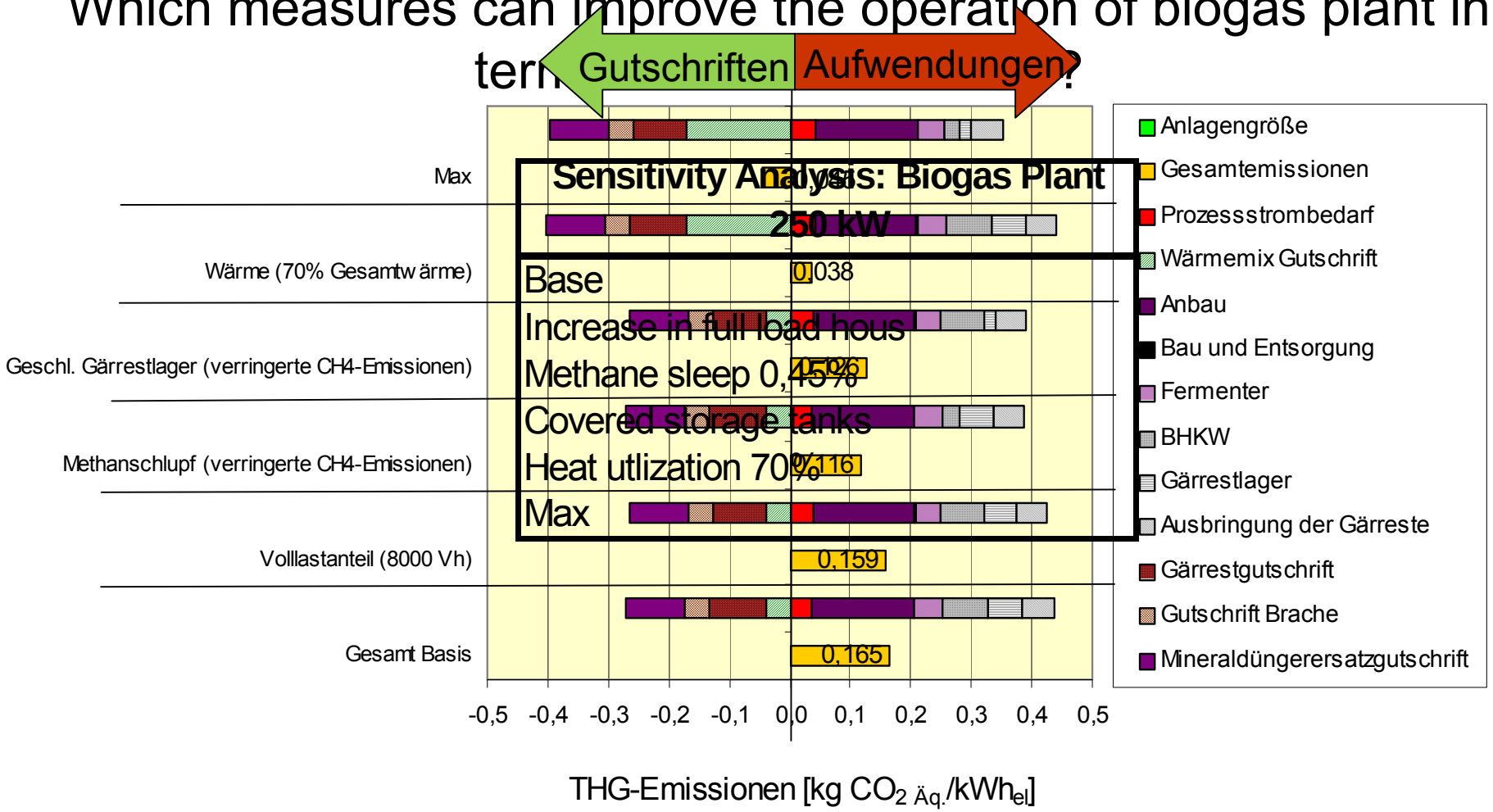
GHG-Reduction (Reference System Electricity-Mix DE) [kg CO_2 Äq./kWh_{el}]



The GHG-Reduction for all plant capacities is in the similar range.

GHG-Emissions 250 kW [kg CO_2 eq./kWh_{el}]

Which measures can improve the operation of biogas plant in term



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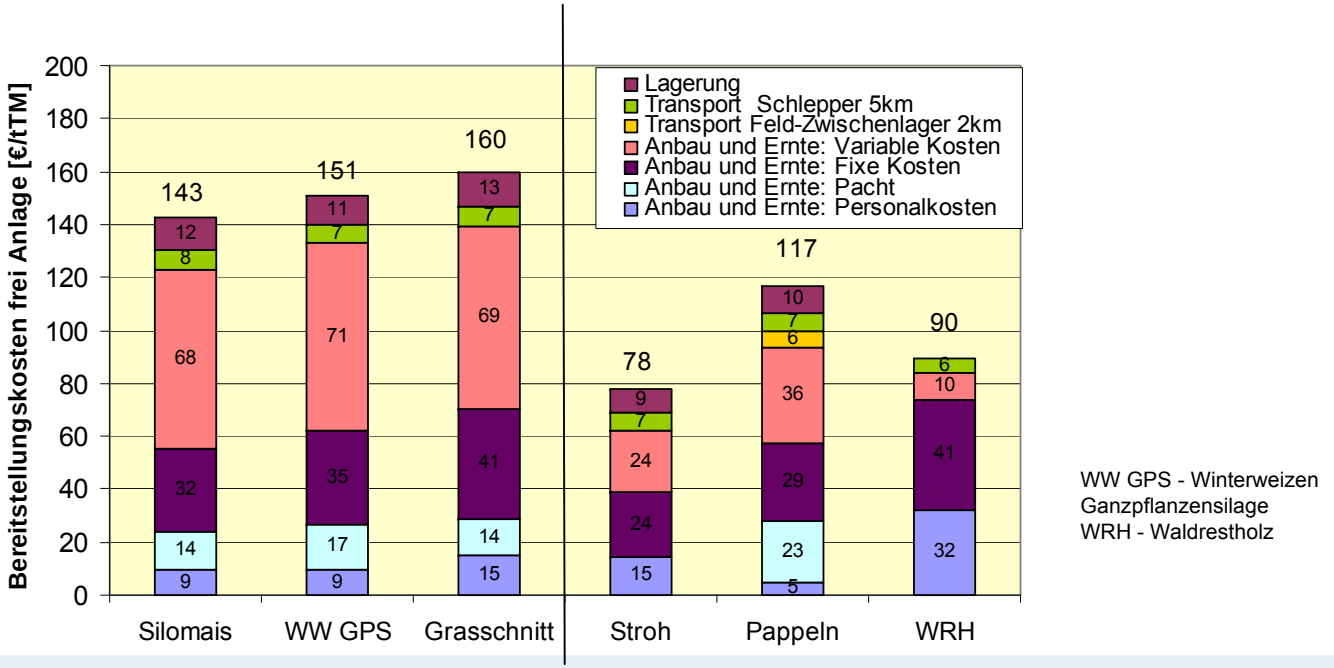
Cost Analysis – Biomass generation system



WW GPS - Winterweizen
Ganzpflanzensilage
WRH - Waldrestholz

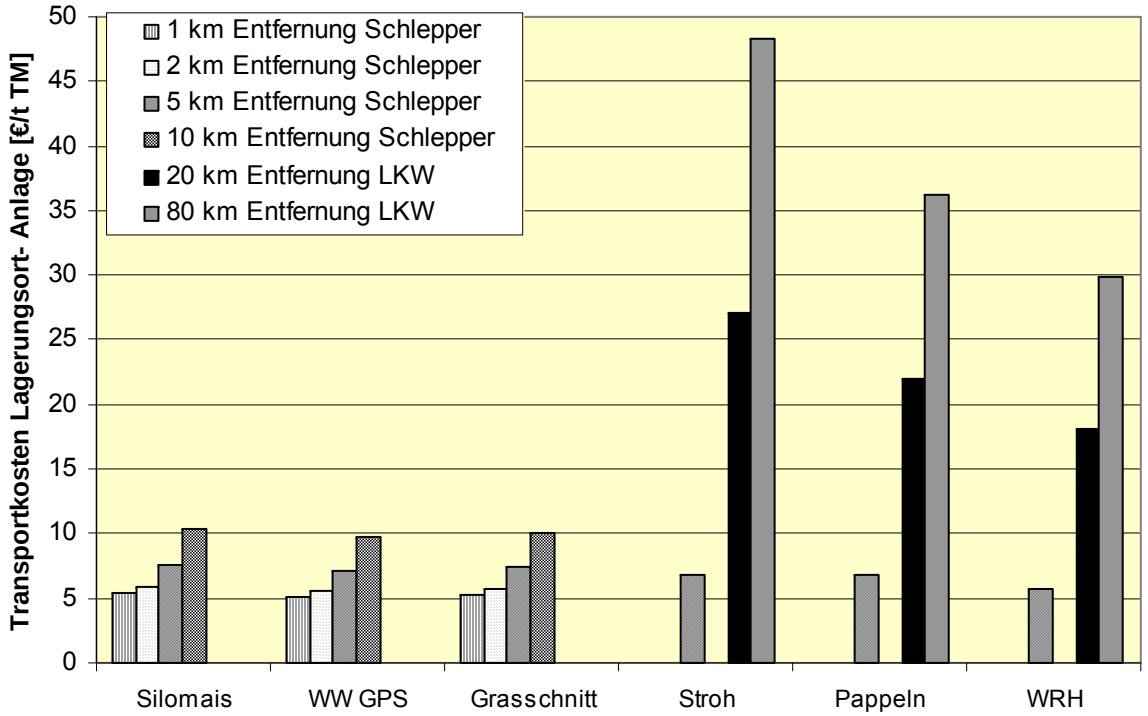
Biogas feedstock:

- Variable Costs (Fertilizers, Diesel, Corn) have highest contribution to the total biomass generation costs
- Storage and transportation costs are in the similar range and independent of production process

Wood-fired power plant feedstock:

- Fix costs of wood residues have highest contribution to the total biomass generation costs

Cost Analysis –Transport distances



- Biogas plant feedstock: Transportation costs do not depend on feedstock type
- Wood-fired power plant feedstock: Transportation costs do not depend on feedstock type at distances of 5km. Straw has highest costs for transportation distances of 20km and 80 km to the facility

Electricity Generation Costs – Biogas model plant [Cent/kWh$_{el}$]

Modellanlage	Stromgestehungskosten	
	Stromgestehungskosten [Cent/kWhel]	
	ohne Wärmenutzung	Basis* mit Wärmeerlös
100 kW	18,7	18,6
250 kW	16,1	16,0
370 kW	16,0	15,5
526 kW	16,6	15,9

* Mit anteiliger Wärmenutzung in der Größenklasse

Electricity generation costs ranges between 16 and 18 cent/kWhel

Plant capacities 250 kW and 370 kW have lowest generation costs

angelehnt an Vidjen 2010

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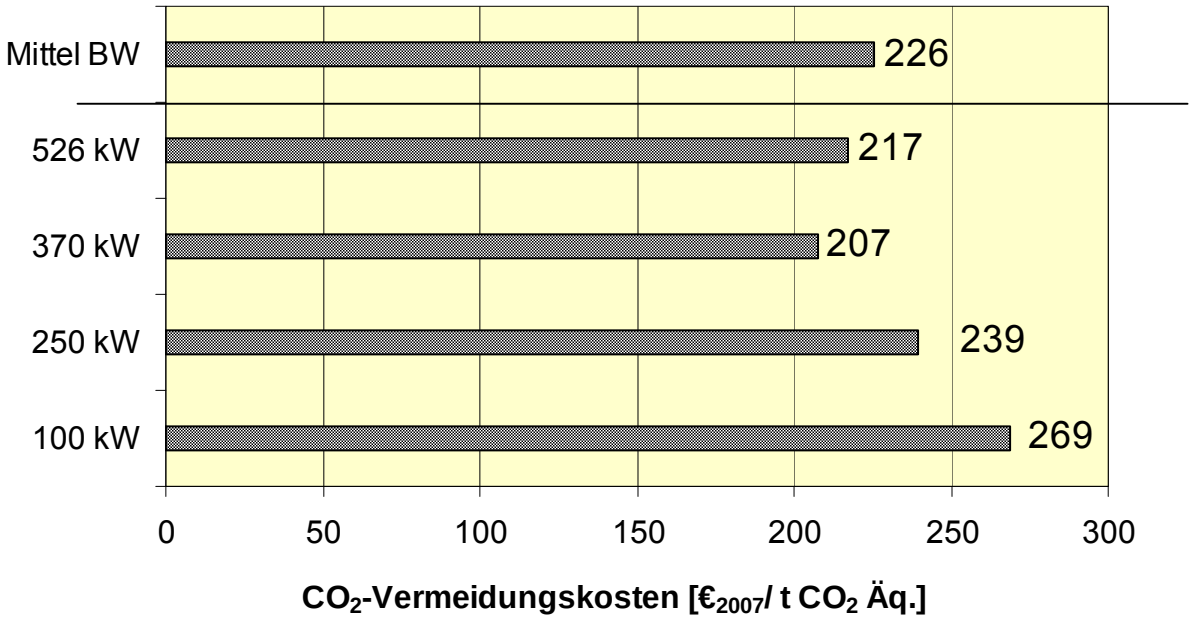
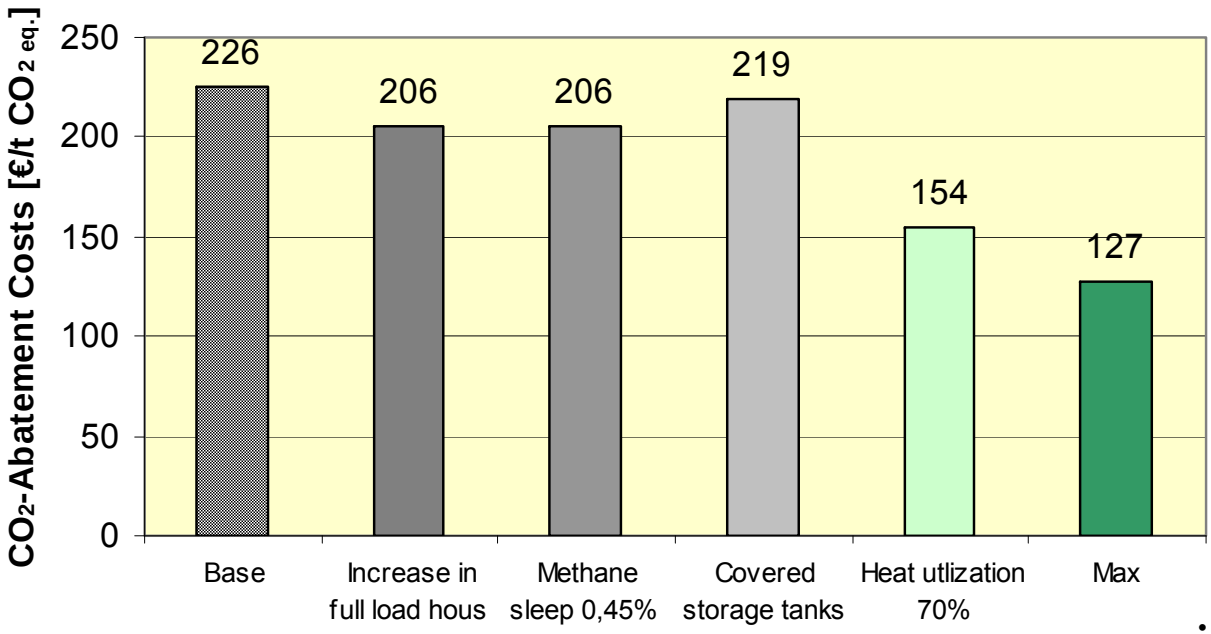
CO_2-Abatement Costs (Reference Electricity-Mix DE)



Die CO_2-Abatement costs decrease with increasing plant capacity

Die CO_2-Abatement equal on the on the average 226 €/t CO_2 eq.

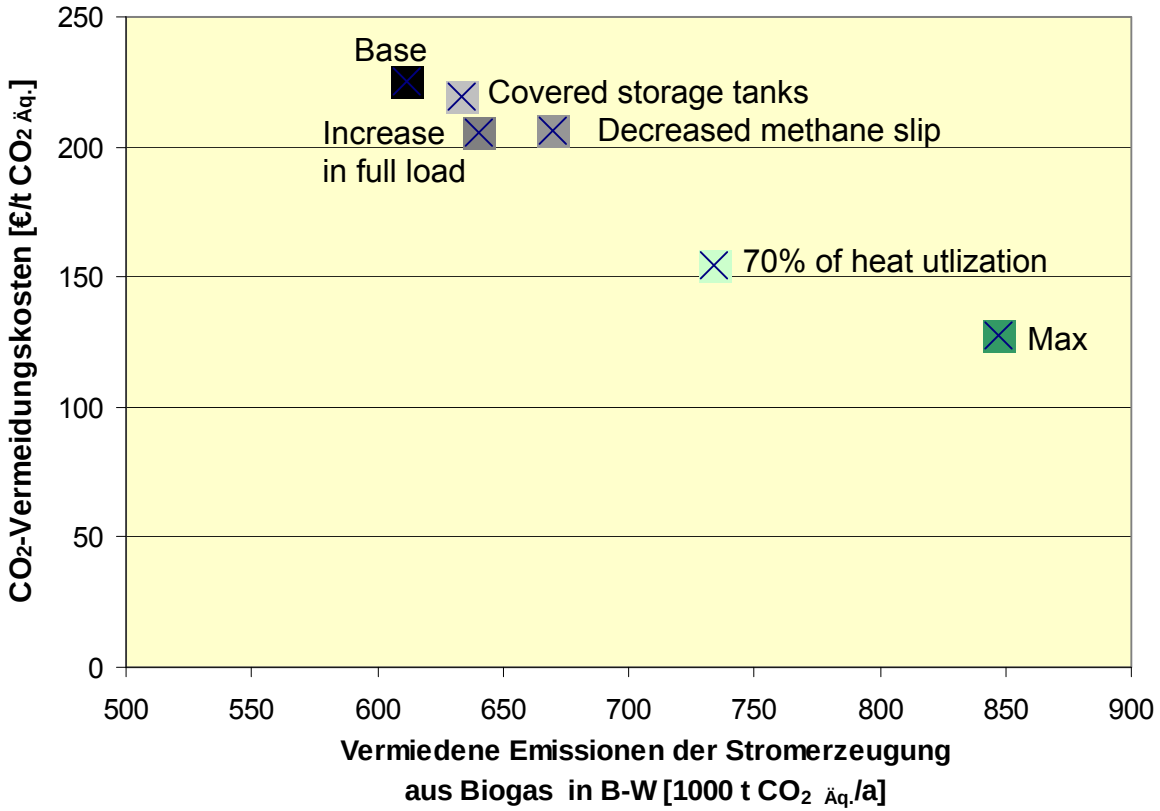
CO_2-Abatement Costs - Sensitivity



- Full load hours: 8000 h/a
- Covered storage tanks
- Methane slip 0,45%
- 70% of total heat utilization

Die CO_2-Abatement costs can decrease depending on the measures

Potential GHG-Reduction through biogas plants in BW



- According to given assumptions approx. 611 1000 t CO_2 eq./a were reduced (Reference System: Electricity-Mix DE)
- The potential for GHG-Reduction is still not exhausted

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Conclusions – German Examples

- **The GHG-Emissions for energy crop and wood cultivation are higher for energy crops mainly due to emission-intensive mineral fertilization.**
- **The GHG-Emissions for biogas plants of different capacities are in the similar range.**

  Small facilities use lots of manure and utilize small amounts of heat. Bigger facilities use in comparison to small facilities less manure but utilize much more heat.
- **The GHG Emissions can be reduced by:**
  - ➢new concepts for heat utilization
  - ➢covering of storage tanks for digested residues and reduction of methane slip and leakage
  - ➢increase in the full load hours.

Conclusions – Overall Implementation

- **With LCA and Cost Analysis different options of**

  - production,

  - processing and

  - utilization of energy crops and wood

  can be compared and assessed from comprehensive approach

- **LCA and Cost Analysis can be filled with regional databases and thus allows for specific (region-oriented) comparative assessment**

Das Projekt wurde gefördert durch das Ministerium für Ländlichen Raum, Ernährung und Verbraucherschutz mit Mitteln der Landesstiftung Baden-Württemberg

Thank you for your Attention
Any Questions?

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