04

Series of the funding programme "Biomass energy use"

Method Handbook

Material flow-oriented assessment of greenhouse gas effects

Methods for determination of technology indicators, levelized costs of energy and greenhouse gas effects of projects in the funding programme "Biomass energy use"

Biomass
energy use

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VOLUME 4

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levelized costs of energy, and greenhouse gas effects
of projects in the funding programme "Biomass energy use"

Edited by Daniela Thrän and Diana Pfeiffer

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PREFACE

It is not an easy task trying to optimise the production of bioenergy with more than one target in mind – every researcher who deals with the development of processes and ideas is well aware of this this. Climate gas reduction, energy efficiency and sustainability are the goals outlined in the German funding programme "Optimisation of the Use of Biomass for Energy Production" (in short "Biomass energy use"). Even though these goals are intuitive and appear synergistic: when the finer details are explored, questions begin to arise. There are issues about general definitions (e.g. what is "the sustainable potential of biomass?"), as well as several related uncertainties about the dynamics of drivers within the bioenergy system (e.g. concerning the assessment of the environmental impact). Optimisation always requires more empirical data to determine e.g. the limits of the system. Without these pieces of information the level of uncertainty becomes all the more greater making the validity of results more difficult to conclude. The implication of this is that there is a great need to provide transparency and harmonisation amongst evaluation methods. The only means of doing so is by providing information and empirical data for as many research projects as possible. This is an arduous task and in many cases can be fraught with risk for the researcher involved and will no doubt always end in some sort of compromise.

This method handbook tries to provide such a compromise: it gives guidance for diverse projects of the programme "Biomass energy use" and as such improves the connectivity of the evaluation findings. The suggested method documentations are based on the current state of scientific knowledge and range from qualitative descriptions of methods to detailed calculation methods. They are limited to selected questions and provide no complete evaluation of sustainability. It is the result of a four-year discussion process, enriched by the project partners of the funding programme. Valuable contribution were generated in working groups and at various workshops. Here the dedication of the working groups "Biomass Potentials", "Life-cycle Assessment", "Thermochemical Gasification" and "Reference Systems" should be particularly mentioned.

This version of the method handbook is now established and through its coordinated reference systems it forms a bridge for the overall classification of the research projects and the funding programme in the framework of the German climate protection discourse. Without doubt, the approaches and calculation procedures listed here only represent a starting point; on which further developments can be based upon, both scientifically and in practical applications. Future constructive and fruitful collaborations within the programme are essential for this and other challenges surrounding the harmonisation of methods. All this is still driven by the need and the goal to further optimise, little by little, the use of biomass in energy production.

It is a strength of the handbook that a common assessment basis was established for different technology systems. This is an issue which is also relevant for other sectors. Even this handbook aims above all at the German framework, the developed methods are also transferable to other areas. That is the reason, why this handbook was translated into English.

Leipzig, June 2014

Prof Daniela Thrän

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Abbreviations

AD	anaerobic digestion (plant)
BioSt-NachV	Biomass Electricity Sustainability Ordinance (Biomassestrom-Nachhaltigkeitsverordnung)
Biokraft-NachV	Biofuel Sustainability Ordinance (Biokraftstoff-Nachhaltigkeitsverordnung)
BiomasseV	Biomass Ordinance (Biomasseverordnung)
Bio-SNG	Synthetic Natural Gas from biomass
BMWi	Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie)
c.f.	compare
chem	chemical
CHP	combined heat and power (plant)
COU	crude oil units
dLUC	direct land use change
DS / ds	dry solids
EEG	Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz)
electr / el	electrical
EU COM	EU Commission
EU RED	European Renewable Energy Directive
FICFB	Fast Internally Circulating Fluidized Bed
FM	fresh material
funding programme	funding programme “Biomass energy use”
GaS	gas and steam
GHG	greenhouse gas
GIS	geographic information system
iLUC	indirect land use change
IPCC	Intergovernmental Panel on Climate Change
KrWG	German Recycling Management and Waste Law (Kreislaufwirtschaftsgesetz)
LCA	Life Cycle Assessment
LCOE	levelised cost of energy
LUC	land use change
mc	moisture content
M&C	measurement and control technology
n (stp)	normal conditions (at standard temperature and pressure)
org	organic
PEC	primary energy consumption
prEN	Draft European Standards
RE	renewable energy (Erneuerbare Energien)
RenFe	renewable feedstock
RME	rape-seed oil methyl ester
RSB	Round Table on Sustainable Biofuels
SRP	short rotation plantation
TCIS (ATKIS)	Official Topographic-Cartographic Information System (Amtliches Topographisch-Kartographisches Informationssystem)
therm / th	thermal
TM	transportation means
unk	unknown
WC	wood chips
VDI	Association of German Engineers (Verein deutscher Ingenieure)

Symbols

Chemical symbols

$CaCO_3$	calcium carbonate
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
FeOH	iron hydroxide
$FeCl_2$	iron(II) chloride
HFCs	hydrofluorocarbons
K	potassium
N	nitrogen
NH_4	ammonium
NO	nitrogen monoxide
N_2O	dinitrogen oxide (laughing gas)
NH_3	ammonia
NaOH	sodium hydroxide
N_2O	dinitrogen oxide
P	phosphorus
PFCs	perfluorocarbons
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide
SO_3	sulphur trioxide
ZnO	zinc oxide

Units

a	year
°C	degree Celsius / degree centigrade
d	day
EE	employee
Eq / eq	equivalents
$g_{CO2\text{-}eq}$	gram carbon dioxide equivalent
GJ	gigajoule

h	hour
ha	hectare
kg	kilogram
kg_{adry}	kilogram absolutely dry biomass
kg_{fm}	kilogram fresh material (wet weight)
kg_{ds}	kilogram dry solids
km	kilometre
kmol	kilomol
kPa	kilopascal
kW	kilowatt
kWh	kilowatt hour
kWh_{el}	kilowatt hour electrical
kWh_{th}	kilowatt hour thermal
L	litre
m^3_n	cubic meter at normal conditions (standard cubic meter)
MW_{out}	megawatt of output
MJ	megajoule
MJ_{CH4}	megajoule of biomethane
MJ_{fin}	megajoule of final energy
MJ_{el}	megajoule electrical
$MJ_{primary}$	megajoule of primary energy
MJ_{th}	megajoule thermal
MOT	means of transportation
MW	megawatt
MW_{AD}	megawatt anaerobic digestion plant
MW_{RTI}	megawatt total rated thermal input
PJ	petajoule
PM_{10}	particulate matter (fine dust) < 10 µm
ppm	parts per million
s	second
t	tonne
t_{adry}	tonne absolutely dry biomass
t_{fm}	tonne fresh material (wet weight)
t_{ds}	tonne dry solids
vol $\%_{abs}$	percentage by volume, absolute
W	watt
wt %	percentage by weight
€ct	eurocent
$€_{2010}$	real levelised costs of energy in 2010

Symbols in equations

A	annuity
B	biomass demand
BPI_t	by-product revenue in period t
C	Carnot efficiency
c_{ht}	specific isobar heat capacity of the heat transfer medium
C_t	costs in period t
E	annual constant energy production
E_t	energy production in period t
$\dot{E}$	energy flow
E_B	total emissions when utilising the biomass
E_F	total emissions of fossil reference systems
$LCOE$	Levelised Cost of Energy
GWP_{100}	specific global warming potential in case of 100 year integration period *(definition see Chapter 3.2.3)*
H_i	inferior calorific value, also referred to as lower heating value (LHV) *(definition see Chapter 3.2.4)*
$H_{i,aux}$	inferior calorific value of the auxiliaries
$H_{i,bm}$	inferior calorific value of the biomass
$H_{i,bp}$	inferior calorific value of the by-products
$H_{i,fu,pretr}$	inferior calorific value of the pre-treated fuel
$H_{i,fu,untr}$	inferior calorific value of the untreated fuel (as received)
$H_{i,lr}$	inferior calorific value of logging residues
$H_{i,pellets}$	inferior calorific value of pellets
$H_{i,res}$	inferior calorific value of the residues
$H_{i,x}$	inferior calorific value of component x of a gas mixture
H_s	superior calorific value (biochemical conversion processes), (*definition see Chapter 3.2.4*)
$H_{s,CH4}$	superior calorific value of biomethane
$H_{s,fm,untr}$	superior calorific value of untreated fresh material (input)
$\Delta_v H$	standard enthalpy of combustion
i	imputed interest rate
I_0	investment cost (ready for use, *definition see Chapter 3.2.2*)
$\dot{m}$	mass flow rate
$\dot{m}_{aux}$	mass flow rate of auxiliaries
$\dot{m}_{bm}$	mass flow rate of biomass
$\dot{m}_{bp}$	mass flow rate of the by-products
$\dot{m}_{exh}$	mass flow rate of exhaust gases
$\dot{m}_{fu,untr}$	mass flow rate of fuel as delivered
$\dot{m}_{fm,loss}$	mass flow rate of silage losses
$\dot{m}_{fu,pretr}$	mass flow rate of pre-treated fuel
$\dot{m}_{fm,untr}$	mass flow rate of untreated fresh material (input)
$\dot{m}_{ht}$	mass flow rate of heat transfer medium (typically water)
$\dot{m}_{res}$	mass flow rate of the residues
$\dot{m}_{wood(adry)}$	mass flow rate of wood relative to the absolute dry condition
mc	moisture content *(definition see Chapter 3.2.4)*

$mc_{fu,del}$	moisture content of fuel as delivered
$mc_{fu,pretr}$	moisture content of pre-treated fuel
$P_{additives}$	power of additives
P_{bed}	power of the bed material
P_{ca}	power for the compression of the necessary compressed air
$P_{ca,el}$	electrical power for the compression of the necessary compressed air
P_{chem}	chemical power *(definition see Chapter 3.2.4)*
$P_{chem,bp}$	chemical power of the released by-products
$P_{chem,del}$	chemical power delivered (auxiliary energy)
$P_{chem,res}$	chemical power of the released residues
P_{del}	power delivered *(definition see Chapter 3.2.4)*
$P_{del,ca}$	power delivered from provision of compressed air
$P_{del,chem}$	chemical power delivered (auxiliary energy) – chemical power of the inputs (operating resources) and auxiliaries
$P_{del,el}$	electrical power delivered (auxiliary energy)
$P_{del,ign}$	power delivered from ignition oil *(definition see Chapter 3.2.4)*
$P_{del,th}$	thermal power delivered (auxiliary energy)
P_{drying}	drying thermal power *(definition see Chapter 3.2.4)*
P_{el}	electrical nominal power *(definition see Chapter 3.2.4)*
$P_{el,pm}$	electrical power of prime mover
$P_{el,net}$	electrical net nominal power *(definition see Chapter 3.2.4)*
$P_{exh,chem}$	chemical waste heat flows of the exhaust gases
$P_{exh,th}$	thermal waste heat flows of the exhaust gases
P_{fm}	substrate power of fresh material (wet weight) *(definition see Chapter 3.2.4)*
$P_{fm,sil}$	substrate power of silage (fresh material / wet weight)
P_{fu}	fuel power *(definition see Chapter 3.2.4)*
P_{gas}	gas power
$P_{gas,dry}$	gas power of dry gas *(definition see Chapter 3.2.4)*
P_{in}	input power of bioenergy system (power of all energies input)
P_{input}	power of the inputs (operating resources)
P_{loss}	power loss of the bioenergy system *(definition see Chapter 3.2.4)*
$P_{loss,cs}$	power loss of conversion stages
$P_{Q,int}$	internally used thermal power *(definition see Chapter 3.2.4)*
P_{out}	output power of the bioenergy system (power of all usable energies)
P_{RTI}	total rated thermal input (relative to the inferior calorific value) *(definition see Chapter 3.2.4)*
$P_{syn,ed}$	power of the educts of a synthesis (downstream gasification)
$P_{syn,prod}$	power of the products of a synthesis (downstream gasification)
P_{th}	thermal power
$P_{th,bp}$	thermal power of released by-products
$P_{th,pm}$	thermal power of prime mover
$P_{th,res}$	thermal power of released residues
P_{res}	power of unburned components (residue)
Δp	pressure difference
$\dot{Q}_{digest}$	power of digester heating *(definition see Chapter 3.2.4)*
$\dot{Q}_{nom}$	nominal heat output *(definition see Chapter 3.2.4)*

$\dot{Q}_{useful}$	useful heat output *(definition see Chapter 3.2.4)*
r	discount rate
t	time, period
T_r	return temperature of the heat transfer medium
T_s	supply temperature (in Kelvin)
$\dot{V}$	volumetric flow rate
$\dot{V}_{CH4}$	volumetric flow rate of biomethane
$\dot{V}_{n,x}$	volumetric flow rate of component x of a gas mixture at normal condition (at standard temperature and pressure)
$\dot{V}_{n,gas}$	fuel gas volumetric flow rate at normal condition (at standard temperature and pressure)
η	efficiency
η_b	boiler efficiency *(definition see Chapter 3.2.4)*
η_{ca}	efficiency of external air compressor (pump / compressor)
η_{cg}	cold gas efficiency *(definition see Chapter 3.2.4)*
η_{chem}	chemical plant efficiency
$\eta_{chem,del}$	chemical plant efficiency less the power delivered *(definition see Chapter 3.2.4)*
$\eta_{chem,net}$	chemical plant efficiency of the anaerobic digestion plant (net)
η_{el}	electrical plant efficiency
$\eta_{el,net}$	electrical plant efficiency less the power delivered *(definition see Chapter 3.2.4)*
$\eta_{el,pm}$	electrical efficiency of prime mover
η_Q	thermal utilisation factor *(definition see Chapter 3.2.4)*
$\eta_{syn,gasif}$	efficiency of the synthesis downstream of the gasification
η_{th}	thermal plant efficiency
$\eta_{th,net}$	thermal plant efficiency less the power delivered *(definition see Chapter 3.2.4)*
$\eta_{th,pm}$	thermal efficiency of prime mover
η_{tot}	total plant efficiency
$\eta_{tot,net}$	total plant efficiency less the power delivered *(definition see Chapter 3.2.4)*
$\eta_{tot,pm}$	total efficiency of prime mover for production of heat / electricity

1 Introduction

The objective of the German funding programme "Optimisation of the Use of Biomass for Energy Production" (in short "Biomass energy use") is to further develop the open questions currently under discussion regarding the production of electricity, heat and fuels from biomass, and to thereby support the bioenergy strategy development (BMU 2009 & 2011). The central concern is to significantly and sustainably improve the climate protection effects which can be achieved by providing and using bioenergy in comparison to the current state of technology and to purposefully develop the potential for implementation beyond any individual project. In this respect, the programme is aimed at technical systems for the production of bioenergy. This requires the plant concept to be classified for individual enterprises and the respective reduction in greenhouse gas emissions to be identified under current and / or foreseeable conditions. To interpret the situation as a whole and derive recommended actions, this information must be determined for purposes of comparison within this programme.

If the results from individual and group projects are to comprehensively produce the intended added value, transparent accounting methods are needed which should be as well harmonised as possible. On the one hand, these have to be suitable for the project approaches, which are very different in type and scope, and therefore as straightforward, clear and comprehensible as possible, yet at the same time they also have to provide a stable database to ensure that results are largely comparable, meaning that a certain amount of complexity is unavoidable.

In view of this background, the objective of this method handbook is to provide a consistent documentation and methodology basis for key calculation and assessment methods used in selected analyses of data energy, economics and environment to be applied by all projects as a general and / or additional basis for the assessment. The method handbook is thus structured into the following six chapters:

- General framework
- Biomass potentials
- Energy and material flow of the conversion processes
- Economic assessment
- Greenhouse gas reduction and other environmental effects
- Reference systems

The methods presented are intended to provide a result with limited expenditure which is suitable for further use. To achieve this, on the one hand simplifications have to be made (e.g. degree of utilisation, start-up processes, etc.) and a standardised database is provided for various areas (e.g. fuel prices). On the other hand, there is no way as such to ensure that these simplifications and standardisations are appropriate and suitable for all projects and generate the desired results. Specifically, this means that the projects should utilise the suggested data and approaches for the calculation and can deviate from them in justified individual cases. When it is not possible to create a consistent database in a standardised fashion (e.g. process-specific indicators for GHG accounting or analysing potential), the harmonisation process focuses on methodological transparency, which is to be ensured based on documentation lists.

This handbook brings together different methods. The assumptions selected take into account current requirements regarding the sustainable bioenergy use. In its present state of revision, the method handbook is not a tool for the complete sustainability assessment of bioenergy systems. For such a task, it would be necessary to take additional parameters[1] into consideration as well as additional guidance regarding the interpretation of the results. The further development of this method handbook into an assessment tool for bioenergy systems remains an important topic of discussion accompanying the "Biomass energy use" funding programme and appears to be useful in the medium term. In this context, the aim of simplifying the methodology while avoiding the levelling out of individual technologies' specific features definitely needs to be fulfilled.

[1] Further parameters will be described in Chapter 7.7.

2 The indicators at a glance

In light of the stated objective, system boundaries and approaches are specified in this handbook to allow the results to be compared with limited effort. In summary, this typically includes the following indicators:

1. Description of the **energy content** of the biomass and (bio)fuels as inferior calorific values, representation of the energy-specific indicators in joules

2. Description of the **feedstock availability** by analysing potential (biofuel potential) or description of the specific reference use (how the intended waste materials / resdiues are currently being used)

3. Calculation of the **efficiency levels** of the project-specific bioenergy plants and (based on that) the expected efficiencies of a tried-and-tested plant if introduced to the market (specifying of the time frame during which this can be achieved)

4. Description of **Plant X** for Germany 2010, assuming that the researched concepts and test, pilot and demo plants are successfully developed and introduced to the market

5. Calculation of the **levelised costs of energy**, based on a dynamic process, the annuity method, using typical cost data

6. Calculation of **GHG emissions** of the whole suppy chain in accordance with EU RED (2009), in part modified by comparators specific to Germany

7. Cost and GHG development **outlook** into the years 2020 - 2030, taking into consideration changing procurement costs for (bio)fuels and the GHG emissions of the energy production in Germany (reference systems)

8. Calculation of the **GHG mitigation costs** from the future cost and GHG reduction results

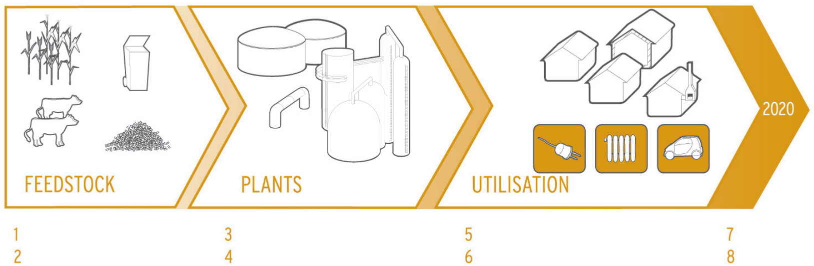


Figure 1: Overview of the indicators reviewed in the method handbook (source: original illustration based on a design by Holger Siegfried)

3 General framework

As general framework, the overriding assumptions and points of view on which the subsequent balancing processes and assessments are based are described below. One crucial factor taken into account when compiling these was that the central focus of the funding programme is on optimising the use of biomass for energy production (above all else, the technical elements) with the objective of Germany playing a major role in climate protection contribution, and that the assessment of energy, economical and environmental factors is to cover this point of view.

3.1 Fundamental references and definitions

The methods described below for determining the technological values, levelised costs of energy and greenhouse gas effects of processes for bioenergy use are based on definitions and standards as pointers towards approaches that preferably have already become established. The key references, on which the harmonisation approaches here are based are:

- European Renewable Energy Directive 2009/28/EC (EU RED 2009)
- Renewable Energy Sources Acts (Erneuerbare-Energien-Gesetze, EEG 2009) and Biomass Ordinance (BiomasseV 2005)
- Ordinance on requirements pertaining to sustainable production of bioliquids for electricity production (Biomass Electricity Sustainability Ordinance – Biomassestrom-Nachhaltigkeitsverordnung (BioSt-NachV 2009 & 2012)
- Biofuels Sustainability Ordinance (Biokraftstoff-Nachhaltigkeitsverordnung, Biokraft-NachV 2009)
- ISO standards for life-cycle assessment (ISO 14040 2006 & 2009 and ISO 14044 2006)
- VDI standard for economy calculation systems for capital goods and plants (VDI standard 6025 1996)
- Standard for solid biofuels – Terminology, definitions and descriptions (DIN CEN/TS 14588:2010)
- Report from the Communication to the council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling (COM (2010)[2] (EU COM 2010a)

In the following chapters, we will come back to the relevant points from these references.

[2] Additional EU processes, such as the Draft Consultation paper definition [of] highly biodiverse grasslands (EU COM 2010b), are being coordinated.

3.2 Definition of terms relevant to the programme

Below, some central terms with high relevance for the funding programme are defined. Generally, some of these involve different bases for definitions, some having beeing created from a scientific / technical point of view and some in a legal context.

3.2.1 Feedstock and product-specific definitions

Bioenergy
Bioenergy is definied as energy from biomass (DIN EN 14588 2010).

Biofuel (bioenergy source, bioenergy carrier)
Biofuels are fuels which are directly or indirectly produced from biomass (DIN EN 14588 2010). They are input materials and / or interim / by-products of different conversion technologies (combustion, gasification, anaerobic digestion) for the production of bioenergy. Biomass can be convereted into solid, liquid and gaseous biofuels.

The term **biomass** is legally defined in

- Aritcle 2 e) of Directive 2009/28/EC (Renewable Energy Directive, EU RED 2009): the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste.

- Section 3 of the German Renewable Energy Sources Act (EEG 2009): as biomass [in accordance with BiomassV] including biogas, landfill gas and sewage gas as well as the biodegradable section of waste from households and industry.

- Section 2 Para. 1 of the German Biomass Ordinance (BiomassV 2005): as "energy sources consisting of phytomass and zoomass". This also includes secondary products and by-products resulting from phytomass and zoomass, residues and waste, the energy content of which originates from phytomass and zoomass (c.f. Appendix I).

- In the literature, there are different definitions of biomass which, depending on the discipline, are less or more closely delineated than the legal definitions. Subsumed under this term are various biomasses which are cultivated (e.g. energy crops) or occur (e.g. wood from landscape management) as well as waste, residues and by-products.

The terms **main product**, **by-product** and **waste** are defined in the waste legislation.

- In accordance with Article 5 No. 1 of the Waste Framework Directive (2008), a by-product is defined as a substance or object, resulting from a production process, the primary aim of which is not the production of that item. A substance or object may be regarded as not being waste referred to in point (1) of Article 3 but as being a by-product only if the following conditions are met:

  (a) further use of the substance or object is certain;

  (b) the substance or object can be used directly without any further processing other than normal industrial practice;

  (c) the substance or object is produced as an integral part of a production process; and

  (d) further use is lawful, i.e. the substance or object fulfills all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.

- In accordance with Article 3 No. 1 of the Waste Framework Directive (2008), waste means any substance or object which the holder discards or intends or is required to discard. Since the Waste Framework Directive only becomes binding in a member state through an implementation act, the relevant national standard [for Germany] for the definition of waste is the German Recycling Management and Waste Law (KrWG 2012). In accordance with Section 3 Para. 1, it is assumed that waste is discarded, if the holder recovers substances or objects regarding the Annex 2 or discards them according the categories set out in Annex 1 of the KrWG (2012) or relinquish the actual ownership over the waste after discontinuation of the purpose.

Even though the term **residue** is mentioned in various laws, it is not defined further. At present, the difference between this and waste and by-products is not clear. In the Directive 2009/28/EC, residues are an independent category, set apart from by-products along with the category of waste. In the Directive, residues and waste have a legal status different from that of by-products (counting double towards the biofuel rate).[3] Even though some residues (such as straw, bagasse, husks, cobs and nutshells, etc.) are explicitly mentioned, there is no systematic delineation between residues and by-products.

In the following, residues are viewed as by-products of bioenergy plants which cannot be put to further use for energy, or composting. They can be used agriculturally or have to be put in a landfill and are therefore to be considered as losses of the bioenergy plant.

For the funding programme, the broadly defined term “(biomass) residues” is utilised, which – in light of the energy / technology / science focus of the programme – is suitable for the relevant disciplines (GHG accounting, analysing potential) and does not exclude any biomass fractions:

Biogenic residues are existing organic material flows that include by-products and / or residues and waste, i.e. all biomass material flows that are not produced as the primary product (c.f. Figure 2).

[3] As part of an amendment to the Directive 2009/28/EC (EU RED 2009), the EU Commission suggests that biofuels (for transport) made of certain wastes and residues should count four times towards the biofuel rate (as of 19 Oct. 2012).

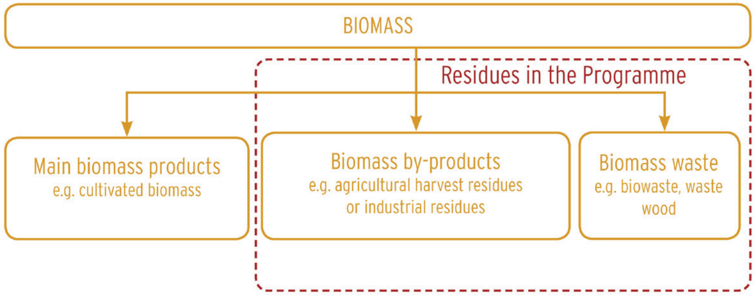


Figure 2: Definitions of biomass in the programme (source: original illustration)

Biomethane

To date, biomethane has not been defined in applicable standards or guidelines, but is a component of various research projects. For the programme, the following technical / scientific definition is used:

Biomethane is methane that is produced from feedstock (biomass) in technical processes. Biomethane can be produced through biochemical conversion (via anaerobic digestion) or thermochemical conversion (as Bio-SNG). It is upgraded to natural gas quality by processing the gas composition, in particular the methane content, accordingly.

Final energy (in accordance with VDI 4608 2005)

Final energy means the traded energy: the electrical energy, district heating, fuels, and by-products which are used for generating and / or converting energy for use at the consumer's property and are thereby finally taken off the market as energy sources.

Useful energy (in accordance with VDI 4608 2005)

Useful energy includes all technical forms of energy that the consumer ultimately needs: heat, mechanical energy, light, electrical and magnetic field energy […] and electro-magnetic radiation, to be able to perform energy services. Useful energy must be generated from final energy by energy converters at the time and place they are required.

Primary energy (in accordance with VDI 4661 2003)

Primary energy is the energy content of energy sources that exist in nature and have not yet been converted technically.

3.2.2 Economic definitions

This chapter basically covers the necessary technical and financial / mathematical definitions. For cross-project comparison, it is vital important to adhere to the following definitions as well as to specify the indicators.

The following terms and indicators are used and have to be taken into consideration for economic calculations:

Annual full load hours (h/a)

The annual full load hours are calculated retroactively via the energy provided using the power plants' rated power (net). To calculate the levelised costs of energy, the annual full load hours are defined as the hours per year during which the power plant is to provide energy at its full power. In this context, the annual full load hours depend, on the one hand, on the availability of the overall plant (technology-specific), and on the other, on the plant operation (heat controlled, electrical power controlled, or in full load operation). With the help of the annual full load hours, the annual electricity production (kWh/a) and the fuel consumption are determined (Konstantin 2007).

Annuity

An annuity is a sequence of payments of equal amounts that occur in each period of the period under review (Götz 2008).

Annuity method

The annuity method assumes the net present value method wherein non-periodic and periodic payment with changeable amounts during a period under review are transformed into periodic constant payments. This makes it possible to transform payments that occur at different points in time and in different amounts into uniform payment sequences and to use those for the further calculation of the levelised costs of energy (Götz 2008), (VDI 6025).

Fuel price based on the inferior calorific value (€/GJ)

The biomass price including delivery to power plant (e.g. 76 €/t_{adry}) and the inferior calorific value of the biomass (e.g. 19 GJ/t_{adry}) produce the fuel price (4 €/GJ), (Konstantin 2007).

Investment cost I_0[4] (€ at point in time of commissioning / reference year)

The investment cost "I_0" is the present value of all investment expenses during the construction phase plus interest up to the time of commissioning. For large projects, the investment expenses occur in more than on instalment during the construction phase which can extend over several years. In practice, the construction interest is calculated separately and added to the present value of the investment expenses (Konstantin 2007).

[4] Published information regarding the investment costs in projects usually refers to the nominal values of investment expenses without financing costs during the construction time. For the sake of completeness, these should be supplemented, depending on the planned construction time.

Maintenance

Measures for maintaining and re-establishing the target condition as well as for determining and assessing the current condition of a systems´s technical devices count as maintenance. As such, maintenance includes cleaning, inspection and repair (measures for re-establishing the target condition of a system's technical devices) (Konstantin 2007).

Net present value method

By means of the net present value method, it is possible to calculate the forecast surplus, which may also be negative, of an investment over a period of time under review for the point in time of commissioning (t=0). As a result, the net present value is the present value of all of an investment's payments occurring during a period under review and is calculated from the sum of all discounted payments of an investment, wherein incoming payments have a positive impact on the calculation and outgoing payments a negative one. A positive net present value shows that the capital used is earning more interest under the assumed framework conditions than the rate of interest and / or minimum return on investment requirement.

Payment

In general, the term "payment" refers to an amount of money that is earned or spent. The value of a payment is calculated based not only on the amount but also on the due date.

Present value

In financial mathematics, payments and series of payments that occur at different points in time are recorded mathematically and rendered comparable. The reason for this is that the invested capital can generate interest over the course of time. Therefore, at a later point in time, an amount of money invested today will have a higher value than the originally invested amount due to the accumulated interest, and vice versa. The value of the payment at the current point in time is called the present value. In accordance with the equivalence principle of financial mathematics, payments are only then comparable and can only be added or subtracted if they have previously interest added or deducted (discounted) relative to the same reference point in time (Konstantin 2007, Götz 2008).

Rate of interest

The rate of interest represents the price for capital and / or the opportunity costs. As such, this interest rate is the return on investment requirement which is determined on the one hand by the outside capital interest and on the other by the requirement with respect to the return on equity.

3.2.3 Definitions related to life-cycle assessment

Allocation

Within life-cycle assessment, allocation means how the input and / or output flows of a process or product system are divided between the various products and functions. This can be done based on physical, economic or other relationships between the products.

Global warming potential (GWP 100)

Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), dinitrogen oxide (nitrous oxide / laughing gas, N_2O), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) have an impact of different intensities on the climate. The global warming potential describes the climatic effect relative to carbon dioxide, the reference greenhouse gas (based on that, methane corresponds to 23 times the climatic effect of CO_2). The global warming potential was determined by the IPCC (IPCC 2001) for a time frame of 100 years. The greenhouse gas levels are indicated in CO_2 equivalents.

Greenhouse gas reduction

Greenhouse gas reduction quantifies the percentage reduction of GHG emission producing and using (solid, liquid and gaseous) biofuels in comparison to fossil fuels.

Life-cycle assessment

To prepare a life-cycle assessment, the internationally applicable standards ISO 14040 and ISO 14044 are used. Within a life-cycle assessment, the life-cycle of the investigated products is analysed from the feedstock exploitation via the production and utilisation to the disposal. In this process, all auxiliary substances and consumables used from the provision of the feedstock to the distribution are captured and assessed, and the emissions connected with the production of these auxiliary substances and consumables as well as with the other products and services.

3.2.4 Definitions related to energy technology

The following definitions are relevant, some of which are defined according to the VDI guideline 4661 (VDI 4661 2003):

The **energy content** of the primary energy, input materials and residues, as well as products, is the chemically bound energy of the biomass that is available in the technical conversion process for conversion into other forms of energy. In the funding programme, the **energy content of all input materials and residues is stated exclusively as the inferior calorific value H_i.** The reference value for the calculation of the chemical power and the efficiency is also the inferior calorific value H_i. The inferior calorific value is also referred to as lower heating value.

Auxiliaries

Auxiliaries are materials inputted into the bioenergy plant that are not directly needed for the generation of the (solid, liquid and gaseous) biofuels. They are included fully in the energy and mass balance.

Boiler efficiency η_b (%) (DIN-EN 303-5 1999)

The boiler efficiency is the ratio of the usable thermal power emitted (nominal heat output) to the total rated thermal input.

Chemical power P_{chem} (kW)

The chemical power of liquid and solid biofuels is the product of the mass flow rate and the inferior calorific value (H_i) of the biofuel that is leaving the conversion plant system (quaternary biofuel).

Chemical net plant efficiency $\eta_{chem,net}$ (%)

The chemical net plant efficiency describes the ratio of the chemical power of the biofuel as a product of the bioenergy plant and its fuel power, taking into consideration its energy delivered.

Cold gas efficiency η_{cg} (%)

Cold gas efficiency, often also referred to as chemical efficiency, characterises the material-linked energy conversion of a gasification system. As part of the funding programme, the cold gas efficiency of the gasification system is defined as the clean gas efficiency. It is the ratio of the chemical gas power at the exit of the gas cleaning path to the fuel power obtained at the entry of the gasifier. The reference value is the respective **inferior calorific value** - $\boldsymbol{H_i}$.

Drying thermal power P_{drying} (kW)

The drying thermal power is the internally provided thermal power that is provided for drying the unconditioned biomass that is used in the conversion process.

Emissions

Emissions are gasses that exit a bioenergy plant unused and are to be considered as its losses.

Electrical net plant efficiency $\dot{Q}_{el,net}$ (%)

The electrical net plant efficiency describes the ratio of the electrical gross power relative to the delivered fuel power of the bioenergy plant at rated operation, while taking into consideration its energy delivered.

Electrical nominal power P_{el} (kW)

The electrical nominal power is the highest producible continuous power of a bioenergy plant (rated operation).

Electrical net nominal power $P_{el,net}$ (kW)

The electrical net nominal power is the electrical nominal power less the power delivered P_{del}.

Fuel power P_{fu} (kW)

The fuel power is the chemical fuel energy per unit of time introduced into the bioenergy plant. The reference value for the calculation of the fuel power is the inferior calorific value H_i. The fuel power has an influence on the calculation of the general indicators of the plant, e.g. on the total plant efficiency in case of gasification.

Gas power $\eta_{gas,dry}$ (kW)

The gas power describes the chemical power of the fuel gas generated. It consists of the sum of the inferior calorific values of the individual components of the dry gas. The chemical power of these individual components is the product of the standard volume stream and the volume-related inferior calorific value H_i.

Ignition oil power $P_{ref,ign}$ (kW)

The ignition oil power is the chemical power of the ignition oil fed to the CHP plant. The reference value for calculating the ignition oil power is the inferior calorific value H_i. Furthermore, the ignition oil is considered as a fuel when calculating the prime mover efficiency in case of gas usage in an engine, and is therefore included in the denominator when calculating the gas power. Here, the power added to the ignition oil is considered as the power delivered (auxiliary power).

Inferior calorific value H_i (MJ/kg$_{ds}$) (VDI 4661 2003)

The inferior calorific value describes the energy content, taking into consideration the reaction heat of full combustion in case of evaporated water. The inferior calorific value is also referred to as lower heating value.

- Biomass that is converted in combustion or gasification processes is to be indicated using the inferior calorific value at a reference moisture. To characterise the energy content of the biomass, the moisture content needs to be specified beside the inferior calorific value.
- Biomass (substrates) that is used in anaerobic digestion plants is to be indicated using the inferior calorific value in dry conditions (105 °C).

Inputs (operating resources)

Operating resources are input materials of the bioenergy plant that are not primarily needed for generating the biofuels (solid, liquid and gaseous). They are involved in the processes, but are not included in the energy and material balance since they exit the conversion plant in the same quantity.

Internally used thermal power $P_{Q,int}$ (kW)

The internally used thermal power includes all types of thermal power that are extracted from the conversion process and that are used internally in the bioenergy plant, e.g. for drying, digester heating or air pre-heating.

Moisture content *mc* (%)

The moisture content specifies the share of water in relation to the total mass of the biomass. It is determined as loss on drying in accordance with the European standard CEN/TS 14774 (2003) at 105 °C.

Nominal heat output $\dot{Q}_{nom}$ (kW)

The nominal heat output is the share of the heat generated in the conversion processes that is transferred to a heat transfer medium while operation at a nominal level and can be applied outside the conversion process. Thermal power that is used in sub-processes of the bioenergy plant – e.g. for drying of fuels or digestate – is in this sense not referred to as nominal heat output but rather as internally used thermal power, e.g. drying thermal power.

Off-heat (in accordance with VDI 4608 2005)

Off-heat is the share of the heat that is released unused into the environment in a conversion process, which includes both radiation losses and exhaust losses as well as the release of excess heat via emergency cooling facilities.

Power delivered P_{del} (kW)

The power delivered corresponds to the sum of all outputs that are made available to the bioenergy plant as auxiliary power. This can be constituted of externally provided thermal, chemical and electrical power. In the calculation of plant efficiencies, the power delivered has to be taken into consideration accordingly.

Power of digester heating $\dot{Q}_{digest}$ (kW)

The power of the digester heating corresponds to the thermal power (heat output) that is withdrawn from the exhaust and cooling water mass flow rate of the heat engine and fed to the digester (fermenter) to adjust the necessary process temperature.

Power loss P_{loss} (kW)

The power loss describes all types of power leaving the bioenergy plant that are not used internally or externally.

Substrate power P_{fm} (kW)

The substrate power is the chemical power (inferior calorific value multiplied by the mass flow rate) of the substrate (input material of a anaerobic digestion plant / fresh material / wet weight), that is fed to a bioenergy plant.

Superior calorific value H_s (MJ/kg$_{ds}$) (VDI 4661 2003)

The superior calorific value describes the energy content taking into consideration condensation heat; the energy content is identical to the standard enthalpy of combustion $\Delta_v H$.

Thermal net plant efficiency $\eta_{th,net}$ (%)

The thermal net plant efficiency describes the ratio of the usable heat relative to the fuel power used (related to the superior calorific value) of the bioenergy plant, taking into consideration the energy it delivers.

Thermal utilisation factor η_Q (%)

The thermal utilisation factor describes the ratio of usable heat to nominal heat.

Total rated thermal input P_{RTI} (kW)

The total rated thermal input is the chemical power introduced into the biomass conversion process (combustion, gasification, anaerobic digestion), i.e. after the biomass processing. The reference value for calculating the total rated thermal input is the inferior calorific value H_i. The total rated thermal input only has an influence on the process-specific indicators, e.g. on the cold gas efficiency in case of gasification.

Total plant efficiency $\dot{Q}_{tot,net}$ (kW)

The total plant efficiency describes the sum of the electrical, chemical and thermal net plant efficiencies.

Useful heat output $\dot{Q}_{useful}$ (kW)

The useful heat output corresponds to the share of the nominal heat that is used for external applications or processes, e.g. to feed into heat grids.

3.3 System boundaries and system elements: the supply chain for the production and use of bioenergy

System boundaries for technical, economic and environmental analysis

The selection of the system boundaries is designed to achieve an analysis that is as programme-oriented as possible and that requires little effort. The analyses and assessments are modelled on the supply chain for the production and use of bioenergy. Figure 3 provides an overview of the different areas of assessment that are pursued in parallel. They include potentials, costs, energy and material flows, and greenhouse gas emissions. In each case, the illustration presents the units for the areas of assessment, the most important indicators and their system boundaries within the supply chain from biomass production to the final energy utilisation, as well as the relevant reference systems. The varios areas of assessment differ both in the units selected and in the relevance of the individual processes along the chain.

To arrive at an analysis that is as goal-oriented as possible and requires little effort, therefore, the following simplifications are suggested:

Potentials can be described for individual areas of the supply chain, with the potential beeing of different sizes depending on the respective reference (due to conversion losses, the bioenergy potential is lower than the biomass potential). Here, the biomass potential is influenced by the utilisation of the available agricultural land and the residual materials occurring within the economic system. The reference systems on which this is based therefore provide important additional information in terms of representing potential. The biofuel potential, furthermore, takes into consideration processing losses and storage losses. The bioenergy potentials, and the additional conversion losses, which differ in importance depending on whether electricity, heat or fuels for transport are provided. The clearl indication of the potential is therefore decisive for the interpretation. Analyses of potential are optional and are to be performed first and foremost in light of the process-specific feedstock availability. A representation of the biofuel potential is to be strived for.

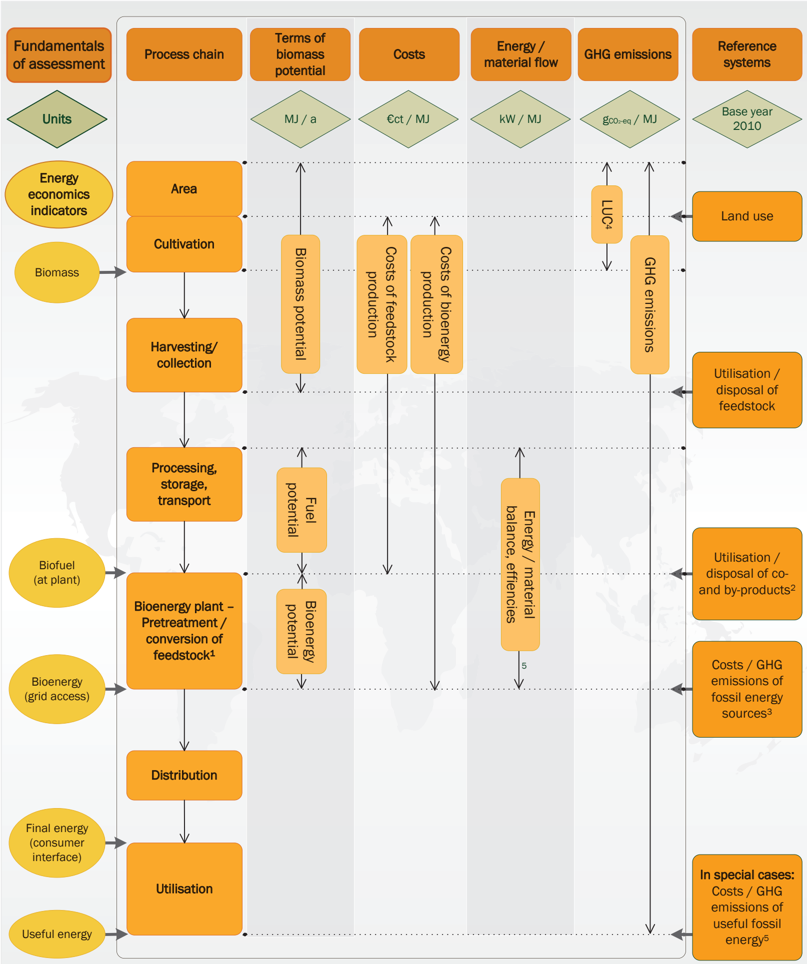
The process engineering **material and energy balances** are only prepared for selected questions regarding the conversion plant, and are relevant whenever process engineering improvements are the subject of the funding. They are limited to analyse the subsystem of the conversion process and therefore only describe a part of the supply chain.[5] The data generated are included in the cost and GHG accounts as parameters, some of which have multiple dimensions of meaning (e.g. methane can be a plant emission [greenhouse gas] or a product of the conversion process). Figure 7 (Chapter 5) shows a detailed scheme of the control volumes and indicators for the material and energy balancing for the production of final (end-point) energy sources in the funding programme.

[5] The technical analysis is limited to the conversion process, as the central issue within the funding programme. Technical analyses of technologies providing and using bioenergy fall under other programmes and are therefore not reviewed here.

In terms of **costs**, a differentiation is made between feedstock and energy production costs, considering the bioenergy plant as interface. In light of the programme´s objective, the cost calculation refers to bioenergy (at grid and / or at plant gate). To complete the supply chain from the feedstock to the useful energy, additional information would be necessary regarding the costs for using the grid, distribution costs, and operation costs, etc. However, since no significant differences are expected for the systems under review between fossil and biomass energy sources (e.g. power grid, gas grid, fuel distribution), these costs are considered to be identical and therefore do not need to be taken into consideration for the comparison. Accordingly, the fossil levelised costs of energy constitute a central reference value for the interpretation. An exception is made for small-scale furnaces in the assessment since, here, it is not possible to distinguish between final energy (heat delivered to the boiler) and useful energy (heat generated by the heating system). For these system concepts, which urgently require useful energy to be taken into account (especially in case of small-scale furnaces), the system boundary for **material and energy balances, costs and GHG emissions** has to be expanded uniformly to include biomass use (see Figure 3).

The **GHG emissions** are assessed along the whole chain from the provision of the biomass to the useful energy. Here, no useful accounting parameters can be presented for individual processes since the climate protection effects due to renewable energy sources only come into play upon their actual utilisation. A detailed figure of the control volumes and indicators can be found in Figure 14 in Chapter 7. This means that the technology-specific material and energy balances are expanded to include information regarding the provision of biomass and regarding the distribution and use of bioenergy. Furthermore, along the supply chain there are various essential influencing variables that are decisive for the result. These include both the feedstock side (utilisation of land and / or residues) and the by-product from the process, as well as the substituted energy sources (electricity, heat, fuel for transport). For these, reference systems are being formulated (Chapter 8). Based on experience, aspects of land use change (LUC) are highly relevant to results in this context, but should – in light of the programme's focus (utilisation of residues) – only require review in a few research projects. At present, unanimously acceptable methods for the quantification of direct land use changes (dLUCs) are only available for greenhouse gas accounting; these are taken into consideration below, accordingly.

The areas of assessment mentioned are thus marked by different system boundaries and interfaces. Generally, there is no lateral connection between the areas of assessment (i.e. the supply chains in the figure are to be interpreted strictly from top to bottom). For the results to be comparable (within the area of assessment and / or when different areas of assessment are merged, as in the environmental / economic analysis), the whole supply chain must be presented. For costs and GHG emissions, this is the case with the method selected here.



[1]... with further processing of biofuels where applicable
[2]... typically here, but where applicable also possible at another site
[3]... at generating plant (producer's price / import prices) at feed-in point (without distribution)
[4]... in the system considered here, LUC includes the direct land use change (dLUC). At present, consensual methods for the quantification of GHG accounting are available only for dLUC.
[5]... expansion of the system balance boundaries in special cases, e.g. small-scale combustion, in which utilisation takes place immediately after conversion.

Figure 3: System boundaries and elements (source: original illustration)

Energy reference value

(Solid, liquid and gaseous) biofuels are used to generate electricity, heat and fuels for transport. Fossil fuels are substituted on the one hand via the exchange of the primary energy source and, on the other via the bioenergy production utilising corresponding conversion technologies. While electricity and fuels for transport and also biomethane are similar to the fossil systems as energy sources and can therefore be utilised in similar systems, the technologies for generating heat from biomass and fossil feedstock do, however, differ. There are distinct differences, among other things, in terms of the conversion efficiency and the expenses for devices (e.g. pellet boiler v. gas-fired condensing boiler). Therefore, as an exception, the GHG emissions have to be set in relation to the useful energy for small-scale furnaces. For biofuels used for transport, the GHG emissions up to the final energy plus the GHG emission of a 100 % conversion in a vehicle have to be used to calculate the GHG mitigation costs.

Reference systems

Along the supply chain, different reference systems are relevant for the technical / economic / environmental classification of the concepts and processes for the bioenergy use. These include:

- Land reference (utilisation of crop land for energy crops): describes how the land is used when no biomass cultivation takes place on them
- Residues reference (utilisation of biogenic residues): describes how the residues are used / disposed of, if they are not used to provide bioenergy; alternatively, an potential analysis (Chapter 4) can be performed.
- Reference for the utilisation of co- and by-products (e.g. biomass glycerine in case of biodiesel production)
- Fossil reference (utilisation of solid, liquid and gaseous biofuels): describes the energy production that is replaced by the bioenergy

In light of the programme's focus, the residues reference and the fossil reference are particularly important, since they make a difference with respect to the efficiency of the greenhouse gas mitigations due to the use of biogenic residues for energy. They are, however, of different complexity and have been researched to a different depth so that, with the methodology presented, only the fossil references can be quantified comprehensively (for details, see Chapter 7).

Due to their suggested allocation among the by-products of a process, no reference is necessary for co-products.

Consolidation of the assessment parameters

If the interfaces are taken into consideration accordingly, the mitigation costs can be derived. We suggest following approach for calculating the greenhouse gas mitigation costs in the following formula:

GHG mitigation costs =

[(costs of bioenergy) – (costs of fossil reference[a])] / [(GHG fossil reference[b]) – (GHG bioenergy[b])]

[a] Fossil producer costs (c.f. Chapter 8 "Reference systems")

[b] In case of small-scale furnaces, the useful energy is to be used as a reference value for calculating the GHG emissions, whereas in case of biofuels for transport, the final energy plus the GHG emissions of a 100 % conversion in a vehicle are to be used, since it is only upon conversion into useful energy that all GHG emissions are released. The costs do not, however, need to be adjusted, since, for simplification purposes, the distribution of the fossil energy and bioenergy can be assumed to be similar.

3.4 Overriding assessment framework

3.4.1 Geographic reference

The reference framework for the calculations is Germany. In other words, values are based on a plant located in Germany and converting biomass into electricity and / or heat and / or fuel for transport. To achieve this geographic reference, the following adjustments are to be strived for:

- Local estimates of potential should – to the extent that this is possible and makes sense – be extrapolated to a German scale.
- For international estimates of potential, the potential availability for the German market should be categorised.
- To the extent that the establishment of the technology in Germany is envisioned, the framework conditions and market prices for Germany should be used as the basis in case of cost analyses. This may also include the fact that feedstock and / or fuel is procured via international markets.
- In case of the introduction of technology in an international context (e.g. biomethane from Eastern Europe), the production costs of energy relevant for Germany should be presented and – if possible – compared to the utilisations of local alternatives.
- With respect to the greenhouse gas accounting, Germany-wide data are generated for the fossil references. On a preliminary basis, the German electricity, heat and biofuel for transport mix will be discussed here. In part, this contradicts the comparators of the EU Directive.
- Additional effects (e.g. added value and evaluation of acceptance) are only calculated in individual cases (most often sample cases), since extrapolations are typically not possible.

3.4.2 Temporal reference

Reference point for the technical / economic / environmental analysis is the presentation of the hypothetical ACTUAL situation for the year 2010. Here, it is assumed that the system has been sucessfully developed and the researched technology has been launched onto the market, i.e. the analysis is based on a plant (plant X) that has largely been optimised in terms of technology and costs. As such, we are describing the technologies' theoretical greenhouse gas mitigation potential.

It is generally the case that the temporal reference of the calculations has to be indicated clearly. Depending on the types of project, they can reach into the past (statistical evaluations) or into the future (scenarios). The following are descriptions of the reference points in time that are preferably to be used as a basis.

Description of the ACTUAL situation:
When evaluating data, a reference point in time that is as current as possible is to be selected, ensuring that the data are very much up to date. This of particular relevance for the conclusions reached in cost analyses; ideally, the year 2009 / 2010 should be selected.[6] For most of the other analysis approaches, older data sets frequently have to be relied on, at least when using statistical data. Here, the most current version is to be selected in each case. In case of considerably varying parameters (e.g. harvest size) three to five annual averages are to be used, if possible, which means that it may not be possible to use the year 2009 / 2010.

Description of the development perspectives:
For the generation of scenarios and other estimates of future developments, three points in time[7] are suggested:

- 2020: Short-term outlook for the further expansion of the use of biomass
- 2030: Mid-term outlook
- 2050: Long-term outlook (optional)

The description of the development perspectives is relevant when identifying of the achievable greenhouse gas reductions.

3.4.3 Energy technology reference

To represent the energy technology indicators, various reference parameters are possible and established (e.g. inferior and superior calorific value). Below, the energy content of the biomass is presented as the inferior calorific value H_i while at the same time specifying the moisture content. Similarly, the fossil reference systems are presented relative to the **inferior calorific value H_i.** As a result, uncommon values result for sub-areas; at the same time, error sources that occur when using differing reference systems are drastically reduced.

[6] It is therefore also expected that the effects of both the high price phase and the financial crisis will not have an appreciable impact on the results.

[7] The term "reference point in time" is not being chosen here, because in the EU RED and the BioSt-NachV the term "reference year" and / or "reference point in time" is already in use and refers to the year 2008 (January).

The thermal, chemical and electrical net plant efficiency are general process indicators that are to be used to compare differing technologies (e.g. gasification and anaerobic digestion) since these are calculated with reference to the inferior calorific value.

These process-specific indicators exist in all three areas of technology (combustion, gasification, anaerobic digestion). The cold gas efficiency, for example, is a process-specific indicator that can only be used to compare gasification systems.[8]

3.4.4 Sustainability requirements

The objective of a sustainable production and use of bioenergy is to achieve positive effects for climate protection (reduction of greenhouse gases) and for agriculture (employment, sources of income). Moreover, at the same time, the aim is to avoid negative effects that may occur in biomass cultivation, in particular on areas with high carbon stock and with high biological diversity.

At the EU level, sustainability requirements are defined in accordance with the Renewable Energy Directive (EU RED, Art. 17) which was implemented in Germany in the BioSt-NachV, for example. These requirements are to be considered as minimum standards. To achieve comparability between studies, results should accordingly be listed based on these assumptions. In addition, it might be quite worthwhile in certain scenarios and variants to apply more ambitious standards than the requirements specified in the laws (e.g. social standards in accordance with the Round Table on Sustainable Biofuels, RSB).

The sustainability requirements are considered to be mandatory, initially in the transport sector for biofuels (liquid and gaseous) as well as for any use of bioliquids in other sectors (e.g. power generation), and precisely when the biomass is referenced to assess the adherence to national objectives and / or obligations regarding the utilisation of renewable energy (e.g. admixture quota) or when financial funding is provided (e.g. EEG).

To date, the application of the sustainability requirements of the EU RED is not mandatory for solid and gaseous biofuels. The European Commission does, however, recommend that member states use the same sustainability standards for solid and gaseous biomass as for liquid biomass (EU COM 2009). For this reason, the sustainability requirements of EU RED[9] are utilised as a minimum standard for all biofuels within the framework of the funding programme "Biomass energy use". Deviations must be marked accordingly.

The sustainability requirements in accordance with Art. 3 of the EU RED are summarised in Table 1. On the one hand, they include requirements regarding the reduction of greenhouse gas emissions, and on the other area-related requirements.

[8] For details see Chapter 5.

[9] Including the specifications for GHG accounting for solid and gaseous biofuels.

With respect to the greenhouse gas reductions, GHG mitigation of 35 % relative to the final utilisation are to be achieved. For old plants, this reduction does not become effective until April 1, 2013 (portfolio protection). This value will be increased to 50 % in 2017 and to 60 % in 2018. In this respect, the required greenhouse reduction in comparison to the fossil reference has to be proven.

Table 1: Sustainability requirements in accordance with BioSt-NachV (2011) and Biokraft-NachV (2012)

Area-related requirements for energy crop production	GHG minimum requirements for the final utilisation in comparison to fossil fuels
On the following areas, the biomass may not be cultivated or only with restrictions:	From 2010 on, at least 35 % (in case of old plants, from 1 April 2013 on),
1. Protection of areas with a high value with respect to biological diversity: - Primary forest and other wooded areas; completely protected - Areas serving nature conservation purposes (protected areas as well as areas still to be listed for the protection of rare, threatened or endangered ecosystems or species); biomass production may not run counter to the nature conservation purpose - Natural grassland with great biological diversity; completely protected - Artificially created grassland with great biological diversity; harvesting of the feedstock is necessary to retain the grassland status	From 2017 on, at least 50 % From 2018 on, at least 60 % for new plants that have become operational since 2017 Adherence to at least specific standard values at each stage of the manufacturing and delivery chain
2. Protection of areas with high carbon stock: - Wetlands; despite biomass production, the status must remain preserved - Contiguously wooded areas; despite biomass production, the status must remain preserved - Areas with a canopy degree of 10 - 30 %; despite biomass production, the status mus remain preserved; unless the utilisation of the cultivated bioenergy shows a positive GHG balance	The comparators for biofuels and bioliquids are: - Petrol / diesel: 83.8 $g_{CO2\text{-}eq}$/MJ for utilisation as fuel for transport
3. Peat bog: Cultivation and harvesting of the respective feedstock must not require previously non-drained peat bog areas to be drained	- 91 $g_{CO2\text{-}eq}$/MJ for power generation[10] - 77 $g_{CO2\text{-}eq}$/MJ for heat generation
4. Sustainable agricultural management within the EU: - Adherence to Cross Compliance - Adherence to minimum requirements for the areas to be in a good agricultural and ecological condition	- 85 $g_{CO2\text{-}eq}$/MJ for combined generation in cogeneration plants

[10] This reference value is considered to be a comparator for the use of bioliquids and biofuels for power generation. A value of 177 $g_{CO2\text{-}eq}$/MJ can be assumed to be typical of the German electricity mix (EU RED 2009).

Area-related requirements adress the protection of areas with great biological diversity, areas with high carbon stock and peat bogs as well as agricultural utilisation in the European member states. Areas with great biological diversity include primary forest and wooded areas, areas serving nature conservation purposes (protected areas and areas still to be listed for protection or rare, threatened or endangered ecosystems or species) and grassland with great biological diversity. Specifications are still beeing formulated on a European level, in particular regarding grassland.[11] In Germany, a detailed specification regarding types of areas has already been undertaken in connection with the funding of electricity from liquid biofuels, but this will have to be adjusted, if necessary.[12]

Listed as areas with high carbon stock are wetlands, wooded areas and areas with a canopy of 10 - 30 %. In addition, there are peat bogs that are characterised by both a high biological diversity and a high carbon stock. The EU Commission published specifications regarding these types of areas in June 2010[13] (see also the Guidelines on Sustainable Biomass [Leitfaden Nachhaltige Biomasse], BLE 2010).

Biomass production is only completely prohibited in primary forests and other wooded areas, as well as on natural grassland areas. For the other protected types of area, the fundamental requirement is that the protection purpose be maintained in case of biomass production (c.f. Table 1). In addition, within the EU, sustainable cultivation is required in accordance with the cross compliance rules and good professional practice. Outside the EU, no requirements are set regarding the conditions of cultivation.

3.4.5 Presentation of results

The results of the accounting of greenhouse gas effects based on the material flow are typically presented as a short description of the technical system[14] with respect to:

- Efficiency (in %), stating all reference parameters
- Land requirements per unit of final energy provided, where applicable
- Cost per unit of bioenergy provided (for small-scale furnaces: useful energy)
- GHG per unit of useful energy provided
- GHG reduction costs per bioenergy unit (except for small-scale furnaces and biofuels for transport, in which case it is per useful energy unit)

All energy value results are given in joules. In addition, further metrics and units commonly used among experts may be used (e.g. kWh, t_{COU}, etc.).

[11] Draft Consultation paper definition [of] highly biodiverse grasslands (EU COM 2010b).
[12] Leitfaden Nachhaltige Biomasse [Guidelines on Sustainable Biomass] (BLE 2010).
[13] Communication from the Commission on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels (EU COM 2010c).
[14] In the spirit of the programme objective, this is generally the centre of the respective project: c.f. www.energetische-biomassenutzung.de/de/vorhaben.html

Additionally, for the concepts investigated, the reference systems for the provision of the feedstock and the final energy generated are to be specified:

- For the feedstock, it must be specified which technical potentials are available (in PJ/a) and / or which uses / disposal these would alternatively have been subject to. This includes land use in case of energy crop production (land reference) as well as collection and treatment steps for the utilisation of residues (e.g. communal collection and composting, disposal in the non-recyclable waste fraction, staying on the field, etc.) (residues reference)[15]
- For the bioenergy generated, the reference utilisation is to be stated and supplemented by information regarding the costs relative to the final energy and greenhouse gas accounting relative to the useful energy. To do so, standard values are suggested (Chapter 7: Methodology for assessing greenhouse gas emissions and additional emissions).

The following have to be included as relevant reference systems:

- The feedstock side references (land reference and residues reference) in descriptive form. Comprehensive presentations offer corresponding analyses of potential; alternatively, the essential paths of the reference utilisation may also be described (e.g. use of animal residues as fuel in the cement industry). A quantification of the costs and GHG effects of these references would be desirable, but is not promising considering the present state of knowledge.[16]
- The energy side reference is quantified based on indicators for fossil fuels (GHG accounting and costs). The basis for the specification of these references is the current German energy mix.[17]

Furthermore, all results must be accompied by notes on when a deviation was made from the suggested approach, and – if possible – an estimation of what effect the modification has on the result (Sample phrasing: "As this based on 6,000 full utilisation hours instead of 8,000 full utilisation hours, the levelized costs of energy are approx. 10 % higher.")

[15] A quantification of the costs and GHG effects of these references would be desirable, but is not promising at the present state of knowledge. For a comprehensive analysis, it would also be necessary to report the greenhouse gas emissions of the reference systems on the feedstock side. In this respect, the reductions related to material flow (e.g. in $t_{CO2\text{-}eq}/t_{ds}$ of treated residue) and those related to energy (e.g. in $t_{CO2\text{-}eq}$/GJ of bioenergy) are relevant to the assessment. The opportunities and limits of such an assessment are to be determined as part of the working group on Life-cycle Assessments.
[16] For a comprehensive analysis, it would also be necessary to report greenhouse gas emissions of the reference systems on the feedstock side. In this respect, both the reductions related to material flow (e.g. in $t_{CO2\text{-}eq}/t_{ds}$ of treated residue) and those related to energy (e.g. in $t_{CO2\text{-}eq}$/GJ of bioenergy) are relevant to the assessment. The opportunities and limits of such an assessment are to be determined as part of the working group on Life-cycle Assessments.
[17] Here, too, methodological discussions are still taking place as part of the working group on Life-cycle Assessments.

4 Methodology for determination of biomass potentials

4.1 Background

The opportunities for the utilisation of biomass in energy systems are considerably determined by the available potentials. Therefore, in several projects, questions regarding the feedstock availability are also discussed. Potential studies often arrive at different results due to differences and heterogeneity of parameters such as:

- the biomass fraction under review (agricultural and silvicultural biomass, residues and wastes)
- the definition of potentials
- the geographic level (local, regional, global)
- the temporal reference
- the type of data collection
- the methodology applied

In addition, the systematisation and terminology of the biomass fraction, data, units and conversion factors used as well as scenario assumptions and framework conditions may lead to deviations between the calculated potentials. Furthermore, additional causes for disparities between the results are different assumptions regarding competing area and biomass utilisations (sustainability aspects, nature conservation issues, material utilisation, etc.), (Koch 2011).

To increase the comparability and accuracy of studies of potential in the funding programme "Biomass energy use", a harmonisation of the definitions and documentation is needed. Due to the diversity of biomass categories described above, a standardised methodology for all biomass fractions cannot be provided, but some definitions, the type of documentation and the approach can be standardised.

The objective of the harmonisation of methods is not only relevant for the funding programme, but was also pursued at the European level. In the BEE project (c.f. BEE 2009), a handbook for the harmonisation of the analysis of biomass potential was created which describes definitions, methodological suggestions and basic data for different sectors (Vis & Berg 2010). Essentially, the terminology used in this document corresponds to that of the European method handbook.

4.2 Definitions of biomass potential

4.2.1 Level of biomass potential assessment

Biomass potential can be defined differently depending on the level of perspective. As such, initially a differentiation is made based on the level at which the determination of potential is performed. The potential can be described as land, feedstock, fuel, or bioenergy potential (c.f. Figure 4).

The land potential describes how much land is available for a specific biomass, e.g. energy crops on arable land or silvicultural biomass. Based on this information, the amount of biomass that can be used as feedsock can be deduced from yield data. Additionally, residues may represent a feedstock potential that does not feature any land relevance. The **feedstock potential** can be stated in tonnes (t) of feedstock.

Vegetable feedstock can feature very differing substrate characteristics and is therefore also suitable for different conversion paths. Closely related to this is that the cost of processing the biomass also varies considerably. Woody biomass can be utilised for energy via minimal processing, whereas biomass with higher moisture content can only be utilized for energy after conversion. The product of the more or less complex processing and / or conversion of the biomass is a solid, liquid or gaseous biofuel. The **fuel potential** specifies the energy content, typically presented relative to the inferior calorific value of the available biofuels.

There are different options for utilisation (electricity, heat, fuel for transport) for different biofuels. The **bioenergy potential** reflects the share of final energy that is provided in the single utilisation pathways after the conversion.

4.2.2 Theoretical, technical, and economic potential

The determination of potentials requires the definition of system boundaries and framework conditions. Therefore, in most of the studies to date adjectives such as “theoretical”, “technical”, or “economic” are used to concret terms of potential. The potential terms used in the following are based on the definitions of Kaltschmitt and Hartmann (2009), which essentially correspond to the definition suggestions of the BEE project (Vis & Berg 2010). These definitions are an orientation to categorise the project results that are achieved as part of the funding programme more clearly.

The **theoretical potential** is the theoretical energy supply in a given region that can be used physically within a specific period of time (e.g. the energy stored in the whole plant mass). It is determined solely by the given physical utilisation boundaries and thus delineates the upper limit of the theoretically realisable energy supply. Since the theoretical potential often can only be tapped to a very small degree due to certain restrictions, it is of no practical relevance in the assessment of the actual usability of the biomass.

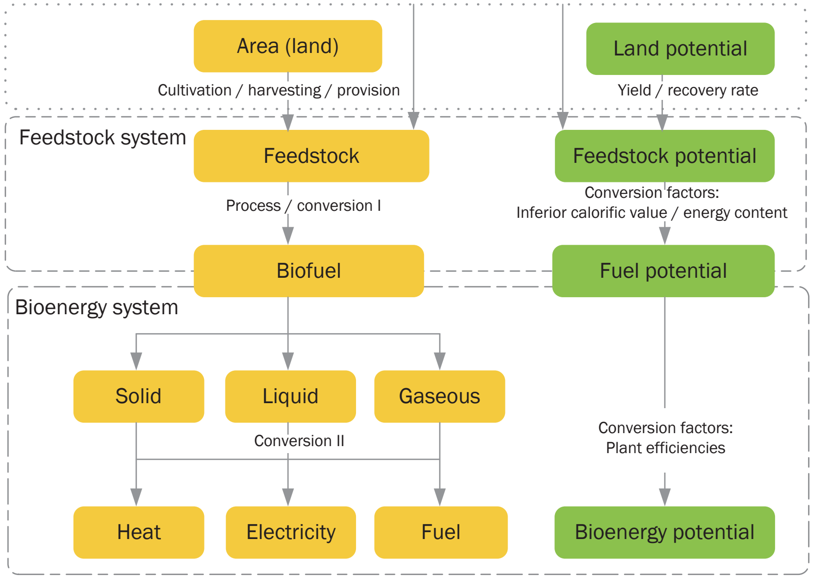


Figure 4: Presentation of the different levels of the utilisation pathway and the corresponding terms of potential. Conversion I: Processing of the feedstock (pelletising, pyrolysis, methanisation, etc.); Conversion II: conversion of the biofuel into energy (combustion in C(H)P, BMC(H)P, engines, etc.) as well as processing into biofuels for transport (source: orignial illustration)

The **technical potential** describes the portion of the theoretical potential that can be used, taking into account the given technical restrictions (e.g. recovery rates, conversion losses). Additionally, the given structural and legal environmental or other limitations are taken into consideration since they are regarded, similar to the technical restrictions, as "insurmountable" (e.g. legally [nature] protection areas, legally / administratively: cross compliance regulation, societal: considering food production and material utilisation). As a result, it describes – primarily from a technical point of view – time and location dependent, possible contribution of the biomass to energy supply. Since the technical potential is considerably influenced by the technical framework conditions, it is, for instance – contrary to the economic potential – considerably less subject to temporal fluctuations. Therefore, the technical potential is quite often presented in studies.

The **economic potential** describes the time and location dependent portion of the technical potential that can be tapped economically under the respective economic framework conditions (including subsidies or apportionment systems such as the EEG). Since the economic framework conditions are subject to short-term changes (e.g. change of the oil price, change of opportunities for tax depreciation, energy tax, eco tax, or CO_2 tax), the economic potential is subject to considerable temporal fluctuations.

From the theoretical to the technical to the economic potential, restrictions progressively become tougher and hence the economic potential only constitutes a portion of the theoretical potential (c.f. Figure 5).

To demonstrate the effect of other restrictions that are taken into consideration in determining the potential, additional terms of potential are used in projects and publications additionally to the theoretical, technical and economic potential.

If typically ecological and environmental factors have been considered with greater importance, this is referred to as an (environmentally) **sustainable biomass potential**. The sustainable potential takes into consideration additional specific aspects of nature conservation discipline, landscape aesthetics and resource protection (e.g. sustainable silvicultural potential, sustainable straw potential). In case of a consistent integration of sustainability aspects into the determination of technical potentials, sustainable and technical potential are congruent.

The **realizable (available) potential** describes the actual contribution to the energy supply. This potential depends on numerous additional socio-political and practical framework conditions. An economic potential becomes realizable (available) only when actors come together and all parties affected have approved of the project. The realizable (available) potential does not necessarily correspond to the economic potential.

These remarks illustrate that definitions of potential and terms of potential always have to be made more precise in the context of the questions.

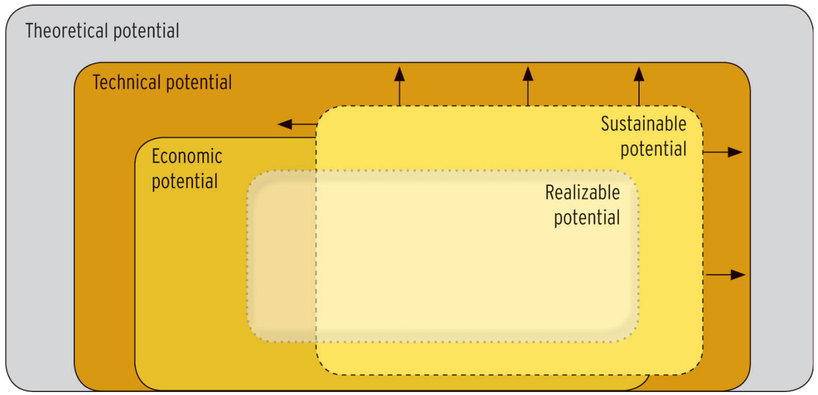


Figure 5: Schematic presentation of the different types of potential and their relationship to one another (source: originial illustration)

4.3 Methodology

The main question of the project determines the types of biomass potential and the degree of detail for potential calculation. In comparison to the theoretical potential, the technical potential has a stronger practical relevance and is compared to the economic potential subject to less fluctuations. Sustainably realizable (available) potentials definitely have the largest information character, but they cannot be calculated in all projects for all biomass fractions in Germany without considerable effort.

In light of the programme's objectives it is therefore recommended to assess and / or list the technical potential in addition to the approach selected in the respective project in order to allow for as much comparability between the projects as possible.

Since there is no standardised methodology for the calculation of the technical potential and since the "insurmountability" of the limitations models itself after the respective question, the region to be investigated, the considered biomass fraction and – wherever applicable – the scenarios used, it should at least be shown clearly which restrictions were taken into consideration at which scope.

Of particular importance is the question of how the material and other competing utilisations of biomass are dealt with. Current or future pathways of biomass utilisation (e.g. composting of biowaste) and food safety considerations, wherever relevant (e.g. for agricultural biomass), should be included in the study. In accordance with the definitions described above, it is recommended to take the following restrictions into consideration in the determination of technical potentials:

- Societal variables (as general agreement whether certain feedstock should receive a generally preferred form of utilisation)
- Demand for food and material utilisation
- Technical variables (cultivation, harvest, recovery and conversion technology)
- Ecological / environmental variables (legal requirements to ensure a sustainable resource base).

Other decisive factors for the results include the type and scope of the biomass under consideration and the approach of data collection. The latter can be performed via direct collection from biomass producers (or residues producers) or be derived from statistical data or applied from availability factors for residues. Generally, it should be presented in the form of a documentation list that includes the biomass fractions and restrictions considered in the determination of the technical potential. Thus, more transparency should be provided. The following documentation lists I and II (Table 2 and Table 3) show the most important factors that lead to deviations between the results and illustrate which sustainability aspects were taken into consideration in the determination of the potentials. Therefore, all results of potentials should be documented with these lists, wherein influencing variables that were not captured are to be supplemented. Furthermore, it should also be specified which parameters varied in the scenario analyses.

Table 2: Documentation list I for important influencing variables for the determination of the biomass potential

Biomass fractions based on origin: (technical, economic, etc.):		**Type of potential**	
Residues from		**Geographic level (country, federal state etc.):**	
Forestry	☐		
Agricultural production	☐	**Temporal reference:**	
Food processing	☐		
Landscape management	☐	**Data collection:**	
Wastes (waste wood, biowaste, etc.)	☐	Acquisition of primary data	☐
Energy crops	☐	Use of statistical data	☐
Other (e.g. algae):		Other:	
Qualities:		**Methodology:**	
Woody biomass	☐	Statistical	☐
Stalk-like biomass	☐	Geographically explicit	☐
Biogas substrates	☐	Cost-supply	☐
Other biomass:		Other:	

Table 3: Documentation list II for important influencing variables for the determination of the technical biomass potential

Supply chain	**Influencing variables**	**Taken into consideration**		
Technical		*(yes*	*/ no*	*/ varies)*
Cultivation	Is average arable land assumed to be available for cultivation (with corresponding yield expectations)?	☐	☐	☐
	Is additional land brought into utilisation (fallow areas / marginal areas)?	☐	☐	☐
	Are changes in the housing systems of the animal production assumed?	☐	☐	☐
	Which type and efficiency of animal housing was set?	☐	☐	☐
	Are conventional use of machines, conventional farming systems and fertiliser use assumed (with corresponding yield expectations)?	☐	☐	☐
	Is a technological learning curve assumed in case of future potentials?	☐	☐	☐
	Are additional catch crops taken into consideration?	☐	☐	☐
	Are multi-year crops taken into consideration?	☐	☐	☐
	Are changes in silviculture and / or the development of certain rough wood assortments assumed?	☐	☐	☐

Supply chain	Influencing variables	Taken into consideration
Technical		*(yes / no / varies)*
Provision	Are the typical silvicultural management practices assumed for the silvicultural management practices?	☐ ☐ ☐
	Have (especially in case of the potentials of residues) source-specific restrictions been taken into consideration (e.g. quantities that are too low or too irregular at some point)?	☐ ☐ ☐
	Have regional and / or seasonal fluctuations been taken into consideration (e.g. multi-year averages in case of the yields of energy crops)?	☐ ☐ ☐
	Have losses in harvest, storage, transport been taken into consideration?	☐ ☐ ☐
	Has a (technical) drying of the biomass been assumed (in case of a thermo-chemical provision of the biofuels?	☐ ☐ ☐
Conversion / Utilisation	Have efficiencies (utilisation factor) of the conversion been taken into consideration?	☐ ☐ ☐
	Has the state of technology been assumed or have optimised technologies been considered?	☐ ☐ ☐
	Has the intrinsic energy demand of the conversion been taken into consideration in the biofuel potential?	☐ ☐ ☐
	Are residues from the biofuel production (e.g. straw, press cake, distiller's residues) also added to the potential?	☐ ☐ ☐
Societal		
Cultivation / Provision	Has the food supply at point in time X in the region been taken into consideration?	☐ ☐ ☐
	Has the food supply at point in time X been taken into consideration globally?	☐ ☐ ☐
	Has the material utilisation of RenFe or residues at point in time X in the region been taken into consideration?	☐ ☐ ☐
	Has the material utilisation of RenFe or residues at point in time X been taken into consideration globally?	☐ ☐ ☐
	Have the existing paths of energy utilisation of RenFe / residues been taken into consideration? (if so, please specify whether via statistics or via the portfolio of systems)	☐ ☐ ☐
	Have direct / indirect land use changes been taken into consideration?	☐ ☐ ☐
Conversion / Utilisation	Is the mix of potentials of the biofuels modelled after the objectives for bioenergy, biofuels for transport, etc.?	☐ ☐ ☐

Supply chain	Influencing variables	Taken into consideration
Environmental		*(yes / no / varies)*
Cultivation / Provision	Have the requirements in accordance with the EU RED and / or the national implementations (GER: BioSt-NachV, Biokraft-NachV) been taken into consideration as a restriction in the determination of potentials?	☐ ☐ ☐
	Have the requirements in accordance with the national nature conversation law (Federal Nature Conservation Act) and international agreements (e.g. Natura 2000, Ramsar, CBD, etc.) been taken into consideration?	☐ ☐ ☐
	Have the water pollution prevention requirements been taken into consideration?	☐ ☐ ☐
	Have further ecological requirements regarding the cultivation been assumed based on the state of research / beyond the sate of research (e.g. sizes of areas, sequence of crops, etc.)?	☐ ☐ ☐
	Have organic farming and its further expansion perspectives been taken into consideration?	☐ ☐ ☐
	Have the soil conservation requirements (e.g. protection against erosion, humus reproduction) in accordance with cross compliance been taken into consideration?	☐ ☐ ☐
	Has adherence to cross compliance regulations (esp. preservation of grasslands) been assumed?	☐ ☐ ☐
Conversion / Utilisation	In the selection of the conversion pathways, has the achieving of the required GHG reduction (in accordance with EU RED) been assumed?	☐ ☐ ☐
Administratively		
Cultivation / Provision	Are import restrictions (duties, etc.) included in the considerations?	☐ ☐ ☐
Conversion / Utilisation	Has it been taken into consideration if a new conversion plant can be approved?	☐ ☐ ☐
	Has the certifiability of the generated biofuels (in accordance with EU RED) been taken into consideration?	☐ ☐ ☐

Where applicable, additional influencing variables that were paid attention to

4.4 Presentation of results and further processing

The technical potentials can be listed as fuel and / or bioenergy potentials in units of energy, preferably in PJ/a.

For illustrative purposes and comparability, it may be useful to present the potentials graphically (e.g. diagrams) and – wherever applicable – cartographically.

The degree of detail of the presentation depends on the question and methodology of the determination of the potentials. A modern geographic information system (GIS) provides comprehensive options for further processing beyond the sole presentation of the results. Figure 6 presents one example of such an evaluation for straw potentials. At the top left, the results of potentials are shown on a rural district level. Utilising high resolution geodata (e.g. ATKIS[18]) and a suitable methodology of evaluation, the potentials of the arable land can be assigned and further processed (Figure 6, top right). With the help of this data foundation, it is, for instance, possible to determine the degree of potential for a freely selectable site (Figure 6, bottom left). Furthermore, corresponding areas of preference can be derived for different questions and framework conditions (Figure 6, bottom right).

[18] TCIS (ATKIS) = Official Topographic-Cartographic Information System (Amtliches Topographisch-Kartographisches Informationssystem)

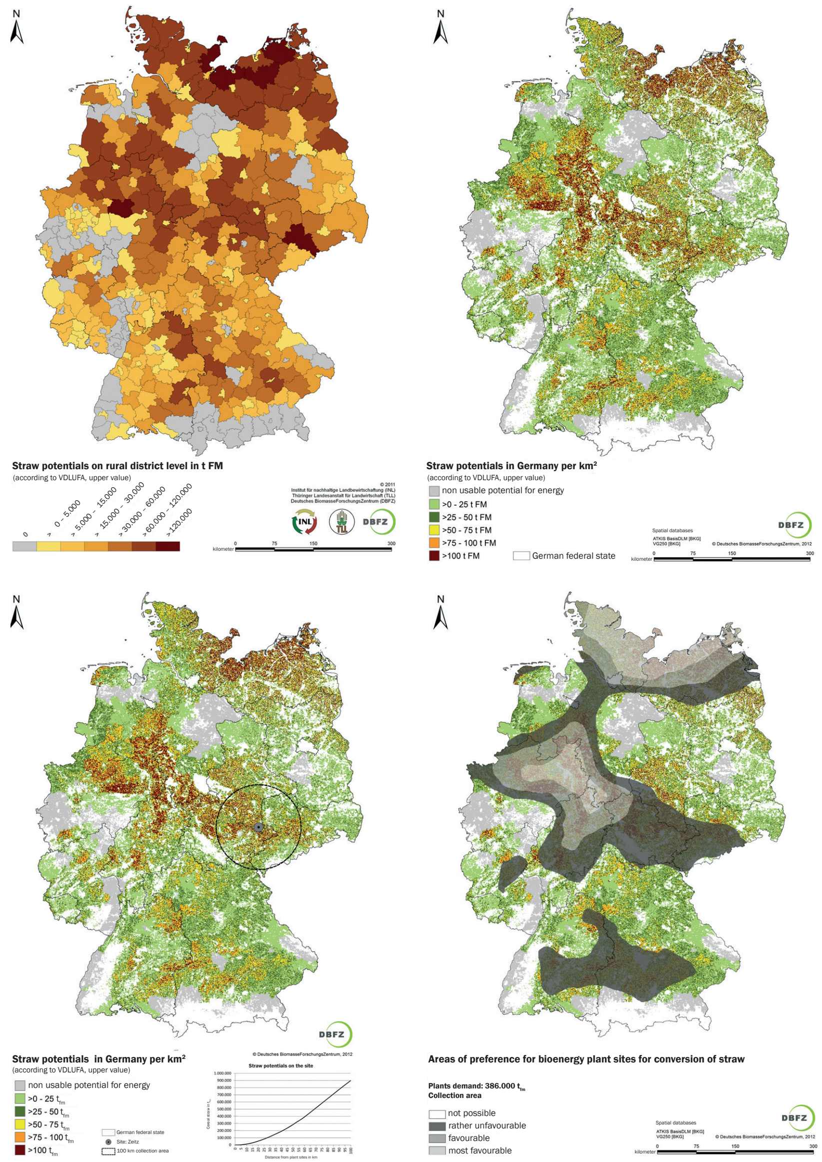


Figure 6: Examples for possible GIS-based presentations and processing of results (source: original illustration)

5 Methods for balancing the energy and material of the conversion process

5.1 Background

Providing bioenergy from biomass involves conversion processes that are characterised by the input and output of material and energy flows. Materials entering and exiting the system (as well as non-material energy forms such as electricity and heat) incur costs, affect revenues and are associated with environmental impacts. As such, balancing the energy and material used for the conversion process is a prerequisite for the economic and environmental analysis of the overall chains, as described in the chapters below.
Furthermore, knowing the input and output of the systems under review allows us to calculate indicators with which the conversion process can be characterised and optimised technically and in terms of energy. The indicators used here are based on material and energy balances and are primarily intended for further development of the individual technology groups (combustion, gasification, anaerobic digestion) and not for cross comparisons between them. For such cross comparisons, another reference base should be selected. Chapter 5.5 “Superior and inferior calorific value - A look at the balancing effects” offers an detailed description of the impact of using the inferior and superior calorific value as a reference value for plant indicators (efficiencies) and thus provides more information on this.
Focussing on how the production and use of bioenergy can affect the climate brings into the foreground the aspects associated with the largest climatic effects.
On the one hand, there is the question of cutting greenhouse gas emissions. The output of greenhouse gases can be reduced by substituting fossil fuels with biomass. This substitution is performed on the one hand by replacing the primary energy source and on the other hand by providing bioenergy utilising corresponding delivery technologies. In this context, optimising the use of bioenergy means that the limited resource of biomass is preferably used in conversion processes which make extremely efficient use of energy resources and provide useful energy whose generation by other means is associated with high GHG emissions. In this context, it is the objective of this method handbook to harmonise the record of the energy flows entering and exiting the system, or the energy conversion efficiencies among the different projects.
On the other hand, some of the conversion processes investigated, such as the production of biogas and biomass gasification, are associated with the production of methane which is emitted e.g. through leaks, diffusion and motor slip. Since methane has a larger greenhouse gas impact than carbon dioxide, the resulting climatic effect is not compensated for by the carbon uptake during the growth of the biomass, but rather has to be taken into consideration additionally. To be able to determine the climatic effect of the processes investigated, the methane emissions resulting from them have to be recorded as fully as possible. In this context, the objective of this method handbook is firstly to use data collection sheets and documentation lists to reveal what methane emissions are generated in the individual conversion processes and can be taken into consideration.

5.2 General methodology

The balancing is structured into two sub-systems: material and energy balancing. Mixing the parameters of the two balance areas when setting up of the sub-systems must be avoided.
The approach involves creating a cumulative view of all flows both entering and exiting the system.

Table 4: Material and energy flows that are taken into consideration in the balancing of the technical processes

Material flows	Input	Biomass: substrates / fuels
		Auxiliaries / inputs (operating resources)
	Output	Products / by-products
		Exhaust / emissions / losses
		Residues: ash / sewage / digestate / filter residues
Energy flows	Input	Chemical and thermal power of the fuels / substrates / auxiliaries / inputs (operating resources) / power delivered
		Auxiliary energy from fossil fuels
	Output	Electricity (electrical energy)
		Heat (thermal energy)
		Chemical and thermal power of the products, by-products and residues

5.2.1 Units used for mass and temporal reference

In general, the units of the SI system are to be applied when characterising the material flows, meaning kilogrammes (kg) for the specification of mass and seconds (s) for the temporal reference. Since the input / output balances of biomass conversion plants are generally calculated over longer periods of up to one year, and since the use of the unit kg/s does not provide a good visualisation of the plant's throughput, material flows are specified in kg/h and /or t/d.

5.2.2 Balancing the material

As a rule, particular attention should be paid to record methane emissions resulting from the process, in addition to capture the important material flows of fuel, products (including by-products), inputs (operating resources), auxiliaries and residues. The essential sources of emissions are diffusion losses and leakages not olny in standard operations but also in case of start-up processes and process disruptions in the area of gas generation and intermediate storage. A further emission source is the methane slip in case of motor fuel gas utilisation or in case of anaerobic digestion plants (AD) the digestate and the gas losses via the fermenter, respectively. Methane emissions recording has to be reviewed on a case-by-case basis since, based on the state of knowledge to date, no harmonisation of methods exists or is possible. Therefore, the way in which they are taken into consideration for each main process has to be documented in accordance with the respective system boundaries for the material and energy balance.

5.2.3 Balancing the energy

Energy balances for technical systems present the amounts of energy flowing into and / or from a system in a specific period of time in case of both stationary and mobile operation. Prior to the preparation of balances for an energy technology system, the balancing groups have to be clearly spacially demarcated and this information documented. At the same time, in addition to the geographic demarcation, the material and temporal limits must be specified. Which geographic, material and temporal balance boundaries are selected for certain purpose depends considerably on the question and the systems under review. (VDI 4661 2003)
In the funding programme, energy accounting is set up accordingly as a stationary energetic balance carried out during the rated operation of the whole bioenergy plant and its main components. Here, the indicators and efficiencies to be provided are determined by the type of conversion process. For operating production plants, an annual balance of the whole bioenergy plant should be prepared additionally which presents the annual total of the energy flows that were received and delivered.

5.3 Assumptions and framework conditions

The material and energy flow balancing is based on a definied energy balance scope and the capturing of all inputs and outputs. The required data can be obtained via direct measurement (measured values), calculation from indirectly measured variables (derived values), and via the closing of the balance (differential values).
Under the funding programme, a simplified model as shown in Figure 7 has been defined to harmonise the methods. All projects that investigate a certain technology have to perform a technical assessment in the form of material and energy balancing based on this model. In this context, only products with a traceable path of energy utilisation or a subsequent composting are to be considered as products or by-products of the bioenergy plant. The energy (thermal, chemical) contained in residues also has to be entered as a loss into the energy balance, if it can be recorded using measuring technology or determined by indirect means.

5.4 Data collection and presentation of results

In the technology-specific projects, the data is collected and the results presented with the help of a data collection sheet and a documentation list which differ for combustion, gasification and ADs. They contain entry fields for the necessary material and energy flows and the calculated indicators, but do not make any claim to completeness. In addition to the absolute numeric values, the type of data collection – measured values, derived values, difference values, or assumptions – is also recorded on the data collection sheet and the documentation list. This is intended to document the material and energy flows as well as the balance indicators transparently and comparably for technologies within one type (e.g. gasification plants) or between different technologies (e.g. gasification and AD plants).

APPENDIX II contains lists for collecting the data necessary for balancing the material and energy flow of the individual areas of technology. The necessary balance indicators must be documented in the first two tables. To illustrate the certainty of the data, the table consists of two parts. The first part is for entering the balance indicators and the second part is for the individual material and energy flows with which these were calculated. Through the addition of the material and energy flows for input and output, the plausibility of the data can very easily be checked and presented transparently. Another point in this context is to specify the boundaries of the balance to which the plausibility check refers. Only the fields shaded in grey have to be filled with the data on the respective system, and the remaining values have to be supplemented via calculation. To make the data collection easier, the data collection sheets and documentation lists in APPENDIX II can be downloaded from the website of the funding programme "Biomass energy use" at www.energetische-biomassenutzung.de. This also contains examples of completely filled-in data collection sheets for each technology field. These are intended to illustrate the use of the data collection sheet and the importance of the "Explanation of data origin".
The symbols and indexes, to the extent that they are not self-explanatory, as well as the calculation rules for efficiencies, losses and balance indicators, correspond to the definitions from Section 3.2.4 as well as the tables for the following areas of technology: combustion (Table 5, Table 6), gasification (Table 7, Table 8) and anaerobic digestion (Table 11, Table 12, Table 13).

The tables present the balance elements, the calculation approaches for the balance parameters and guide values for input parameters, respectively. As well as calculating the plant parameters in a standardised manner, it is also neccessary to determine the individual parameters in a suitable, standardised manner in order to be able to acquire comparable data. Furthermore, if possible, the potential measuring error and an error review should be performed for each individual calculable value (input parameter). However, in practice, this is not always applicable to all parameters. To further harmonise the approach used for the technical assessment of bioenergy plants, Table 6, Table 8 and Table 12 present guide values for determining different input parameters relevant to the balancing. Where possible, additional substitute values (default values) have been suggested for parameters if it is not planned for or not possible to determine the parameters as part of the project. Since other technologies involve other material and energy flows, a separate review is necessary for other plants (plant concepts).

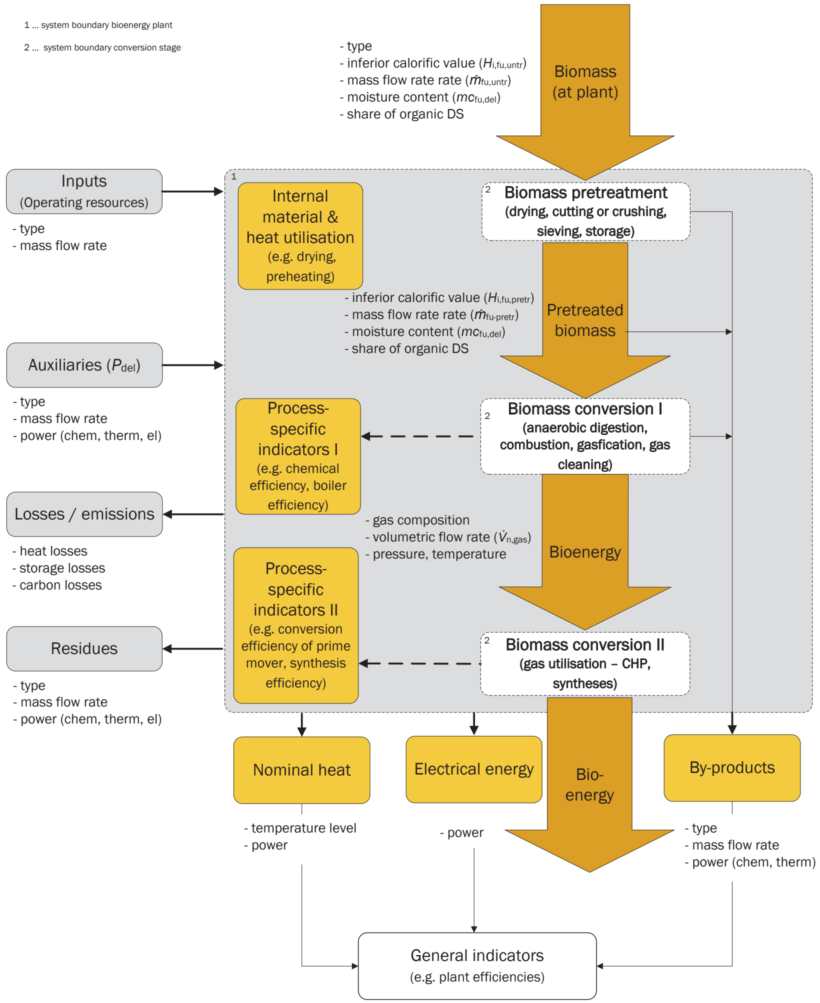


Figure 7: Technology-independent representation of the accounting limits and indicators for balancing the material and energy involved in the energy production from biomass (source: orginal illustration)

5.4.1 The technology field of combustion

Almost half of the heat generated from renewable energy sources comes from using biogenic solid fuels in private households (BMU 2012). Small-scale biomass combustion systems therefore make a crucial contribution towards reducing anthropogenic CO_2 emissions and as such also constitute the focal point of the following remarks. The peculiarities in case of biomass-fired combined heat and power stations are not presented. Energy and material flow balancing in case of plants with greater thermal and electrical power is more complex and should be reviewed separately. Figure 8 provides an overview of relevant indicators and control volumes that are of importance when assessing the efficiency of small-scale furnaces. The conversion is characterized by input and output materials, by different conversion stages, by emissions, residues and corresponding conversion losses. The figure is intended to illustrate the connection between the issues mentioned.

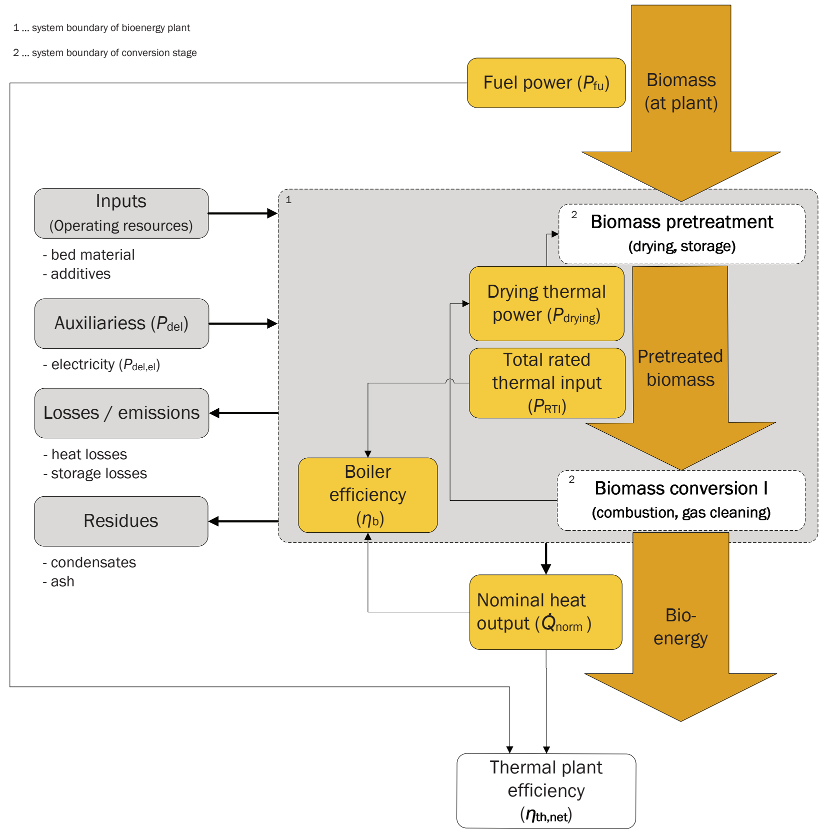


Figure 8: Accounting limits and indicators for the technology field of biomass combustion (especially for small-scale combustion plants and for the most part also for heating plants), (source: original illustration)

The untreated solid biomass constitutes the input for the subsequent conversion into bioenergy. If necessary, the biomass is processed in an initial conversion step (subsequent to delivery, “balance boundary: at gate of bioenergy plant”). This can e.g. include the drying of the biomass, the cutting or crushing, the homogenisation or measures regarding storage. Ideally, the energy required for this processing (pretreatment) is provided by the subsequent conversion processes. In most cases, the energy required for the processing originates from the subsequent conversion process and as such reduces the overall thermal plant efficiency. In the next conversion step, "biomass conversion I" (“balance boundary: boiler”), the previously conditioned biomass is combusted. The energy chemically bound in the fuel is converted into thermal energy. Most of the time, additional inputs (operating resources) and auxiliaries are needed for this conversion step. Furthermore, undesired emissions and residues are generated and process-induced losses occur. At the end of the overall process, the bioenergy is created, i.e., the energy provided by biofuel (solid, liquid or gaseous) via individual conversion steps.

A systematic listing of the data necessary for carrying out the material and energy balancing of a small-scale furnace is found in APPENDIX II (Table 47 to Table 51). To make the data collection easier, the data collection sheets and documentation lists are made available on the website of the funding programme "Biomass energy use" at www.energetische-biomassenutzung.de. P_f_u=m˙ m_(fu,untr)

Table 5 and Table 6 indicate the applicable indicators that are required for assessing the performance and efficiency of small-scale furnaces, as well as information on how to determine them. The scientific discussion to date has shown that to harmonise the methods across technologies, harmonisation should first be strived for each area of technology. Even within the technology group of small-scale furnaces, a series of different processes, methods and calculation rules are applied during material and energy balancing (Hartmann et al. 2006, Konersman et al. 2007, Kunde et al. 2007). The following tables therefore attempt to formulate equally applicable connections for all conversion technologies (where possible) within the technology field of small-scale furnaces.

Table 5: Calculation instructions for the balance indicators of small-scale biomass combustion plants

Calculation of balance indicators		Formula	Unit
Input	Fuel power	$P_{fu} = \dot{m}_{fu,untr} \cdot H_{i,fu,untr}$	kW
	Power delivered	$P_{del} = P_{del,chem} + P_{del,th} + P_{del,el} + P_{input}$	kW
	Total rated thermal input	$P_{RTI} = \dot{m}_{fu,pretr} \cdot H_{i,fu,pretr}$ (in accordance with DIN EN 304:2004-01)	kW
	Inputs (operating resources)	$P_{input} = P_{bed} + P_{additives}$	kW
Output	Nominal heat output	$\dot{Q}_{nom} = \dot{m}_{ht} \cdot c_{ht} \cdot (T_s - T_r)$ (in accordance with DIN EN 304:2004-01)	kW
	Losses	$P_{loss} = P_{exhaut,th} + P_{exhaust,chem} + P_{res}$	kW
Indicators	Thermal plant efficiency	$\eta_{th,net} = \frac{\dot{Q}_{Nom}}{P_{fu}} \cdot 100\%$	%
	Boiler efficiency	$\eta_b = \frac{\dot{Q}_{Nom}}{P_{RTI}} \cdot 100\%$	%

Table 6: Guide values for the input parameters of a small-scale biomass combustion plant

Parameters		Relevance	Type & frequency of determination	Error / robustness	Substitute value / assumption	Comment
Fuel	**Mass flow rate**	P_{RTI}, LCOE, GHG	Continuously over the duration of the test	± 10 % relative	10 kg/h at 48 kW	–
	Moisture content	H_i, H_s, fuel quality	DIN CEN/TS 14774-1 (2003) or equivalent method, representative sampling.	± 3 % absolute	< 10 % in case of wood pellets	–
	Inferior calorific value	P_{RTI}	E.g. in accordance with CEN / TS 14918 (2005) or calorimetrically	Calculated value depends on the humitidy (± 3 % absolute)	$H_{i,pellets}$: 18.2 MJ/kg$_{adry}$; $H_{i,lr}$: 17.2 MJ/kg$_{adry}$	–
Energy delivered	**Electricity**	η_{net}, LCOE, GHG	E.g. continuously (or roughly so) via impulse counter	± 2 %	0.4 % of the nominal heat output (max . 600 W)	–
Exhaust gas	**Mass flow rate**	$\dot{m}_{exh}$	E.g. as for room heaters fired by solid fuel in accordance with DIN EN 13240 (2005)	approx 10 %, depending on method	Dependent on combustion quality	–
Bioenergy	**Useful heat**	η, LCOE, GHG, remuneration in accordance with EEG (> 60 %)	Heat meter, continuous	Dependent on the LCOE of the temperature and water volume measurement.	Framework conditions: min. total 75 %, max. heat utilisation: 60 %	–

5.4.2 The technology field of gasification

Here, the collective term "gasification" includes technologies which involve a technological conversion step via thermal processes (temperatures of above 200 °C) generating a flammable gas from biomass which is utilised for the production of electricity and / or heat as well as fuel or chemicals in subsequent process steps (clearly separated from the gasification zone).
Comprehensive data collection sheets and documentation lists for collecting the data necessary to balance the material and energy of a biomass gasification plant are found in APPENDIX II: Data collection for material and energy balancing (Tables 39 to 42). To make the data collection easier, the data collection sheets and documentation lists are made available on the website of the funding programme "Biomass energy use" at: www.energetische-biomassenutzung.de.
For small-scale biomass gasification, a focal point among the biomass gasification projects within the funding programme, the technology-specific balancing parameters with their essential system connections are presented in Figure 9. The chemical efficiency of Conversion Stage I (gasifier) presented in that diagramme corresponds to the cold gas efficiency.
If a biomass gasification plant utilises heat within the plant, e.g. to preheat the gasification agent, it does not count towards the plant´s nominal heat. The exception to this is the drying heat that is used to dry the plant´s fuel; this is included in the nominal heat. Heat for contract drying of fuels counts towards the nominal heat anyway. The by-products of a biomass gasification plant can consist of, for instance, screened-out quantities of fuel that have a particle diameter which is too small for the gasification plants but which can still be used to manufacture pellets. The only point which has to be taken into consideration in this context is that the utilisation path of the by-products is secured, traceable, and used for energy.
Table 7 and Table 8 indicate the applicable indicators required for assessing the performance and efficiency of biomass gasification systems, as well as the information on how to determine them.

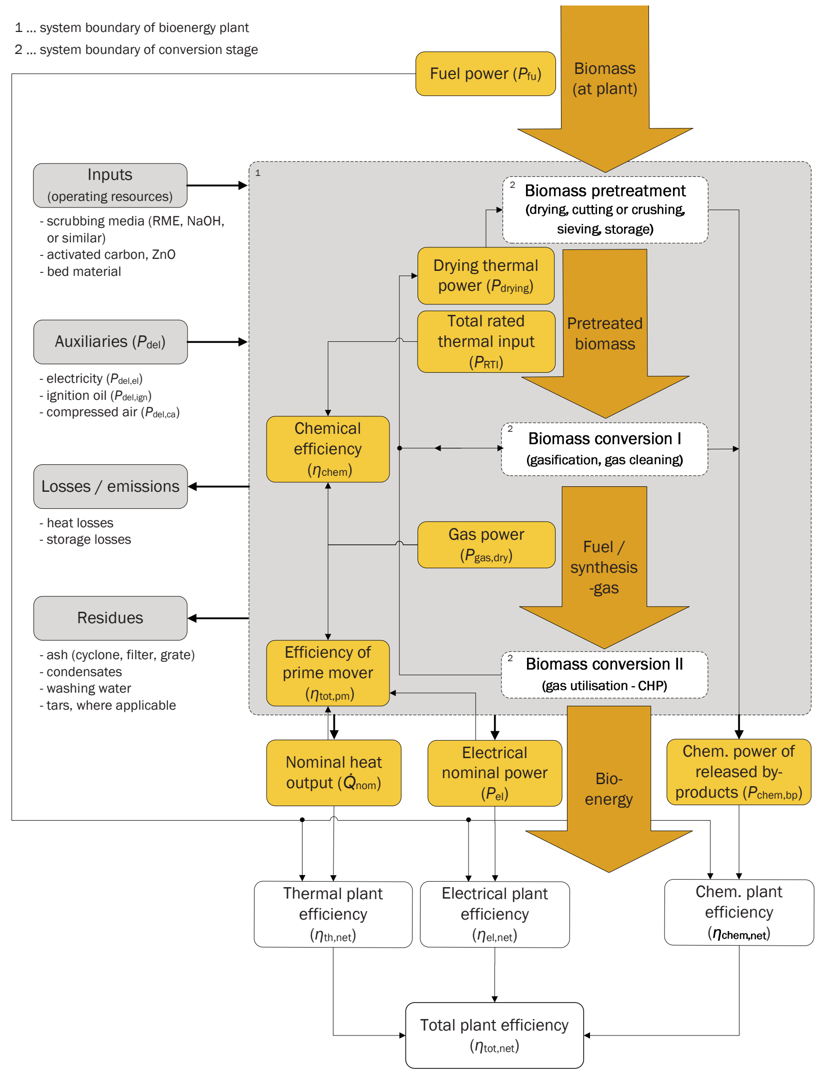


Figure 9: Sample scheme of the most important balancing parameters of a biomass gasification plant (source: own illustration)

Table 7: Instructions for calculating the balance indicators of small-scale biomass gasification plants

Calculation of balance indicators		Formula	Unit
Input	Fuel power	$P_{fu} = \dot{m}_{fu,untr} \cdot H_{i,fu,untr}$	kW
	Total rated thermal input	$P_{RTI} = \dot{m}_{fu,pretr} \cdot H_{i,fu,pretr}$	kW
	Chem. power of auxilaries	$P_{del,chem} = \sum(\dot{m}_{aux} + H_{i,aux})$	kW
	Power delivered	$P_{del} = P_{del,chem} + P_{del,th} + P_{del,el} + P_{del,ign}$	kW
Output	Gas power	$P_{gas} = \sum(\dot{V}_{n,x} \cdot H_{i,x})$	kW
	Chem. power of by-products	$P_{chem,bp} = \sum(\dot{m}_{bp} \cdot H_{i,bp})$	kW
	Chem. power of residues	$P_{chem,res} = \sum(\dot{m}_{res} \cdot H_{i,res})$	kW
	Power loss	$P_{loss} = P_{th,res} + P_{th,bp} + \sum P_{loss,cs}$	kW
Process-specific indicators	Cold gas efficiency	$\eta_{cg} = \frac{P_{gas}}{P_{RTI}}$	%
	Synthesis efficiency	$\eta_{syn,gasif} = \frac{P_{syn,prod}}{P_{syn,ed}}$	%
	Electrical efficiency of prime mover	$\eta_{el,pm} = \frac{P_{el,pm}}{P_{gas} + P_{del}}$	%
	Therm. efficiency of prime mover	$\eta_{th,pm} = \frac{P_{th,pm}}{P_{gas} + P_{del}}$	%
	Total efficiency of prime mover	$\eta_{tot,pm} = \eta_{el,pm} + \eta_{th,pm}$	%
General indicators	Electrical plant efficiency (net)	$\eta_{el,net} = \frac{P_{el}}{P_{fu} + P_{del}}$	%
	Chem. plant efficiency (net)	$\eta_{chem,net} = \frac{P_{chem,bp}}{P_{fu} + P_{del}}$	%
	Therm. plant efficiency (net)	$\eta_{th,net} = \frac{\dot{Q}_{nom}}{P_{fu} + P_{del}}$	%
	Total plant efficiency (net)	$\eta_{tot,net} = \eta_{el,net} + \eta_{chem,net} + \eta_{th,net}$	%

Table 8: Guide values for the input parameters of a small-scale biomass gasification plant

Parameters		Relevance	Type & frequency of determination	Error / robustness	Substitute value / assumption	Comment
Biomass	**Mass flow rate**	P_{RTI}, LCOE, GHG	Weighted over the balance period	± 10 % relative	Must be measured	Control value of cold gas efficiency (≤ 80 % for optimal parallel-flow gasifier)
	Moisture content	H_i, H_s, fuel quality	During the balancing period, 10 samples at even intervals	± 3 % absolute	Must be measured	–
	Inferior calorific value	P_{RTI}	Measurement during the balancing period, 10 samples at even intervals	Calculated value depends on the moisture (± 3 % absolute)	$H_{i,pellets}$: 18.2 MJ/kg_{adry}; $H_{i,lr}$: 17.2 MJ/kg_{adry}	–
Energy delivered	**Electricity / compressed air**	η_{net}, LCOE, GHG	Meter, continuous	± 2 %	8 % gross power generation	Calculation of the power demand in the case of external generation of compressed air: $P_{ca} = \frac{\Delta p \cdot \dot{V}}{\eta_{ca}}$ with η_{ca} = 30 %
	Ignition oil	η, LCOE, GHG	Discretionary assessment over the balance period	15 %	10 % of the product gas volume or 7.5 % of the fuel input volume	–
Product gas	**Cold gas efficiency**	Process characterisation and control	Calculated value over the balance period	8 - 10 %, dependant on the specificity of the system	Max. 80 % in case of optimal design with air pre-heating, max. 75 % without heat recovery / air pre-heating	–
	Inferior calorific value	P_{gas}, η_{kg}	CO, CO_2, CH_4, H_2, H_2O optional, process as desired, continuous measurement / measuring interval ≤ 5 min	5 - 8 % of measured value	Must be measured	Moisture content: 12 vol $\%_{abs}$ as correction value for wet / dry
	Volumetric flow rate	P_{gas}, η_{kg}	As desired / continuous	± 10 % relative (manufacturer's data...) $f(c_i,T,p)$	Must be measured, or calculated from fuel mass flow rate	1 kg_{ds}/h fuel results in 3 m^3_n/h dry fuel gas*

* Seth & Babu 2009

Parameters		Relevance	Type & frequency of determination	Error / robustness	Substitute value / assumption	Comment
Bioenergy	**Useful heat**	LCOE, GHG, remuneration in accordance with EEG (> 60 %)	Heat meter, continuous	± 10 % for calibrated meters (European calibrating regulations)	Framework conditions: min. total 75 %, max. heat utilisation: 60 %	If drying heat is counted towards useful heat, the value after drying has to be used as H_i of the entered biomass (RTI calculation)
	Electricity	η, LCOE, GHG	Electricity meter, continuous	± 2 %	–	–
Inputs	**RME**	Determination over the balance period / extrapolation, if necessary	RME: 1 €/kg		RME sludges: 1 % $m_{wood(adry)}$	If substitute values for inputs (operating resources) are assumed, the mass flow rates of the inputs have to be added to the mass flow rates of the waste substitute values
	Bed material		–	–	–	
	Activated carbon		Activated carbon: 1500 €/kg		Activated carbon: 0.05 % $m_{wood(adry)}$	
Wastes, residues	**Slightly contaminated ashes, condensate**	Determination over the balance period	Upon proof	May be placed in landfill (Cat. 2) or discharged	Approx. 80 €/t_{ash}; approx. 5 €/m³ wastewater	–
	Hazardous ashes, condensate	Determination over the balance period	Upon proof	Pollutant concentrations so high that this is considered to be hazardous waste	Hazardous wastes: 500 €/t or €/m³; 3 % $m_{wood(adry)}$ for coal/ash	–
Emissions	**Methane**	Exhaust gas volumetric flow rate, exhaust gas concentration	–	Greenhouse gas impact	Assumptions regarding the gas composition: CO=20 %; H_2=20 %; CH_4=2 %; Motor slip: 3 %	Product of product gas volumetric flow rate and motor slip

Determining the efficiency of wood gas CHPs

When determining the efficiency of wood gas CHPs, some peculiarities have to be taken into consideration. Due to the many years of development and the high quality of the fuel (natural gas), natural gas engines generally are considerably more efficient than identical engines using wood gas. "When using product gas from biomass gasification, fuel-specific problems arise due to the properties of the gas. For instance, the inferior calorific value of the wood gas leads to a lower engine power and to lower electric efficiency in comparison to natural gas operation. This is magnified by the fact that charge air cooling is mostly lower (higher filling temperature at the start of compression), as are the supercharging pressures, meaning that hydrocarbons of higher valency are prevented from condensing in the turbocharger and that improved availability can thus be ensured" (Merker et al. 2012).

In order also to be able to assess demo plants whose engines do not currently use gas, theoretical CHP efficiencies are assumed for wood gas. Since these do not, however, correspond to the efficiencies in natural gas operation, performance data from an identically constructed gas engine with natural gas and with wood gas utilisation were compared to each other (see Table 9). Due to the readily available and validated data, it was possible to use the 4-stroke GE-Jenbacher AG gas / gasoline engine with direct ignition and a gas blender, which is in use at the Güssing site, among other places, for this purpose (GE Energy 2010). A direct comparison of the fuels shows, as initially described, that - in comparison to natural gas operation - a lower performance and a lower electric efficiency have to be expected in case of an engine converted to wood gas. Furthermore, the comparison can be used to determine a correction factor for converting the performance data of natural gas CHPs, to be used in wood gas operation.

Table 9: Real measured values of the Jenbacher JMS 620 GS-S.L (Güssing, GE-Jenbacher AG) (GE Energy 2010, Pecka 2004)

Fuel	P_{gas} *in kW*	P_{el} *in kW*	P_{th} *in kW*	η_{el} *in %*	η_{th} *in %*	η_{tot} *in %*
Natural gas (approx. 10 kWh/m³ n (stp))	7,351	3,352	3,048	45.6	41.4	87.0
Wood gas (approx. 2.5 kWh/m³ n (stp))	5,410	1,964	2,490	36.3	46.0	82.3
Correction factor: natural gas to wood gas	73.6 %	58.6 %	81.7 %	79.6 %	111.2 %	94.6 %

Based on the manufacturers' survey carried out by the Working Group for Frugal and Environmentally Friendly Energy Consumption (ASUE 2011) and the correction factor between natural gas and wood gas operation that was determined, theoretical efficiencies and performance categories can be determined for gas engines in wood gas operation (see Table 10). By separating the data into performance categories, it is furthermore possible to identify and represent the increasing electric efficiency as plant size increases.
Contrary to the assumption that engines in the lower performance bracket suffer higher thermal losses, given that increasing radiation losses have to occur due to their construction, the thermal efficiency of these systems is particularly high. The reason for this can be found in the differing assumptions regarding the heat concept. In case of small systems, in particular, their supply temperature is usually assumed to be lower, meaning that additional heat flows from the engine cooling and the partial condensation of exhaust gas can be made usable and a higher heat yield appears possible. It can be assumed in general that the shorter transport distances in small and extremely small fields of application also allow heat flows to be used at a lower temperature level; thus, it is definitely permissible to perform an assessment based on these values. In conclusion, it should be emphasised once more that this approach is necessary in order to allow for a comparison of plants with insufficient measured values or not using gas at all. Even though some plants are known to have higher electric efficiencies, this evaluation makes it possible to carry out a conservative, yet, also realistic and comprehensible comparison. The evaluation does not assume that the efficiencies are reduced due to wear during operation.

Table 10: Efficiencies of gas engines separated into performance categories (ASUE 2011)

Efficiencies of natural gas CHPs

P_{el} in kW less than	30 kW	50 kW	70 kW	100 kW	150 kW	260 kW	420 kW	700 kW
η_{el} (gross) in %	29.0	33.8	34.3	35.5	36.2	36.2	38.3	42.0
η_{th} in %	61.3	54.7	53.4	51.2	53.7	52.6	49.3	45.9
η_{tot} (η_{el} + η_{th}) in %	90.3	88.5	87.7	86.7	89.9	88.8	87.6	87.9

Efficiencies of wood gas CHPs (adjustments via correction factor)

P_{el} in kW less than	20 kW	30 kW	40 kW	60 kW	90 kW	150 kW	250 kW	410 kW
η_{el} (gross) in %	23.1	26.9	27.3	28.3	28.8	28.8	30.5	33.4
η_{th} in %	68.1	60.8	59.4	56.9	59.6	58.5	54.7	51.0
η_{tot} (η_{el} + η_{th}) in %	91.2	87.7	86.7	85.2	88.5	87.3	85.2	84.5

5.4.3 The technology field of anaerobic digestion

Fundamentally, all gases rich in methane that are produced by biological anaerobic digestion processes excluding air can be considered to be biogas. Within the context of the funding programme, only such processes will be reviewed that utilise agricultural products, excrement or residues, as well as residues and waste of a general nature. At present, biogas is mainly used for the combined generation of electricity and heat in CHPs. In the future, both the flexible electricity production and the production of biomethane are expected to become increasingly relevant. In both cases, the anaerobic digestion plant (AD) is partially or completely decoupled from the CHP with respect to capacity and performance. The peculiarities of cleaning to produce biomethane are not taken into consideration here. Figure 10, below, presents the technology-specific supply chain with the necessary system boundaries and balancing parameters. One essential factor for characterising the efficiency of the biogas production (Biomass Conversion I) is chemical efficiency, which is primarily controlled by the biodegradation of organic matter. As it is customarily known as "fresh material" (or wet weight), the input of ADs is not described as a fuel here, though it comes down to the same thing. Furthermore, agricultural substrates have to be made storable by silaging, causing losses which reduce the original substrate power. The biogas utilisation (Biomass Conversion II) is controlled by the efficiency of the prime mover. Due to the substrate-specific and process-specific electricity and heat demands of the plants under review, significant differences may result when determining the total plant efficiency. Contrary to what is the case for gasification, any chemical power delivered - e.g. due to antifoaming materials that are decomposed in the process - is not included in the power delivered since these materials are to be considered as a substrate. The digestates occurring are basically considered to be residues when used as a fertiliser or in case of composting. If their further utilisation for energy is strived for and traceable, they can be seen as by-products, as with the gasification of biomass. In this case, the chemical energy in the digestates would have to be included in the total plant efficiency.

The list of the necessary data to be collected is found in APPENDIX II (Table 44 to Table 47). To make the data collection easier, the data collection sheets and documentation lists are made available on the websote of the funding programme "Biomass energy use" at www.energetische-biomassenutzung.de.

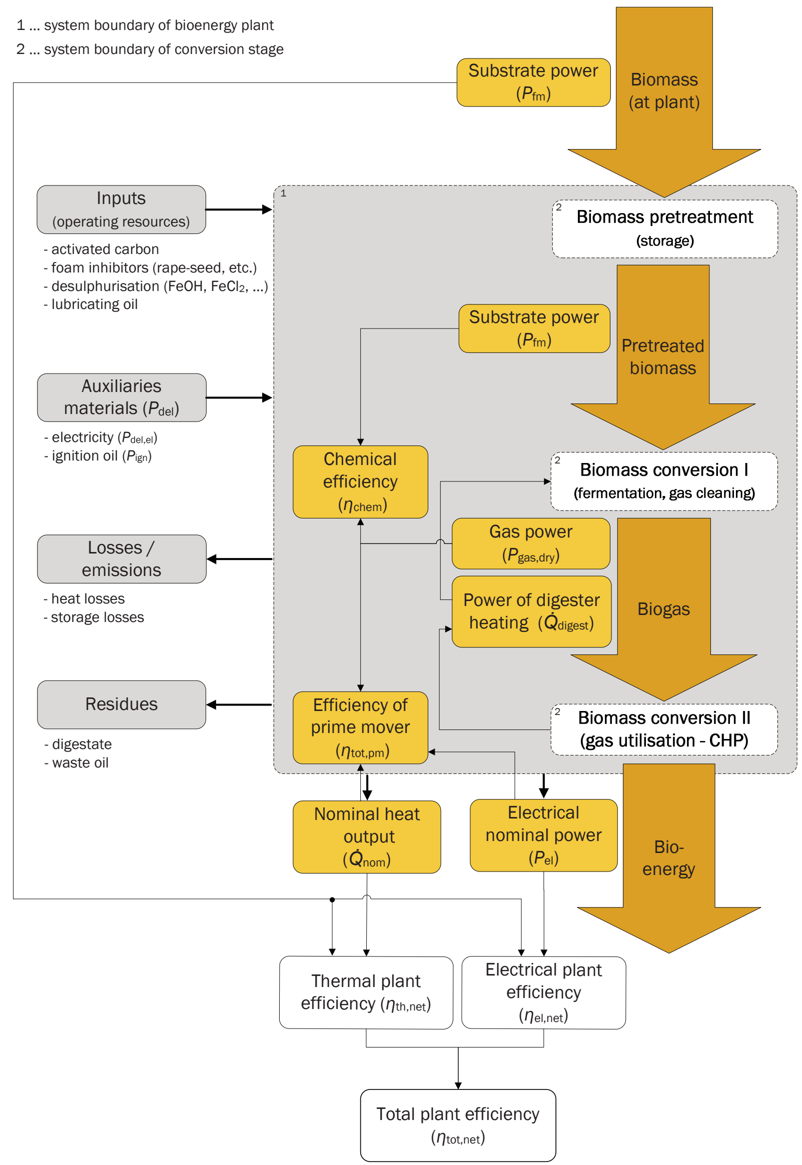


Figure 10: Basic scheme of important balancing parameters in case of the energy production from biogas (source: original illustration)

Table 11 and Table 12 indicate the applicable indicators required for assessing the performance and efficiency of ADs, as well as information on how to determine them. Since the biological conversion processes fundamentally allow the superior calorific value potential to be used, the inferior calorific value is not used here. For a direct comparison between the production of biogas and combustion and / or gasification, the formulas listed below, accordingly, have to be put in relation to the inferior calorific value H_i.

Table 11: Calculation of balance indicators at ADs

Calculation of balance indicators		Formula	Unit
Input	Substrate power of fresh material	$P_{fm} = \dot{m}_{fm,untr} \cdot H_{s,fm,untr}$	kW
	Substrate power of silage	$P_{fm,sil} = (\dot{m}_{fm,untr} - \dot{m}_{fm,loss}) \cdot H_{s,fm,untr}$	kW
	Power delivered	$P_{del} = P_{del,chem} + P_{del,th} + P_{del,el} + P_{del,ign}$	kW
Output	Gas power	$P_{gas} = \dot{V}_{CH_4} \cdot H_{s,CH_4}$	kW
Process-specific indicators	Chem. efficiency of the anaerobic digestion	$\eta_{chem} = \frac{P_{gas}}{P_{fm}}$	%
	Electrical efficiency of prime mover	$\eta_{el,pm} = \frac{P_{el,pm}}{P_{gas} + P_{del}}$	%
	Therm. efficiency of prime mover	$\eta_{th,pm} = \frac{P_{th,pm}}{P_{gas} + P_{del}}$	%
	Total efficiency of prime mover	$\eta_{tot,pm} = \eta_{el,pm} + \eta_{th,pm}$	%
General indicators	Electrical plant efficiency (net)	$\eta_{el,net} = \frac{P_{el}}{P_{fm} + P_{del}}$	%
	Chem. plant efficiency (net)	$\eta_{chem,net} = \frac{P_{gas}}{P_{fm}}$	%
	Therm. plant efficiency (net)	$\eta_{th,net} = \frac{\dot{Q}_{useful}}{P_{fm} + P_{del}}$	%
	Total plant efficiency (net)	$\eta_{tot,net} = \eta_{el,net} + \eta_{th,net}$	%

Table 12: Guide values for input parameters for the characterisation of ADs

	Parameters	Relevance	Type & frequency of determination	Error / robusness	Substitute value / assumption	Comment
Biomass	**Mass flow rate**	P_{RTI}, GHG	Input materials in accordance with BiomasseV in case of agricultural plants; continuous weighing upon delivery and in the portioner. Mass flowmeter	< ± 5 % absolute	Must be measured	–
	Moisture content	H_s, reference heat	Upon a substrate or silo change and / or weekly	± 3 % absolute	Standard values from databases / literature	–
	Superior calorific value	P_{RTI}	Min. simple calorimetric measurement of the individual substrates during the balancing period, 10 samples at even intervals	± 10 % absolute	Standard values from databases / literature	–
Energy delivdered	**Electricity**	η_{net}, GHG	Electricity meters for main consumers and / or groups, continuous	± 2 %	10 % of the gross power generation	
	Ignition oil	η, GHG	Via documentation of the delivered quantities	15 %	10 % of the gas power	Adhere to max. limits set by energy supplier
Biogas	**Gas power**	Process characterisation and control	Calculated value over the balance period	unknown	55 % of the substrate power	Monitoring of degradation performance
	Superior calorific value	P_{gas}, η_{kg}	Calculation based on continuous gas analyses, only CH_4 share relevant	unknown	Calculation using standard values from databases / literature	–
	Volumetric flow rate	P_{gas}, η_{kg}	Continuous, measurement not wide-spread; generally, determination based on standard yields and backwards calculation	min. ± 10 %, dependent on the selected process	Standard calculation is based on the substrate volume /mass flow rate or on the backwards calculation from the electricity production to the feedstock demand	Direct measuring methods are very imprecise, measurement can be verified only indirectly
Bioenergy	**Useful heat**	η ,LCOE, GHG, remuneration in accordance with EEG	Heat meter, continuous	± 10 % for calibrated meters (European Calibration Order)	Plant- / system-specific, in case of EEG plants from 2012 on min. 35 % of gross heat	Share of specific heat
	Electricity	η, LCOE, GHG	Electricity meter, continuous	± 2 %	Plant-specific	With respect to transformer losses and power loss, pay attention to measuring points

Table 13: Listing and guide values for inputs (operating resources), residues and emissions in the biogas production

Parameters		Quantity	Cost	Quality / properties	Substitute value / assumptions	Comment
Inputs (operating resources)	**Foam inhibitor**	Very small amount for foam control in special cases	Vegetable oil approx. 1 €/kg	No particular requirements	Not used during normal operations	Utilisation only required in special cases
	Activated carbon	Dependent on the pollution of the biogas	–	Suitable for fine desulphurisation, storage subject to fire protection requirements	Plant-specific	Utilisation requires sufficient drying of gas
	Iron preparations	Plant- / system-specific dosing, based on substrate and pollution of the gas	–	No particular requirements	Plant- / system-specific	Can be replaced with air injection or external columns, in this case, additional inputs (operating resources) are required
	Lubricating oil	In accordance with the manufacturer's data of the aggregate	–	Motor oil, gearbox oil in accordance with manufacturer's specifications	Plant- / system-specific	Monitoring via analysis at regular intervals
Wastes, residues	**Waste oil**	Plant- / system-specific	–	Adhere to water protection guidelines, proof of waste disposal required	–	–
	Digestate	Determination over the balance period	Linked to substrate delivery	Adhere to spreading times, fertiliser regulations, water protection and cross compliance	Volume between 80 and 95 % of the substrate input, depending on moisture content	–
Emissions	**Methane**	Measurement of residual gas potential in accordance with VDI 4630 (2006), measurement in exhaust gas volumetric flow rate, measurement of leakages; balancing via substrate input and production of electricity / heat	Equal to LCOE	Greenhouse gas impact	2 % of the total methane production	Direct measurement of emissions only possible in selected spots and therefore not representative, additional emission sources and types in VDI 3475 Sheet 4 (2010)

5.5 Superior and inferior calorific value - A look at the balance effects

5.5.1 Fundamentals

For the calculatory description of energy technology processes, material-linked energy flows play an important role. A material-linked energy flow can, on the one hand, occur as a "tangible" physically material-linked energy flow, e.g. as liquid water with a temperature of 70 °C. But there is also the "tangible and latent" physically material-linked energy flow, e.g. water in the form of steam. The physical energy content of steam can be released via cooling down to the point of condensation temperature ("tangible, physical" energy content) and condensation ("latent" physical energy content).

Material flows in which chemical energy is bound play another important role. The most important example of this is the fuel energy flow (or "chemically bound energy flow" of the fuel flow). This energy flow can be released in a chemical reaction (e.g. combustion). Fuel energy flow has the same physical dimension as heat flow or electrical energy flow (e.g. kW). In experimental balancing, a fuel energy flow is determined by determining the material flow rate (mass flow in kg/h or mole flow in kmol/h) as well as the energy content relative to the quantity (MJ/kg or MJ/kmol), and then multiplying them with one another.

5.5.2 Reference state in technology assessments

TThe relevant question here is the one of the reference state of the energy flows. This is the same as asking which state of the substance is assigned the enthalpy value of ZERO as energy value. Such an assignment is absolutely necessary, since the enthalpy of substances can never be specified in absolute terms.

For the energy calculation it is also important whether the enthalpy value of ZERO is assigned to the liquid water or to the gaseous water (steam)[19] If liquid water at 25 °C is selected as reference state, the gaseous water at 25 °C[20] can immediately be assigned an enthalpy content of +2,440 kJ/kg. That is evaporation enthalpy, a kind of latent energy.

If gaseous water at 25 °C is arbitrarily selected as reference state, however, liquid water of this temperature necessarily has a negative energy content (condensation enthalpy, with -2,440 kJ/kg, identical in its amount to the evaporation enthalpy).

The definition of the reference state is also important when quantifying chemical energy. The reaction products when energy feedstocks are chemically converted contain water. If the reference state is defined as 25 °C with water in the liquid state, one is dealing with the superior calorific value. If a temperature of 25 °C and gaseous water (steam) is used as reference state, you are working with the inferior calorific value.[21] The superior calorific

[19] The specification of a reference pressure is intentionally not being discussed here.

[20] To visualize steam at 25 °C, a very low pressure has to be assumed. The vapour pressure of water at 25 °C amounts to 3.17 kPa, which occurs in evaporation processes as partial pressure.

[21] Isobar changes of state are always assumed.

value therefore refers to an energetically lower state than the inferior calorific value, and as such typically[22] features higher values than the latter. The more water contained in the reaction products, the greater the difference will be. This can lead to a situation where an energy feedstock – e.g. liquid manure or fresh biomass with a very high moisture content (mc) – may exhibit negative values for the inferior calorific value even though the superior calorific value is positive.

In combustion technology as it developed historically over time, the cooling of flue gas was technically designed in such a way that no condensation takes place before it leaves the plant (at temperatures of 150 °C or more). In such a situation it is no problem at all to treat the inferior calorific value as the maximum energy obtainable. This is why it has been unproblematic to use the inferior calorific value as the INPUT parameter in efficiency calculation. This practice – using the inferior calorific value as reference value – has become standard when balancing solid biofuel technologies.

In energy technology, particularly in regenerative energy technology, processes with liquid water are increasingly common – water not as a materially separate work medium, but as part of homogeneous or heterogeneous mixtures with energy feedstocks, or as reaction products of the energy feedstock. Examples of such processes are superior calorific value boilers and drying processes as well as anaerobic digestion processes and low-temperature heat recovery processes.

In condensing boiler technology, more energy can be extracted from the process via the condensation of steam than inferior calorific value calculations predict. In the classical efficiency definition, the use of the inferior calorific value leads to efficiencies of more than 100 %!

The calculation of the efficiency for an energetic process with liquid manure or mashed biomass as input fails due to its negative inferior calorific value resulting from the high percentage of water it contains. One way to help solve the situation is to apply, when calculating, a physical separation of the pure liquid water that takes place prior to the energetic process (being theoretical, energy technically required to do this is not part of the calculation). A non-involved share of water could be defined for this purpose. This assumption is an arbitrary one, especially with respect to the quantity[23] of non-involved water which none of the chemical energy will be used to evaporate. For this approach, therefore, a standardisation will be necessary if any comparability is to be achieved. But this standardisation likely will pose problems more difficult than the conversion to using liquid water as reference point (in other words, the superior calorific value), as described above. Even though this method will depict the general efficiency parameters of the “overall process” with only rather mild distortion, when preparing partial balances which must fit together for assessment purposes, it is probable that considerable, perhaps even insurmountable, difficulties will arise.

[22] If no water whatsoever is contained in the reaction products, superior and inferior calorific value assume identical values just as in the combustion of pure dry carbon or carbon monoxide.

[23] It would be a logical option to consider all of the fuel water as non-involved water. But this can lead to a conflict if it is taken into consideration that in ADs a certain amount of water is split and converted to biogas.

In certain processes, the traditionally typical efficiency factors are not used. For example when assessing the energetic output of biogas (anaerobic digestion) plants, the methane yield of the substrate is used instead of the otherwise typical efficiency factor. As such, the work with material-linked energy flows otherwise common in energy technology is replaced with quantity flows of substrates to which the characteristic “specific gas yield” (e.g. in standard cubic metres methane per kg of input substrate) is assigned. As a result, the process optimization does not feature any typical direct comparability to otherwise common, more absolute units of energy – in practice, this leads to information which is largely relative and comparable in a limited way, namely when compared to other ADs. In addition to the fact that this method of assessment has worked well for many years, stubborn adherence to this practice may also be a reaction to the fact that the work with degrees of efficiency that are based on the inferior calorific value is not at all constructive when dealing with feedstock with high moisture (water) content . A supplemental calculation based on the superior calorific value, in addition to the otherwise typical gas yield calculations, could improve the situation quickly – and in turn raise the level of comparability.

5.5.3 Conclusions / Ramifications

Assessing of complex energy technology systems using different partial balances can lead to confusion and errors if the reference states are not defined consistently across the board. The energy difference between the different reference states used then appears as either lost or generated energy flow. As explained above, working with inferior and superior calorific values within the same system is the same as using different reference states. For classic thermochemical processes, which take place at very high temperatures, consistently working with inferior calorific value related energy flows is effective and a rather obvious choice since it is backed by long technical tradition.

But it is not quite as obvious a choice for fuel gases from renewable energy sources. In case of natural gas, for example, it has long been common to work with liquid water as the reference state, in other words using the superior calorific value. It is standard practice to use superior calorific value for this fuel.

This lays the groundwork for the trend towards a shift away from the inferior calorific value reference and towards the superior calorific value reference in technology assessment. In the future, a thorough transition should be made, to a standard practice of calculating energy content for material flows based on the same methodology, thus allowing for comparative assessments across technologies. The increasing interconnections between the technologies, be it for comparison purposes or for material interconnection, speak for this clear and consistent approach. This is also planned for in the future European standardisation (cf. draft for the Ecodesign Directive).[24]

[24] Where power plant technology and energy process engineering calculation methods meet, the conflict between superior calorific value reference – meaning liquid water at 25 °C – and physical standard condition – meaning liquid water at 0 °C – must be considered.

The above discussion makes it clear that for an increasingly scientifically-sound cross-technological assessment of bioenergy technology to be possible, there are very clear indications that shifting to the standard use of superior calorific value to characterize the flow of energetic material is nearly imperative. Awareness of this dialectic, and the possibilities for distorted results if ignored, is an important first step in increasing clarity in representing and comparing these processes. Easy, direct comparability of energy value is important in communication and development within the field of energy economy and for clear communication with non-scientists dealing with this topic.

5.5.4 Sample calculation: Anaerobic digestion of wet biomass / biochemical conversion

Table 14: Simplified comparison of inferior and superior calorific value – Anaerobic digestion of wet biomass / biochemical conversion

	Description of the material / energy flow (as delivered)	Material flow balancing	Energy flow balancing based on		Deviation from inferior and superior calorific value reference in %
			Inferior calorific value	Superior calorific value	
Input	50 wt % liquid manure[25] with 90 % mc	50 kg/h	-16.0 kW (-0.32 kWh/kg)	15.5 kW (0.31 kWh/kg)	unknown
	50 wt % maize silage[26] with 65 % mc	50 kg/h	58.0 kW (1.16 kWh/kg)	86.0 kW (1.72 kWh/kg)	32.6 %
Interim product (dry)	Biogas[27]	12.3 m^3/h n (stp)	64.4 kW (4.3 kWh/kg)	71.4 kW (4.8 kWh/kg)	11 %
	Methane (approx. 53 % of the biogas)	6.5 m^3/h n (stp)	–	–	–
Unused share of superior calorific value	–	–	–	7.0 kW	–
Output	Electrical energy	–	19.4 kW	19.4 kW	0 %
	At 80 °C decoupleable nominal heat	–	31.0 kW	31.0 kW	0 %
Gross plant efficiency ($\eta = \frac{P_{Out}}{P_{In}}$)	Electrical	–	45.9 %	19.0 %	-58.6 %
	Thermal	–	73.4 %	30.5 %	-58.6 %
	Total	–	119.2 %[28]	49.5 %	-58.6 %
Gross efficiency of heat engine ($\eta = \frac{P_{Out}}{P_{In}}$)	Electrical	–	30.0 %	27.1 %	-9.7 %
	Thermal	–	48.0 %	43.4 %	-9.7 %
	Total	–	78.0 %	70.5 %	-9.7 %

[25] Cattle manure data changed in accordance with ANNAMALAI et al. (1987), pp. 49-57.
[26] Maize silage data in accordance with TOVAR-GOMEZ et al. (1997), pp. 77-88.
[27] Biogas, standard values in accordance with KEYMER (2013).
[28] Calculatory efficiency based on addition of the input yields.

5.5.5 Sample calculation: Biomass gasification / thermochemical conversion

Table 15: Simplified comparison of inferior and superior calorific value – Biomass gasification / thermochemical conversion

	Description of the material / energy flow (as delivered)	Material flow balancing	Energy flow balancing based on		Calorific value deviation relative to the inferior calorific value
			Inferior calorific value	Superior calorific value	
Input: Fuel	WC with 50 % mc	50 kg/h	114.4 kW 2.3 kWh/kg	140.1 kW 2.8 kWh/kg	22.5 %
	WC with 10 % mc	50 kg/h	233.0 kW 4.7 kWh/kg	252.1 kW 5.0 kWh/kg	8.2 %
Cleaned product gas (dry)[29, 30]	WC with 50 % mc	76.6 kg/h 70 m^3_n/h	104.4 kW 1.4 kWh/kg	113.5 kW 1.5 kWh/kg	8.6 %
	WC with 10 % mc	136.8 kg/h 125 m^3_n/h	186.4 kW 1.4 kWh/kg	202.7 kW 1.5 kWh/kg	8.6 %
Unused share of superior calorific value	WC with 50 % mc	–	–	9.1 kW	–
	WC with 10 % mc	–	–	16.3 kW	–
Output: electr. energy + nominal heat at 80 °C	WC with 50 % mc	–	28.1 kW_{el} 63.5 kW_{th}		0 % 0 %
	WC with 10 % mc	–	52.8 kW_{el} 106.1 kW_{th}		0 % 0 %
Gross plant efficiency $\eta = \frac{P_{Out}}{P_{In}}$	WC with 50 % mc	Electrical	24.6 %	20. 0 %	-18.4 %
		Thermal	55.5 %	45.3 %	
		Total	80.1 %	65.4 %	
	WC with 10 % mc	Electrical	22.6 %	20.9 %	-7.6 %
		Thermal	45.5 %	42.1 %	
		Total	68.2 %	63.0 %	
Gross efficiency of CHP[31] $\eta = \frac{P_{Out}}{P_{In}}$	WC with 50 % mc	Electrical	26.9 %	24.7 %	-8.0 %
		Thermal	60.8 %	55.9 %	
		Total	87.7 %	80.6 %	
	WC with 10 % mc	Electrical	28.3 %	26.0 %	-8.0 %
		Thermal	56.9 %	52.3 %	
		Total	85.2 %	78.4 %	

[29] The impact of the differing moisture content of the gas composition was not taken into consideration in calculating the gas yields. For both cases, a standardised gas composition was used for the calculation.
[30] The product gas standard volumetric flow rates correspond to the assumptions on which the product gas mass flow rates are based.
[31] c.f. Chapter 5, Table 10.

6 Methodology for calculating the levelied costs of energy

6.1 Background

In accordance with the objectives of the funding programme, the further expansion of the production and use of bioenergy has to guarantee that the limited biomass resources are used as efficiently and as economically as possible for a broad range of purposes. One way of determining the cost of GHG mitigation is to calculate the production costs or levelised costs of energy (LCOE) and carry out an environmental assessment of the different bioenergy production routes. Ultimately, the statements which can be made by this means regarding economic efficiency can help minimise the costs of climate protection and thereby increase societal acceptance of bioenergy, provided the results are implemented politically. In light of the rapidly changing technological and economic framework conditions, a well-founded discussion is only possible if a multitude of variant calculations are performed to map the whole range of parameters. Introducing the production costs (not including delivery to the plant) as a criterion of economic efficiency makes it possible to compare the biomass utilisation routes with their different technological approaches, service lives, supply volumes, and separation into the bioenergy forms of fuel, heat and electrical energy. The LCOE are calculated based on the annuity method and are applied uniformly in accordance with the provisions of VDI 6025 (1996). The micro- and macroeconomic effects are intentionally not presented, since difficult, concept-specific assumptions would need to be made that have far-reaching consequences and therefore cannot be presented in a generalised form.

6.2 General methodology and system boundaries

To be able to assess the economic consequences of a substituted or new investment, generally multiple variants should be assessed individually and subsequently compared to one another based on the same system boundaries, and a detailed analysis should be performed of the site-specific framework conditions (characteristic annual curve, service life, availability of feedstock, etc.).
The system boundaries included in the cost calculation for the projects in the funding programme “Biomass energy use” are the conversion plant, respectively including fuel pretreatment at the plant (chipper, sieve systems, drying, etc.), fuel storage and systems for conditioning the form of energy produced. The upstream chain (biomass supply) is taken into consideration under the costs of fuel procurement. As such, the pure LCOE is calculated, not taking into account potential effects of distribution, to be able to subsequently calculate the GHG mitigation costs. For the (solid, liquid and gaseous) biofuels produced, the following interfaces are defined with respect to pretreatment the possible forms of energy:

- Electrical energy: Transformer system (incl. switching system) for feeding into the power grid
- Heat: Heat exchanger for extracting process heat / district heat (not included pumps and control of the heat grid)
- Fuels for transport: Tank farms and facility for filling of tank trucks (incl. rail connection and / or street connection)
- Gaseous fuels: Compressor system for feeding into a 16 bar supply grid (excluding odourisation and potential addition of propane)

In this context, note that the calculation needs to include not only necessary investments, maintenance expenditures and inputs (operating resources) but also auxiliary energy. To be able to subsequently calculate the greenhouse gas mitigation costs, it is necessary to determine the costs of the fossil reference energy at the same system boundary (opportunity costs) and compare them to those of the regenerative energy.

General methodology

To estimate the economic advantages of a planned plant, the fuel, electricity and / or heat levelised costs of energy are determined, depending on the plant, based on VDI 6025 and subsequently compared to the opportunity costs. All regulations regarding the determination of the respective costs are listed in detail in VDI 6025 (e.g. annuity method) and are to be applied analogously to the calculations. This method is generally recognized, even though other approaches such as the present values method or the calculation of the internal interest rate are also utilised to determine economic efficiency and are also more informative in certain cases. However, so that the results can be generalised and compared, the following will be limited to the annuity method and how it is adjusted to calculate the LCOE. The approach is presented schematically in Figure 11 and explained in detail below.

The calculation is based on the production costs for the main product (electrical energy, heat, fuel), which are determined from the costs and minus the revenues from by-products.

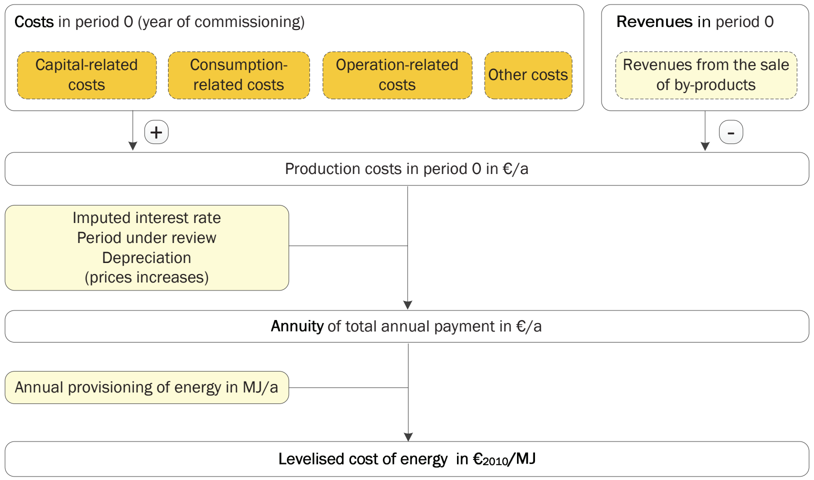


Figure 11: Calculation of the fuel, electricity and heat levelised costs of energy (LCOE), (Zeymer et al. 2013)

The annuity method is used to transform both non-periodic and periodic payments (sums vary) during a certain time into periodically constant payments; these are divided by the annual, constant energy production to produce the levelised costs of energy (€ct/ MJ) (Formula 6.1), (Zeymer et a l. 2013), (OECD 2010).

$$LCOE = \frac{A}{E}$$ *Formula 6.1*

A = Annuity in €/MJ
E = Annual constant energy production in MJ/a
LCOE = Levelised Cost of Energy (LCOE) in €ct/MJ

If the annual energy production is not constant, this approach is not possible since only constant payments (annuities) can be divided by a constant energy production without a systematic error. All payments and the annual energy production have to be subjected to an assumed discount rate for all points in time of the review relative to the time of commissioning (t=0). There is extensive discussion regarding the amount of the discount rate. One option is to select the capital interest rate for the costs (borrowing rate) or outgoing payments, meaning negative surpluses, and accordingly also for the energy production. Typically, discount rates are between 5 and 10 %. The present values determined this way now feature a standardised point of reference and can be divided to produce levelised costs of energy (Formula 6.2), (Zeymer et al. 2013), (OECD 2010).

$$LCOE = \frac{\sum_{t=0}^{n} \frac{C_t - BPI_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}}$$ *Formula 6.2*

E_t = Energy production in period t in MJ/a
LCOE = Levelised Cost of Energy in €ct/MJ
C_t = Costs in period t in €/a
BPI_t = By-product revenue in period t in €/a
r = Discount rate in %

For all calculations, for all fuels, the inferior calorific value (H_i) and the base year 2010 have to be used. If costs exist for e.g. feedstock or conversion systems for other years, these initially have to be discounted down or accumulated up to the reference year 2010 using suitable rates of price increase (e.g. based on the Federal Statistical Office[32] or the Kölbel-Schulze-Index for chemical plants).

[32] Federal Statistical Office (2013): Prices. Data on energy price trends - Long-term series from January 2000 to May 2013. URL: https://www.destatis.de/DE/Publikationen/Thematisch/Preise/Energiepreise/Energiepreis entwicklungPDF_5619001.pdf?__blob=publicationFile (as of: 20 Oct 2013).

To determine the relative advantage of multiple investment projects, a direct comparison of the individual LCOE is necessary. The absolute advantage of an investment can be determined by comparing the LCOE and the opportunity costs. These are:

- in case of LCOE of fuels for transport, the costs of the fossil reference and / or of the fossil substitute (e.g. petrol, diesel or natural gas),
- in case of LCOE for electricity, the remuneration in accordance with the Renewable Energy Sources Act (EEG) or the mitigation made by a self-generated supply with electrical energy,
- in case of LCOE for heat, the costs for the heat supply to date or an optional heat supply.

However, at the same time, as the comparison is limited to the LCOE calculation, the positive external effects are not taken into consideration, e.g. the effects of supplying electrical energy from biomass as opposed to wind and photovoltaics due to a significantly higher guaranteed performance (Zeymer et al. 2013). For biomass, this amounts to 88 %, for wind only to 5 - 10 %, and for photovoltaics only to 1 % of the plant's output (DENA 2010, pg. 23). When comparing the grid-level bioenergy production costs with wind or solar power plants, extra costs for additional reserve power and grid expansion will therefore have to be taken into consideration, especially if the percentage of fluctuating fuels increases further (Zeymer et al. 2013).

Annually constant rate of price increase

For the economic assessment of energy projects, current energy prices are generally used and an "annually constant rate of price increase" is assumed for the duration of the project. This kind of approach does not, however, conform to reality in the energy market, since the costs incurred during biomass production are highly volatile and very difficult to forecast (Konstantin 2007). Therefore, the base case for economic assessments uses the average prices of the last year for calculations. Since the year 2010 is taken as a reference point in time, then, if there is no other option, an older database has to be used instead, and said data will have to be forecast for the year 2010. To improve the comparability of the areas in which biomass is used, i.e. heat, electricity, CHP and fuel for transport, we are not calculating LCOE with annual rates of price increase. It is urgently necessary to take price increases into consideration, especially when taking advantage of EEG remuneration to determine the economic efficiency, as the remuneration of electrical energy is fixed over 20 years. However, in the heat and fuel for transport market, rises in the prices of feedstock, for instance, can be passed on to the consumer. In this context, therefore, sensitivity considerations are more suitable which take into account significantly higher and lower prices for feedstocks, operation-related and capital-related parameters, allowing potential risks to be analysed and potential fluctuations to be described transparently.

6.3 Assumptions and framework conditions

A tested conversion plant that has been established on the market is the basis for calculations. In projects where this has not (yet) been achieved, the available data have to be developed further so that values that are as reliable as possible can be used for a technology that is close to market readiness. In this context, the point in time also has to be specified at which market availability is expected.

Generally, there are a wide range of assumptions and framework conditions which can vary widely depending on the focus of the examination, the design of the plant (peak /continuous load, heat / flow-driven), the site and maturity of the technology (reliability, service lives, maintenance expenditure) and which therefore need to be adjusted on a case-by-case basis. Therefore, the central basis for calculating the LCOE is the process and plant / system-specific indicators (e.g. efficiencies and specific emissions) determined in the material and energy balances, and their extrapolation to a tried-and-tested plant concept. When calculating the LCOE, the thermal utilisation factor of a plant should also be specified, since it can have a considerable impact on the result.

To achieve as much transparency as possible, the investment costs should - if possible - be broken down into plant costs (construction technology / machine technology / electrical engineering and instrumentation and control systems), engineering services for planning and monitoring, development services, construction interest, and unforeseen. The very wide range of technologies and concepts in the provision of biomass means that no statements can be made regarding the amounts to be invested; these therefore need to be calculated on a project-by-project basis. In addition to the investment costs in a plant, the repair and maintenance costs are of particular relevance; they are combined under the maintenance costs. Peters et al., 2003, provides estimates for processes of different complexity, and maintenance costs in terms of wages and material depending on the process conditions. Table 16 lists the maintanance costs as a percentage of the investment costs per year. Assumptions regarding maintenance costs should be modelled on this depending on the process and technology.

Table 16: Estimate of the maintenance costs of chemical processes (Zeymer et al. 2013), (Peters et al. 2003)

Chemical processes	Maintenance costs as percentage of the investment costs per year		
	Wages	Material	Total
Simple thermochemical process	1 – 3	1 – 3	2 – 6
Process of average complexity under normal process conditions	2 – 4	3 – 5	5 – 9
Complex process under corrosive conditions or with complicated M&C	3 – 5	4 – 6	7 – 11

For the following conversion technologies in the tables, a highly detailed listing was created with respect to the framework conditions and assumptions for the LCOE calculation (see Table 17 - Table 19). All statements regarding prices for feedstock, auxiliary substances, residues and auxiliary energy are based on an average cost basis in the year 2010. To simplify matters and to make it easier to compare plants, a single value was specified when calculating the LCOE for all parameters, instead of a range being indicated. Large regional differences do generally exist, but these are not taken into consideration in this context, in order to create a standardised cost basis for all projects and also to render the results transparent and comparable. If significant deviation between the real values and the suggested assumptions and / or framework conditions are to be expected in a specific project, this definitely needs to be mentioned and needs to be taken into consideration and / or discussed in the subsequent sensitivity review.

The following plant / system concepts are described:

Anaerobic digestion plant (AD) / biodiesel plant / bioethanol plant

From a simplified point of view, ADs / ADs including conditioning, bioethanol plants and biodiesel plants feature a similar technical maturity and complexity, and can therefore be grouped together with respect to the economic assumptions as well as the framework conditions. An overview is provided in Table 17.

Biomass combustion plants

Biomass combustion plants show a wide range of total rated thermal input ranging from a single kilowatt to several hundred megawatts. However, since not only the capacity varies considerably, but also the mode of operation and other framework conditions, Table 18 differentiates between the biomass combustion plants.

Biomass gasification plants

Due to the considerably higher specific investment costs in biomass gasification plants as opposed to conventional biomass heat and power stations, the costs of maintanance and cleaning are considerably higher, though the percentages are similar. The more complex technology and the lower degree of operational experience require this higher expenditure, as well as additional unexpected costs. The feedstock situation and / or competition among suppliers are comparable to those of biomass heat and power stations, since a similar range of feedstock can be utilised and / or is strived for (e.g. straw pellets). The predicted annual operating hours have, however, not yet been achieved across all technologies, though they have been confirmed by certain plants (FICFB gasification plant in Güssingen, Germany; Harboøre plant in Denmark) and constitute the minimum objective in regular operations at the planned plants.

Table 17: Typical assumptions and framework conditions behind LCOE calculation (net, 2010) - ADs / ADs incl. conditioning, bioethanol plants and biodiesel plants

Parameters	Assumptions and framework conditions
Annual full load hours (AD with conditioning)	8,200 h/a
Annual full load hours (all others)	8,000 h/a
Capital-related costs	
Investment costs (ready for use, not included construction interest costs)	I_0
Calculatory composite interest rate	8 %/a
Maintenance and repair	see Table 16
Period under review[33]	20 years
Consumption-related costs	
Costs for the biomass production: - Certified rape-seed oil - Rape-seed - Certified palm oil - Liquid manure - Sewage sludge (dilute sludge, 5 % DS), biowaste - Maize and / or maize silage - Cereal grain - Grass silage - Alfalfa silage - Sunflower silage - Sugar beet leaf silage - Feeding rye silage	 890 €/t 370 €/t 810 €/t 0 €/t_{fm} ("own production") / 2 €/t_{fm} (additional purchase(s)) - 30 €/t_{fm} 35 €/t_{fm} 165 €/t_{fm} 35 €/t_{fm} 30 €/t_{fm} 30 €/t_{fm} 25 €/t_{fm} 25 €/t_{fm}
Price of electricity (reduction of auxiliary power)	3.33 €ct/MJ_{el} (12 €ct/kWh_{el})
Propane	1 €/kg
Defoamer	3 €/kg
Process water	2 €/m³
Disposal: - Contaminated digestates with 85 % DS content (e.g. from utilisation of sewage sludge) - Grate ash (provision of steam in case of bioethanol production) - Fly ash (provision of steam in case of bioethanol production)	 85 €/t 80 €/t 150 €/t
Operation-related costs	
Staffing requirements (AD plant) [EE]	0.5 EE/MW_{AD}
Staffing requirements (biofuel plants for transport) [EE]	0.25 EE/MW_{out}
Specific staff costs [€/(EE · a)]	50,000
Maintenance and cleaning	see Table 16
Administration	(0.5 % · I_0)/a
Insurance (construction not included)	(1.00 % · I_0)/a
Unforeseen costs	(0.50 % · I_0)/a
Revenue from co-products	
Heat credits: - Heat up to 130 °C - High-pressure steam	 0.83 €ct/MJ_{th} (3 €ct/kWh_{th}) 1.39 €ct/MJ_{th} (5 €ct/kWh_{th})
Co-generated products: - Oil meal - Press cake - Distillers Dried Grains with Solubles (DDGS) - Vinasse - Raw glycerine (70 %) - Pharmaglycerine	 165 €/t 160 €/t 140 €/t 70 €/t 70 €/t No market prices available
Price of electricity (reduction of auxiliary power)	3.33 €ct/MJ_{el} (12 €ct/kWh_{el})
EEG remuneration (plant-specific)	...€ct/MJ_{el} (€ct/kWh_{el})

Table 18: Typical assumptions and framework conditions behind LCOE calculation (net, 2010) – Biomass combustion plants

	Private use		Commercial use		
Parameters	Single small-scale furnaces	Central heating	Central heating	Heating plants	Heat and power stations (EEG)
Annual full load hours (continuous operation) [a/h]	–	–	–	–	7,500
Annual full load hours (heat-driven) [a/h]	1,000	1,800	2,000	3,000	6,000
Capital-related costs					
Investment costs (ready for use, construction interest costs not included)	I_0	I_0	I_0	I_0	I_0
Calculatory composite interest rate	8 %	8 %	8 %	8 %	8 %
Maintenance and repair	(3.0 % · I_0)/a	(3.0 % · I_0)/a	(3.0 % · I_0)/a	(2.5 % · I_0)/a	(2.5 % · I_0)/a
Period under review[33] [a]	20	20	20	20	20
Consumption-related costs					
Costs for the biomass production: - Waste wood (wood shavings, ex plant, mc 40 %) - Waste wood of categories I and II (at plant gate) - Wood from landscape management (atplant) - Straw - Industry pellets - Wood pellets (DIN plus)	 90 €/t_{adry} – – – – 190 €/t_{adry}	 90 €/t_{adry} – 40 €/t_{adry} 80 €/t_{fm} – 190 €/t_{adry}	 75 €/t_{adry} 35 €/t_{adry} 40 €/t_{adry} 80 €/t_{fm} 120 €/t_{adry} –	 75 €/t_{adry} 35 €/t_{adry} 40 €/t_{adry} 80 €/t_{fm} 120 €/t_{adry} –	 75 €/t_{adry} 35 €/t_{adry} 40 €/t_{adry} 80 €/t_{fm} 120 €/t_{adry} –
Price of electricity (auxiliary power)	3.88 €ct/MJ (14 €ct/kWh)			3.33 €ct/MJ (12 €ct/kWh)	
Disposal: - Grate ash - Fly ash	 – –	 – –	 80 €/t –	 80 €/t 150 €/t	 80 €/t 150 €/t
Operation-related costs					
Staff requirements [EE]	–	–	0.10	0.5 EE/MW_{RTI}	0.5 EE/MW_{RTI}
Specific staff costs [€/(EE · a)]	–	–	30,000 €	40,000 €	50,000 €
Maintenance and cleaning			c.f. Table 16		
Administration	–	–	0.75 % · I_0)/a	0.75 % · I_0)/a	0.75 % · I_0)/a
Insurance (construction not included)	–	–	(1.0 % · I_0)/a	(1.0 % · I_0)/a	(1.0 % · I_0)/a
Unforeseen costs	–	–	(0.5 % · I_0)/a	(0.5 % · I_0)/a	(0.5 % · I_0)/a
Revenues from by-products					
Heat credits: - Heat up to 130 °C - High-pressure steam	 – –	 – –	 0.83 €ct/MJ_{th} –	 0.83 €ct/MJ_{th} 1.39 €ct/MJ_{th}	 0.83 €ct/MJ_{th} 1.39 €ct/MJ_{th}
Price of electricity (reduction of auxiliary power)	–	–	–	–	3,33 €ct/MJ (12 €ct/kWh)
EEG remuneration (plant-specific)	–	–	–	–	... €ct/MJ_{el} ... (€ct/kWh_{el})

[33] The period under review is neither the technical nor the economic service life (depreciation), but rather a standardised period. The technical service life should be used as depreciable life, and - if necessary - replacement investments as well as liquidation proceeds should be taken into consideration (calculation in accordance with VDI 6025).

Table 19: Typical assumptions and framework conditions behind LCOE calculation (net, 2010) – Biomass gasification (use in engines or methanisation)

Parameters	Assumptions and framework conditions
Annual full load hours (continuous operation)	7,500 h/a
Annual full load hours (heat-driven)	6,000 h/a
Capital-related costs	
Investment costs (ready for use, construction interest rate not included)	I_0
Calculatory composite interest rate	8 %/a
Maintenance and repair (technology-dependent)	see Table 16
Period under review[33]	20 years
Consumption-related costs	
Costs for biomass production: - Waste wood (wood shavings, at plant gate, moisture content 40 %) - Waste wood of categories I and II (at plant gate) - Wood from landscape management (at plant gate) - Straw - Wood pellets	75 €/t_{adry} 25 €/t (at H_i=3.8 kWh/kg) 25 €/t_{adry} 60 €/t_{fm} 120 €/t_{adry} (industry pellets)
Price of electricity (reduction of auxiliary power)	3.33 €ct/MJ_{el} (12 €ct/kWh_{el})
RME	1 €/kg
ZnO	20 €/kg
$CaCO_3$	0.05 €/kg
Process water / feed water	2 €/m³ / 6 €/m³
Disposal: - Grate ash / fly ash/ uncontaminated wastewater - Contaminated ash / wastewater (hazardous waste)	80 €/t / 150 €/t / 5 €/m³ 500 €/t and / or €/m³
Operation-related costs	
Staff requirements (depending on technology and concept) [EE]	0.5 EE/MW_{RTI}
Specific staffing costs [€/(EE · a)]	50,000
Maintenance and cleaning	see Table 16
Administration	(0.50 % · I_0)/a
Insurance (constructions not included)	(1.00 % · I_0)/a
Unforeseen costs	(0.5 % · I_0)/a
Revenues from by-products	
Heat credits: - Heat up to 130 °C - High-pressure steam	0.83 €ct/MJ_{th} (3 €ct/kWh_{th}) 1.39 €ct/MJ_{th} (5 €ct/kWh_{th})
Price of electricity (reduction of auxiliary power)	3.33 €ct/MJ_{el} (12 €ct/kWh_{el})
EEG remuneration (plant- / system-specific)	... €ct/MJ_{el} (€ct/kWh_{el})

For the a standardised calculation of the biomass demand and the feedstock costs, Table 20 lists the average inferior calorific value and information on the moisture content (mc) of biomass feedstock for conversion purposes.

Table 20: Average inferior calorific value of various biomass fuels

Fuel	H_i in GJ/t_{adry}	H_i in GJ/t_{fm}	mc of fresh material in %
High-pressure straw bales	17.2	13.9	14.0
Pellets	19.0	16.3	9.0
Wood shavings	19.0	13.0	23.0
Waste wood	16.0	13.3	18.0
Energy grass	–	15.3	17.3
Rape-seed oil	–	37.2	0.1
Grass silage	–	5.8	65.0
Wheat	17.0	13.4	17.0
Maize silage	–	6.4	65.0

Outlook for 2020 and 2030

When calculating of the LCOE for 2020/2030 time horizons, it is necessary to adjust certain framework conditions. Here, three aspects have to be taken into consideration:

1. Investment costs (real)
2. Costs for the biomass production (real)
3. Development of the real reference costs (producer costs)

In addition to the investment costs, which will potentially drop due to learning effects, and the increase in plant efficiency that is to be determined specifically in the projects, feedstock prices for each time frame are specified below (Table 21). In order to render the results for the different time frames comparable to one another, it is important to relate all assumptions regarding costs and / or prices to the year 2010 and to list the real LCOE in $€_{2010}$, without taking into consideration a potential nominal price increase in the future.

Table 21: Development of the production costs of biomass

		Production costs of biomass	
Biomass	**Unit**	**2020**	**2030**
Waste wood (wood shavings at plant gate, mc 40 %)	$€_{2010}/t_{adry}$	94	107
Waste wood of categories I and II (at plant gate)	$€_{2010}/t$ (at H_i=3.8 kWh/kg)	25	25
Wood from landscape management (at plant gate)	$€_{2010}/t_{adry}$	31	36
Straw	$€_{2010}/t_{fm}$	89	98
Industry pellets	$€_{2010}/t_{adry}$	151	171
Wood pellets (DIN plus)	$€_{2010}/t_{adry}$	239	271
Rape-seed oil	$€_{2010}/t$	1,177	1,334
Rape-seed	$€_{2010}/t$	365	414
Palm oil	$€_{2010}/t$	806	913
Liquid manure	$€_{2010}/t_{fm}$	0	0
Sewage sludge (Dilute sludge, 5 % DS, proceeds)	$€_{2010}/t_{fm}$	-30	-30
Maize and / or maize silage	$€_{2010}/t_{fm}$	33	37
Cereal grain	$€_{2010}/t_{fm}$	134	147
Grass silage	$€_{2010}/t_{fm}$	33	37
Alfalfa silage	$€_{2010}/t_{fm}$	22	25
Sunflower silage	$€_{2010}/t_{fm}$	28	31
Sugar beet leaf silage	$€_{2010}/t_{fm}$	26	28
Feeding rye silage	$€_{2010}/t_{fm}$	27	29

The assumption underlying the LCOE is that this is a tried-and-tested conversion system which has been introduced to the market. This offers the advantage of economically comparing technologies in different states of development. Furthermore, it is possible to estimate the future potential of pilot and demo plants, and to make strategic decisions with respect to further funding. However, in order not to consider the results entirely independently of the state of development, it is necessary to document either the assumptions or the real data. In this context, information regarding the state of development, the market availability and the need for development are intended to render the results more transparent and to point out deviations from commercial plants. The LCOE are therefore to be gathered and published together with the documentation list (see Table 22).

6.4 Presentation of results

If possible, results should be presented in a graphical form in addition to a tabular form, in order to visualize the different cost structures of different supply concepts. As an example, the LCOE (Figure 12) are presented below.

To calculate the differential cost of providing bioenergy, a fossil reference system should be selected that would be considered as an alternative to bioenergy. The assumptions with respect to the thermal utilisation efficiency have to be the same in the calculations of the material and energy flows, the LCOE and the GHG emissions in order to ensure comparability of the GHG mitigation costs.

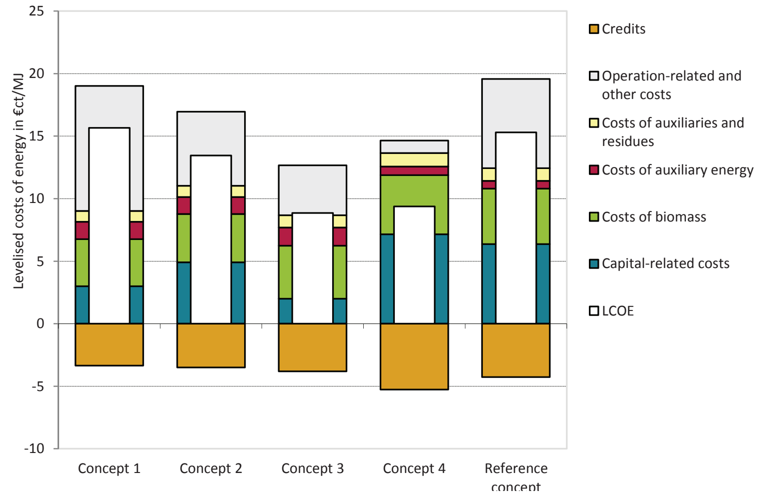


Figure 12: Levelised costs of energy (source: original illustration)

The assumptions and system boundaries used to calculate the LCOE for bioenergy and for the fossil reference have to be similar. In addition, sensitivity analyses may help to illustrate the main influencing factors and uncertainties inherent in the LCOE calculation. In this context, an appropriate range of variation for each parameter has to be selected and should be included in the evaluation. For small-scale furnaces, it is necessary to expand the system boundaries to include the useful energy, since there are significant differences in the cost structure of distribution and utilisation in comparison to fossil systems. For all other conversion routes, the bioenergy production is sufficiently exact as a system boundary, with the GHG emissions of the final combustion in the engine being taken into consideration for biofuels and fossil fuels for transport.

Table 22: Documentation list of important variables influencing the calculation of LCOE

Parameters	Information	Explanation
State of development of the plant	☐ Test plant ☐ Pilot plant ☐ Demo plant ☐ Commercial plant	Total rated thermal input: Cumulative operating hours: Annual operating hours:
Plant capacity	Planned total rated thermal input of the market-ready plant:	Necessary scaling factor
Development expenditure	☐ Basic research ☐ Concept development ☐ Component development ☐ Scaling ☐ Fuel adaptation ☐ Process optimisation	Technical obstacles: Economic obstacles:
Planned commercialisation (market availability of the plant)	☐ < 1 year ☐ < 5 years ☐ < 10 years ☐ No commercialisation possible under the current framework conditions	Planned market introduction strategy

Parameters	Data collection			Explanation of the data: Method, calculation, source of assumption
	Measurement and / or real data	Calculation	Assumption	
Investment costs	☐	☐	☐	
Service life of the plant components	☐		☐	
Mode of operation				
- electricity-driven	☐		☐	
- heat-driven	☐		☐	

7 Methodology for balancing greenhouse gas emissions and other emissions

7.1 Background

Assessing the environmental implications of bioenergy production is crucial, in order to support the ongoing climate and environmental policy debates. In the classical life-cycle assessment (LCA), there are numerous degrees of freedom with respect to the methodology, thus reducing the comparability of different balanced results. Therefore, a harmonisation of the calculation methodologies should be strived for where possible, with regards to the projects conducted as part of the funding programme “Biomass energy use”. The objective of the methodology suggested within this chapter is to “provide” a simpler and more transparent methodology which allows, as best as possible, the production of comparable balanced results. Therefore, the application of the EU RED (Directive 2009/28/EG) methodology is the most preferable approach for the calculation of greenhouse gas (GHG) emissions, acidification and particle emissions. It differs from the complete life-cycle assessment in accordance with ISO 14040 and 14044, this methodology limits itself to the calculation of greenhouse gas emissions. In the current discussion of the production and use of bioenergy, these two approaches have been discussed the most. The calculation methodology, with regards to an auxiliary function, therefore, appears to currently be the only applicable compromise between the necessity for methodical complexity and ensuring the comparability of the results through approaches and methods that are as straightforward and transparent as possible. The methodology definitely does not constitute a substitute for the life-cycle assessment in accordance with ISO 14040 and 14044.

The method presented below constitutes the basic requirements for estimating the potential emissions from a particular bioenergy system.[34] The simplified methodology for estimating the acidification and the particle emission, is introduced below.

Of course, all projects involved in the funding programme are free to go beyond this simplified approach and make detailed calculation steps, where data and project conditions allow.

[34] For the further development of the process, the working group "Life-cycle Assessment" in the funding programme "Biomass energy use" provides a platform for, e.g., the selection of system boundaries, selection of the database for emissions factors, the handling of by-products, the handling of different effect category results on the interpretation of results, etc., in order to provide the participants of the funding programme with methodical support in dealing with these issues.

7.2 General methodology

The methodology for the life-cycle assessment can organised into four steps (Figure 13): (i) Goal and scope definition, (ii) life-cycle inventory analysis, (iii) impact assessment, (iv) interpretation. The first step – goal and scope definition – describes the system boundaries and defines the functional unit. Within the life-cycle inventory analysis all emission along the supply chain and within the system boundaries are determined.In the impact assessment step the emissions are sorted into associated environmental impact categories and characterized as to the amount each emission may contribute to a potential impact, i.e. 1 kg CO_2= 1 kg CO_2-equivalent. The interpretation step involves the analysis of both the results from the life-cycle inventory and the impact assessment. .

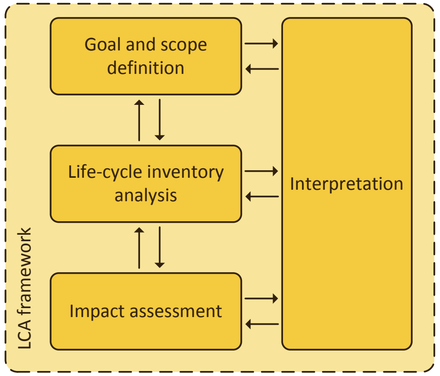


Figure 13: Methodological approach in accordance with DIN ISO 14040 (ISO 14040)

The methodology recommended for the calculation of GHG emission in accordance with the EU RED in the context of the funding programme "Biomass energy use" is in essence modelled after the layout in accordance with DIN ISO 14040, but considerably restricts the degrees of freedom of the balancing. The approach of the EU RED differs in various items from that of DIN ISO 14040. Conducting GHG balances in accordance with the EU RED ensures the provision of clear calculation requirements, with respect to the system boundaries to be taken into consideration, the co-generated products, CO_2 conversion factors and the fossil reference systems. Furthermore, the methodology of the EU RED to date only applies to liquid and gaseous biofuels, as well as bioliquids for the generation of power, heat and cooling. While there is a need to improve the sustainability criteria for solid and gaseous biomass used in the generation of power, heat and cooling[35], it is currently not recognized at the European level. The EU Commission (hereinafter referred to as EU COM) is making recommendations to member states that want to expand the sustainability standards also to solid and gaseous biomass (EU COM 2010a). The methodical requirements of the EU RED are shown below and outline the recommendations of the EU COM with regards to the calculation of GHG balances for solid and gaseous biomass used in the generation of energy.[35]

[35] If in the following there is an abbreviated mention of solid and gaseous biomass for the generation of energy, it should be pointed out, here, that gaseous biomass as biofuel is subject to the sustainability requirements of the EU RED for biofuels.

7.3 Assumptions and framework conditions

Goal and scope definition. The system boundaries for the generation of bioenergy includes the whole supply chain, from the cultivation and the provision of the biomass to the conversion and processing all the way to the energy production, including logistics, distribution, and use[36] (Figure 14).

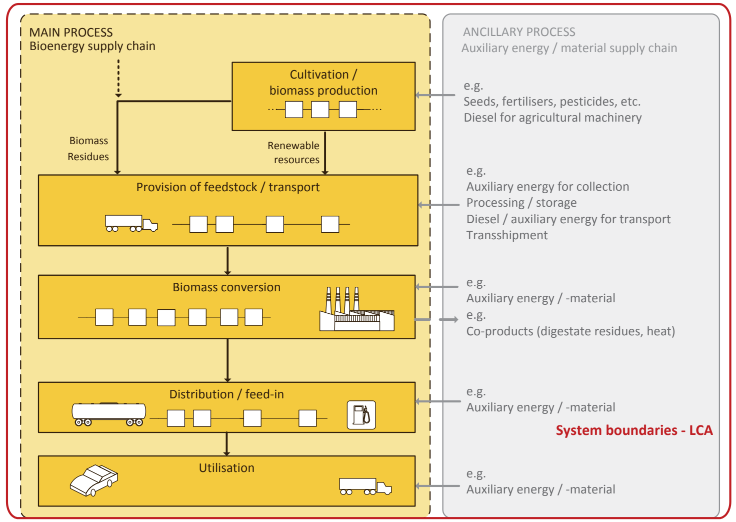


Figure 14: System boundaries (source: original illustration)

For the biomass supply chain the major processing steps include:

- Feedstock production: (i) Inputs for the production of the different feedstock and substrates. This should include all inputs relating to the production such as; fertilisers, seeds, diesel and pesticides, as well as, in case of energy crops any land use change. (ii) In accordance with the selected methodology for the calculation of the GHG emission, residues only include inputs relating to their collection and processing, all other aspects relating to the the pre-production chain (upstream) are not considered (outside the scope).
- Provision of biomass: Transport to the conversion plant (including biomass pretreatment; drying, chopping, pelletising)
- Conversion: Conversion of the biomass into useful energy or energy carrier (e.g. through chemical, thermological, or biological processes)

[36] The following applies to the balancing of GHG emissions: The greenhouse gas emissions upon use are assumed to be zero.

- Distribution: Transfer of energy / energy carrier to the final user (e.g. via rail, road or pipe)
- Utilisation: With respect to the balancing of GHG emissions, the CO_2 released on combustion of a biofuel is determined to be negligible. This is with respect to the assumption that any CO_2 emitted through the combustion of a biofuel is mitigated, due to the CO_2 uptake of the crop during its growth phase. Therefore resulting in an overall balance of zero.

Life-cycle inventory analysis. The life-cycle inventory analysis includes the data collection and the calculation for the quantification of all relevant input and output flows of the whole supply chain (Figure 15). All emissions determined within the life-cycle inventory analysis are sorted in the impact assessment step, condensed, and analysed with respect to their potential environmental impacts.

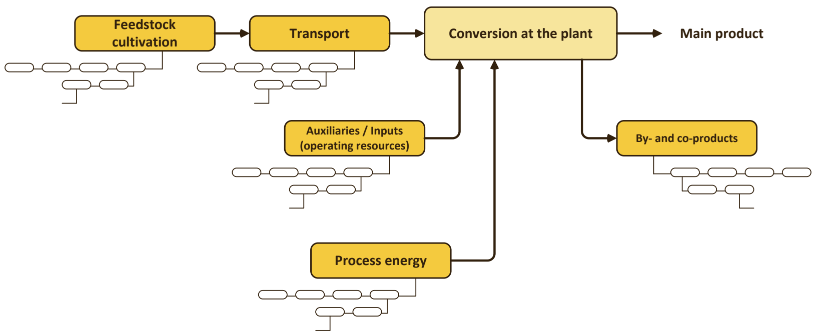


Figure 15: Schematic presentation of a supply chain (source: original illustration)

Typically, the data collection takes place with the help of data collection sheets. These sheets contain documentation lists of all relevant material and energy flows belonging to the different processes, as presented in Figure 14. The corresponding documentation lists for the conversion processes can be found in Chapter 5 “Methods for energy and material balancing of the conversion process” (see Chapter 5.4 “Data collection and presentation of results”).

Table 23: Documentation list of the relevant material and energy flows for the processes of feedstock production, provision / transport, distribution and use

Feedstock production	Unit	Data entry (including method of collection)
Type of feedstock	–	
Total amount of feedstock	t/a	
Origin of feedstock		
Size of field	ha	
Yield	t/ha	
Moisture content	%	
Final destination of straw and / or residues	kg/ha*a	
Diesel consumption for cultivation / harvest /	L/ha	
processing (e.g. chopping):	–	
N fertiliser	kg/ha	
P fertiliser	kg/ha	
K fertiliser	kg/ha	
Lime	kg/ha	
Farm manure	kg/ha	
Organic manure (please specify)	kg/ha	
Pesticides	kg/ha	
Electricity needed for drying	kWh/kg	
Fuel oil for drying (possibly other	MJ/kg	
fuels, to be specified in more detail)	–	
Status of the cultivated area prior to	–	
01 Jan 2008 (for eligibility for RenFe bonus	–	
before 01 Jan 2005)		
Provision of feedstock / transport	**Unit**	**Data entry**
Means of transportation (truck, train...)	–	
Payload of means of transportation utilised	t/TM	
Transport energy utilised	–	
(diesel, biodiesel, electricity...)	–	
Energy consumption loaded	L/km	
Energy consumption empty	L/km	
Transport distance loaded	km	
Transport distance empty	km	
Feedstock transport per means of transportation	t/TM	
Feedstock losses	%	
Silage losses	%	
Distribution / transport	**Unit**	**Data entry**
For transport processes, see data retrieval	–	
Provision of feedstock / transport	–	
Energy consumption of gas compressor stations	MJ/m³	
Energy consumption of gas station per fuel	kWh/MJ	
Use	**Unit**	**Data entry**

Emissions determined within the life-cycle inventory analysis are sorted in the impact assessment step, into their related impact categories and characterized as to the amount each emission may contribute to a potential impact. In accordance with the EU RED and the EU COM, the impact assessment method for GHG calculations are performed in accordance with IPCC 2001 emission factors (IPCC 2001). For the application of more recent or current impact assessment methods (e.g. characterisation factors in accordance with JRC (EU COM JRC 2011)), the project should also publish the life-cycle inventory data.

A basic requirement for all calculations is a conversion plant concept which has been established in the market. In projects where this has not (yet) been achieved, assumptions need to be made on the most appropriate available data. In this context, the point in time also has to be specified at which market availability is expected.

Consideration of co- products. The handling of the co-generated products is performed, in accordance with the requirements of the corresponding regulations and recommendations as described in the following section.

Co-products are products that result from the same production process. They are taken into consideration by means of allocation. Allocation means that the sum of the expenditures and the emissions and energy expenditures associated therewith that are incurred for the production of the co-product are distributed between the main product and the co-product (Figure 16). The allocation is performed for the bioliquids and biofuels for transport in accordance with the EU RED based on the inferior calorific value[37].

A special arrangement exists for the handling of excess electricity from cogeneration plants. According to that, GHG reductions associated with excess electricity produced shall be equated with the volume of GHG that would be emitted through the generation of the equivalent amount of electricity produced at a power plant that uses the same fuel as the CHP plant.

When dealing with heat as a co-product, the recommendations of the EU COM, stipulate the allocation between main product and useful heat co-products with the help of the Carnot efficiency (C), in which C assumes the value 1 for all products / co-products except for useful heat. The exact methodology of calculation can be found in the recommendations of the EU COM for solid and gaseous biomass (see APPENDIX III: Methodology for GHG accounting).

The provision of unallocated data is recommended in order to enhance the transparency and transferability (i.e. to be utilized by others) of the given dataset.

[37] The inferior calorific value (H_i) is the inferior calorific value of the whole co-product and not just the inferior calorific value (H_i) of its dry share.

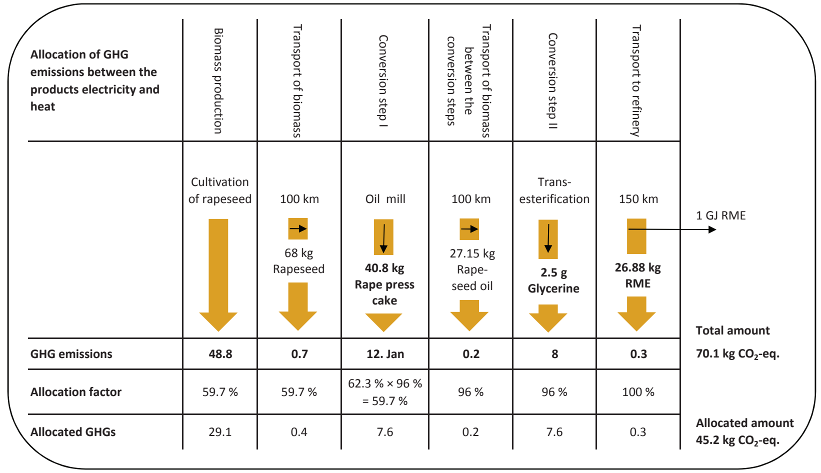


Figure 16: Schematic presentation of the allocation based on the example of rape-seed [oil] methyl ester (RME) (Fehrenbach et al. 2007)

Functional unit. Presented in a simplified form, the functional unit quantifies the benefit provided by a product system. The result of the balancing can then be listed relative to the benefit provided. In this sense, the following functional units of GHG emission resulting from the bioenergy production are recommend as follows:

- Electricity: 1 MJ_{el}
- Heat: 1 MJ_{th}
- Fuels for transport: 1 MJ

Additional framework conditions for the calculation:

- Direct land use changes. In accordance with the formula for the calculation of greenhouse gas emissions listed in APPENDIX III, emissions due to land use changes are taken into consideration. Detailed instructions regarding the calculation methodology can be found in the Guideline for Sustainable Biomass Production of the Federal Office for Agriculture and Food (BLE 2010). The remarks regarding this are presented in excerpts in APPENDIX III.
- Infrastructure expenditures. Since the emissions associated with the manufacturing of the plants and equipment have a negligible impact on the overall balance (IEE 2008) of bioenergy systems, infrastructure inputs (e.g. steel, concrete relating to buildings) are not taken into consideration, as opposed to the reference systems presented in Chapter 8.

- All field emissions are calculated in accordance with the IPCC guidelines (IPCC 2006) or a future update of said document. Furthermore the use of artifical fertilisers, organic fertilizer or any nitrogen related imputs used in the production of biomass, must be included within the GHG balances.
- For the use of residues and wastes, only emissions relating to the the collection and pretreatment processes (e.g. cleaning, drying) are included. Those emissions relating to processes prior to collection i.e. from the upstream chain are not taken into consideration. The use of biomass residues and wastes for energy reduces competitions of use, as they are caused by energy crops. However, in the use of residues and wastes, the resource competition to material utilisation needs to be kept in mind, too.

The framework conditions of the calculation methodology are summarised in Table 24.

Table 24: Methodical assumptions regarding the calculation of GHG emissions

Aspects / criteria	Framework conditions for the calculation
System boundaries	From the production and provision of feedstock to utilisation (see Figure 3).
Dealing with co-products	Allocation of co-products based on their inferior calorific value[38]; for separating out heat, allocation by means of Carnot efficiency (c.f. APPENDIX III)
CO_2-eq. characterisation factors	IPCC 2001[39] (e.g. CH_4: 23; N_2O: 296)

7.4 Calculation of the greenhouse gas reduction potential

The greenhouse gas reduction represents the potential mitigations of greenhouse gas emissions (in percent) due to bioenergy use, in comparison to the substituted fossil fuels.[40] The calculation of the greenhouse gas reduction is performed with the help of the following formula:

$$Greenhouse\ gas\ reduction = \left[\frac{E_F - E_B}{E_F}\right] \cdot 100\%$$

E_B = total emissions of bioenergy use
E_F = total emissions of fossil reference systems

Fossil reference systems For the calculation of the greenhouse gas reduction potential, the average systems for the production of electricity, heat and fuel suggested in Chapter 8 "Reference Systems" should be applied. However, we suggest that for biofuels for transport and bioliquids the greenhouse gas reduction in comparison to the fossil comparators specified in the EU RED (Table 25) be determined. Which reference systems are to be applied at what point in time is explained in the following table using the fuel biomethane as an example.

[38] The inferior calorific value (H_i) is the inferior calorific value (H_i) of the whole co-product and not just the inferior calorific value (H_i) of its dry share.
[39] In accordance with the provisions of the EU RED, the conversion factors of the IPCC 2001 (IPCC 2001) apply.
[40] Here, "fossil fuels" is representative of the respective energy mix used.

Table 25: Application of the fossil reference systems for the calculation of the greenhouse gas reduction potential using biomethane as an example

Biomethane use option	Fossil reference system
Electricity from biomethane	Characteristics of the electricity production at local consumer (low voltage level): 166 gCO_2-eq./MJ (2010); 151.2 gCO_2-eq./MJ (2020); 107.1 gCO_2-eq./MJ (2030)
Heat from biomethane	Characteristics of the production of heat mix natural gas / fuel oil: 87.8 gCO_2-eq./MJ (2010); 85.4 gCO_2-eq./MJ (2020); 84.1 gCO_2-eq./MJ (2030)
Biomethane as biofuel for transport	Characteristics of the production of petrol and 100 % conversion in a mid-range car with gasoline engine: 90.2 (2010); 89.5 (2020); 89.4 (2030) gCO_2-eq./MJ and fossil reference for petrol / diesel EU RED: 83.8 gCO_2-eq./MJ

The assumptions with respect to the material and energy flows as well as the thermal utilisation factor for the balancing of GHG emissions and for the calculation of the differential costs of the energy production from biomass have to be the same in order to calculate the GHG mitigation costs. For the balancing of GHG emissions, a fossil reference system should be selected that matches the selected reference system of the calculation of the differential costs of the bioenergy production.

7.5 Calculation of the acidification potential and the particle emissions

The acidifying and particle emissions are calculated in the same manner as the GHG emission outlined in the previous sections. Since there is no stipulated fossil reference system for acidifying and particle emissions within the EU RED, the average systems suggested in Chapter 8 “Reference Systems” are applied to the calculation of the reduction potentials.

The most important acidifying damaging substances are SO_2, NO_x and NH_4. The unit is kg SO_2-equivalent. The acidifying effect is presented as SO_2-equivalent. To estimate the acidifying effect, the material flows are considered in Table 26 in accordance with JRC (EU COM JRC 2011) . The characterisation factors and corresponding data sets are available via the web page on Life-Cycle Assessment of the Joint Research Centre (EU KOM JRC 2013).

Table 26: Emissions with an acidifying effect (EU COM JRC 2011)

Name	Molecular formula
Sulphur dioxide	SO_2
Dinitrogen monoxide (laughing gas)	N_2O
Ammonia	NH_3
Nitrogen monoxide	NO
Sulphur trioxide	SO_3

7.6 Presentation of results

The results of the LCA should be presented in a comprehensive and transparent and in the form of a bar chart (Figure 17) and / or in tabular form. For better comparability between GHG balances, a listing of the emissions in CO_2-equivalents relative to the functional unit is recommended.

The assumptions regarding the balancing of GHG emissions and levelised costs of energy have to be similar in order to calculate the GHG mitigation costs.

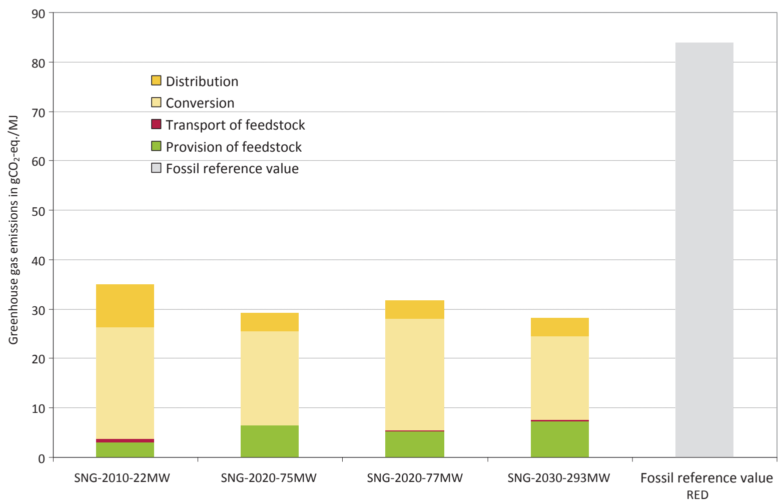


Figure 17: Biomethane as biofuel - Presentation of greenhouse gas emission results in gCO_2-eq./MJ_{CH4} as an example (source: original illustration)

7.7 Additional sustainability aspects

Some essential factors that are important for the sustainability assessment of the projects within the funding programme cannot be taken into consideration in the necessary depth within as part of this method handbook. Therefore, their importance is only briefly referenced in the current version:

- Humus effects: For sustainability reasons, the humus balance of soils should be balanced long-term (balance objective of between -75 and +100 kg, max. +300 kg Humus-C/ha). The humus balancing determines the need for organic carbon that is necessary for maintaining the humus reserves and thereby the soil's fertility. An effect on the humus is provided by, for example, harvest residues and straw, but also by green manuring (catch crops) or organic fertilisers (such as liquid manure or digestates) that are left or spread on the field. A "humus balance surplus" (> 300 kg Humus-C/ha) causes an increased N mineralisation; thereby, the risk of nitrate leaching increases, but also that of increased laughing gas emissions.

  Different material flows that are discharged and supplied, and especially the individual conversion technologies have a very different effect, here. Since in addition the individual humus effect of the co-generated products as well as of the conversion residues differs a lot and since preceding crops can also have an impact on the type of crop under consideration, the system boundaries should be fundamentally expanded and crop sequence considerations should be applied (VDLUFA position on humus balancing - Method for the assessment and sizing of the humus supply of arable land, VDLUFA self-publishing 2004; currently undergoing an update).

- (Indirect) land use change: Biomass originates from the cultivation of and harvesting from arable land, meadows or forests and is therefore associated with land use.[41] When using wastes or residues, this depends on the allocation between the main and by-products. The production and use of bioenergy may also lead to a conversion of areas, if, for instance, short rotation plantation is established on former grazing land (land use change = LUC).

  An assessment is not easy, however: One of the difficulties is that an LUC at one site can trigger cascade-like LUCs at other sites via displacement effects. This is referred to as "indirect land use change", or - in short - iLUC, as opposed to direct land use changes (dLUC). Also possible are impacts due to a more intense utilisation of the remaining areas than before.

  One of these impacts are emissions of greenhouse-relevant gases. If direct land use changes exist, the emissions from direct land use changes (dLUC) have to be taken into consideration in the calculation of the GHG reduction in accordance with the EU RED (c.f. Chapter 7.3 and APPENDIX III).

[41] Generally, the land use for biomass production is not to be assessed differently than that for foodstuffs or feedstuffs.

Greenhouse gas effects due to direct land use changes are taken into consideration in the methods at hand. The social and economic impacts of the land use and / or its change can also be of considerable relevance. A presentation of the methods would, however, go beyond the scope of this method handbook. Interested projects may refer to Berndes 2012, EU COM 2012, Fritsche 2012, Fritsche & Wiegmann, 2011; RSB 2012 (iLUC).

- Land use: Biomass cultivation does not differ in a manner inherent in the system from the agricultural cultivation of food and feed crops. To be able to determine difference on the land use process level, it is necessary to revert to the management level of the primary production, which is not (yet) possible with the current instruments for the determination of GHG emissions and other emissions. Silage maize for biomass is, for instance, in principle no better or no worse than silage maize for feeding – the cultivation management controls the environmental compatibility. Therefore, an identical production method is to be assumed initially in the calculation of GHG and other emissions.

- P as resource: Significant differences in the assessment of different bioenergy processes may result if P no longer is considered only to the extent of the manufacturing expenditure for fertilizer, as has been done to date, but rather as a scarce resource. In case of exclusively biochemical conversion technologies, P is maintained completely in (re)circulation, whereas in case of thermochemical processes, phosphate is quite often converted into an insoluble form that cannot be used by plants. To not let a P deficiency situation develop in the soil in the first place, with, for example, subsequent biomass yield reduction, thermochemical processes have to be expanded, for example, beyond their system boundaries with a P recycling / processing component in order to keep the phosphorus in circulation for resource protection. This can lead to a significant worsening of thermochemical processes in the assessment that is based on GHG emissions and other emissions due to the additional production step.

- Micro- and macroeconomic effects of the bioenergy production: With the increasing interaction of renewable energy sources, additional effects become important in the economic assessment of the bioenergy production that cannot be described by a pure assessment of the LCOE. But if a comparison of the different renewable energies under aspects that maximise the walfare of the economy is strived for, the system boundaries have to be expanded to include the production of useful energy. Further external effects must be taken into consideration mandatorily, whereby the complexity and the expenditure of the analysis increases significantly (Zeymer et al. 2013). For example, the costs for distribution, grid infrastructure and the costs of ensuring grid stability as well as the transmission loss are not taken into consideration in the LCOE calculation at plant gate. If the focus of the assessment is on the overall walfare of an economy, the costs and proceeds of the external effects furthermore need to be internalised in order to be able to assess the advantageousness of a conversion path. Considering the further energy transition to renewable energies and the increasingly diverse supply tasks of the different fuels it becomes more and more relevant to take these effects into account.

8 Reference systems

In order to assess the balance results of bioenergy systems, the comparison to reference systems is necessary. For the production of energy, these so-called conventional reference systems[42], which are to be referenced as standardised basis of comparison by the projects in the funding programme "Biomass energy use", are described below.[43] Presented are the reference systems for electricity, heat and fuels for transport, each with values for a review of the average and for a marginal analysis, with concrete data with respect to

- emissions of greenhouse gases (GHG),
- emissions of air pollutants (acidifying emissions and fine dust) as well as
- the cumulative non-renewable primary energy consumption (PEC).

It is recommended to generally use the values of the average systems as reference.

8.1 Definition, system space and temporal reference of the reference systems

Reference systems are comparison processes for the production of electricity, heat and fuels for transport, whose characteristics for environmental aspects were determined from life-cycle calculations with GEMIS Version 4.8 (IINAS/ÖKO 2012). The background data for the calculation of the life-cycle paths of the respective reference systems are contained in GEMIS in disaggregated and transparent form.

The geographical reference of the reference systems is Germany, but for the upstream supply chains costs for fuels, corresponding processes abroad are included, too.

The temporal reference is the year 2010, wherein additionally also 2020 and 2030 are listed in accordance with the data from IINAS/ÖKO 2012, which is based on data of the BMU lead study (DLR 2010a, DLR 2010b, BMU 2010) as well as a continuation based on Prognos/EWI (Prognos/EWI/GWS 2011) and SRU 2011 as part of the ongoing UBA project renewbility-II (ÖKO/DLR-IVF/ISI 2012).

For the GHG emissions, the CO_2-equivalents were each determined based on IPCC 2007 for the specific global warming potential in case of a 100 year integration period (GWP_{100}). The information regarding GHG emissions for the production of electricity and / or heat refers to free plant park. For fuels for transport, the data are listed for final energy, plus the emissions that are released upon a 100 % conversion in a vehicle. This way, comparability

[42] Further essential reference systems are the alternative utilisation of the available areas and / or residues. But, at present, these cannot be sensibly harmonised across project and should therefore be documented in the respective projects.

[43] The selection of the reference systems was discussed and specified at the "Reference Systems" workshop on June 8, 2010 in Darmstadt (Germany). See also: www.energetische-biomassenutzung.de/index.php?id=529

is ensured, since the utilisation options and effects of fossil and biomass final energies are identical. All data regarding degrees of utilisation and / or degrees of efficiency refer to the inferior calorific values (H_i). Also included in the information are always the upstream processes, domestically and abroad, as well as the manufacturing expenditures.

8.2 Reference systems for the electricity production

As reference system for electricity, the generation mix of the public power plant park is assumed, since this represents the relevant metric for **average** considerations **without** reference to the power grid.

For the electricity production in the year 2010, the statistical data of the Federal Ministry for Economic Affairs and Energy (BMWi 2011) was used and on this basis, the average characteristics of the German public power plant park were presented. The continuation for 2020 and 2030 was performed based on the updated lead scenario (see above); it is presented in Table 27. The characteristics of the reference system "Electricity from the German power plant park" derived therefrom are presented in Table 28.

In addition, this reference system is considered with the transmission and distribution losses down to the low voltage level added in, since this constitutes the more applicable basis of comparison for situations with lower electrical power (e.g. smallest CHPs). For this, here, the data of the generation mixes for electricity were linked with the data from GEMIS regarding the transmission and distribution of electricity free low voltage consumer. The supplemental values are shown in Table 29.

As further supplemental information for marginal analysis, the large power plants for natural gas GaS and imported black coal are relevant; the indicators are presented in Tables 27 to 30.

Table 27: Characteristics of the public power plant park in Germany, 2010 – 2030 (in % share of the generation of electricity)

Energy source material	2010	2020	2030
Black coal	19.0	10.8	4.5
Lignite	23.4	14.0	6.0
Natural gas incl. other gases	16.2	18.5	17.4
Oil	1.3	1.0	0.0
Waste	1.5	1.6	1.5
Nuclear power plant	22.7	9.0	0.0
Water power	3.3	4.0	4.5
Wind	5.9	22.5	35.0
PV	1.9	8.0	11.5
Geothermal	0.0	0.3	1.1
Landfill gas, sewage gas and biogas	0.3	0.3	0.3
Wood, straw, other biomass	4.3	10.0	13.3
RE import	0.0	0.0	5.0
Share of non-renewable	**82.7**	**53.3**	**27.9**
Share of renewable (incl. waste)	**17.3**	**46.7**	**72.1**
Share of CHP (fossil, biomass)	**11.5**	**25.0**	**30.0**

Source: Own calculation based on the Federal Ministry for Economic Affairs and Energy (BMWi 2011) as well as for 2020 and 2030 as part of the ongoing UBA project renewbility-II (ÖKO/DLR-IVF/ISI 2012) based on DLR (DLR 2010a, 2010b); DLR/IWES/IfnE (BMU 2010), Prognos/EWI/GWS 2011 and SRU 2011.

Table 28: Characteristics of the electricity production at the power plant park, 2010 – 2030

Indicator	Units	2010	2020	2030
GHG as CO_2eq	g/MJ_{el}	163.9	107.7	60.1
- of those, CO_2	g/MJ_{el}	156.7	101.8	55.6
- of those, CH_4	g/MJ_{el}	0.19	0.13	0.07
- of those, N_2O	g/MJ_{el}	0.01	0.01	0.01
Acidifying emissions	$g\ SO_2\text{-eq.}/MJ_{el}$	0.22	0.17	0.09
- of those, SO_2	g/MJ_{el}	0.09	0.06	0.02
- of those, NO_x	g/MJ_{el}	0.16	0.12	0.08
- of those, NH_3	g/MJ_{el}	0.01	0.01	0.01
Fine dust (PM_{10})	g/MJ_{el}	0.01	0.01	0.01
$PEC_{non\text{-}renewable}$	$MJ_{primary}/MJ_{el}$	2.30	1.37	0.65
Producer costs	$€_{2010}/GJ_{el}$	20.4	26.3	27.9

*Source: IINAS/ÖKO 2012, data **without** power grid.*

Table 29: Characteristics of the electricity production at local consumer (low voltage level), 2010 – 2030

Indicator	Units	2010	2020	2030
GHG as CO_2eq	g/MJ_{el}	168.7	111.2	62.2
- of those, CO_2	g/MJ_{el}	161.6	105.1	57.5
- of those, CH_4	g/MJ_{el}	0.20	0.13	0.08
- of those, N_2O	g/MJ_{el}	0.01	0.01	0.01
Acidifying emissions	g SO_2eq./MJ_{el}	0.23	0.17	0.09
- of those, SO_2	g/MJ_{el}	0.09	0.06	0.02
- of those, NO_x	g/MJ_{el}	0.16	0.12	0.08
- of those, NH_3	g/MJ_{el}	0.01	0.01	0.01
Fine dust (PM_{10})	g/MJ_{el}	0.01	0.01	0.01
$PEC_{non-renewable}$	$MJ_{primary}$/MJ_{el}	2.37	1.42	0.67
Producer costs	€$_{2010}$/GJ_{el}	51.3	59.9	68.4

*Source: IINAS/ÖKO 2012, data **including** power grid.*

Table 30: Characteristics of the electricity production from new natural gas GaS power plants, 2010 – 2030

Indicator	Units	2010	2020	2030
η_{el}	%	58.1	60.1	62.1
GHG as CO_2eq	g/MJ_{el}	112.7	107.4	105.4
- of those, CO_2	g/MJ_{el}	105.8	101.6	99.7
- of those, CH_4	g/MJ_{el}	0.22	0.19	0.20
- of those, N_2O	g/MJ_{el}	0.00	0.00	0.00
Acidifying emissions	g SO_2eq./MJ_{el}	0.11	0.08	0.06
- of those, SO_2	g/MJel	0.00	0.00	0.00
- of those, NO_x	g/MJ_{el}	0.16	0.11	0.08
- of those, NH_3	g/MJ_{el}	0.00	0.00	0.00
Fine dust (PM_{10})	g/MJ_{el}	0.00	0.00	0.00
$PEC_{non-renewable}$	$MJ_{primary}$/MJ_{el}	1.93	1.86	1.83
Producer costs	€$_{2010}$/GJ_{el}	22.6	24.6	25.9

*Source: IINAS/ÖKO 2012, data **without** power grid.*

Table 31: Characteristics of the electricity production from new power plants for imported black coal, 2010 – 2030

Indicator	Units	2010	2020	2030
η_{el}	%	45.8	50.1	51
GHG as CO_2eq	g/MJ_{el}	246.8	216.9	210.3
- of those, CO_2	g/MJ_{el}	232.1	206.2	202.0
- of those, CH_4	g/MJ_{el}	0.45	0.31	0.28
- of those, N_2O	g/MJ_{el}	0.01	0.01	0.00
Acidifying emissions	g SO_2eq./MJ_{el}	0.33	0.22	0.20
- of those, SO_2	g/MJel	0.17	0.08	0.08
- of those, NO_x	g/MJ_{el}	0.22	0.20	0.17
- of those, NH_3	g/MJ_{el}	0.00	0.00	0.00
Fine dust (PM_{10})	g/MJ_{el}	0.025	0.015	0.015
$PEC_{non-renewable}$	$MJ_{primary}$/MJ_{el}	2.48	2.16	2.12
Producer costs	€$_{2010}$/GJ_{el}	15.1	14.4	13.7

*Source: IINAS/ÖKO 2012, data **without** power grid.*

As share towards the supply mix of electricity for marginal analysis, power plants for 50 % natural gas GaS and 50 % imported black coal were assumed, which results in the "marginal mix" presented in Table 32.

Table 32: Characteristics of the marginal mix (power plants for natural gas GaS and imported black coal), 2010 – 2030

Indicator	Units	2010	2020	2030
GHG as CO_2eq	g/MJ_{el}	179.7	162.2	157.8
- of those, CO_2	g/MJ_{el}	169.0	153.9	150.9
- of those, CH_4	g/MJ_{el}	0.33	0.25	0.24
- of those, N_2O	g/MJ_{el}	0.01	0.01	0.00
Acidifying emissions	g SO_2eq./MJ_{el}	0.22	0.15	0.13
- of those, SO_2	g/MJ_{el}	0.08	0.04	0.04
- of those, NO_x	g/MJ_{el}	0.19	0.15	0.12
- of those, NH_3	g/MJ_{el}	0.00	0.00	0.00
Fine dust (PM_{10})	g/MJ_{el}	0.014	0.01	0.01
$PEC_{non-renewable}$	$MJ_{primary}$/MJ_{el}	2.21	2.01	1.97
Producer costs	€$_{2010}$/GJ_{el}	18.8	19.5	19.8

The values for the average consideration (total generate mix) in comparison to the marginal analysis (50 % mix, each, from power plants for natural gas GaS and imported black coal) are in terms of the GHG emission by 2020 lower by approx. 35 % than for the marginal mix, and in 2030 by almost 65 %. With respect to the air pollutants, the average consideration in 2010 and 2020 is by a little more than 10 % above the marginal mix, while it is by approx. 30 % below the marginal mix in 2030. In terms of the $PEC_{non\text{-}renewable}$, the average consideration in 2010 is about level with the maringal mix, while in 2020 its values are by approx. 30 %lower than for the marginal mix, and by 2030 by approx. 70 % lower.

This brief discussion shows that it is important to make a clear distinction between the average consideration and the marginal analysis for the environmental effects of the reference systems for electricity.

To simplify the comparison of project results, it is therefore recommended to always use the average system as a reference system for the electricity production, and - time permitting - to represent the sensitivity of the results by using a marginal analysis. In justified case, another approach may also be selected.

8.3 Reference systems for the heat production

As reference system for the heat production, a production mix from natural gas and fuel oil low-temperature heating units is assumed, since this represents the relevant metric for average considerations. For the determination of this mix system, the individual data of low-temperature heating systems for natural gas and fuel oil are used.

Table 33: Characteristics of the heat production from natural gas heating, 2010 – 2030

Indicator	Units	2010	2020	2030
η_{th}	%	86	88	90
GHG as CO_2eq	g/MJ_{th}	79.3	74.3	73.4
- of those, CO_2	g/MJ_{th}	73.3	70.6	69.5
- of those, CH_4	g/MJ_{th}	0.23	0.14	0.15
- of those, N_2O	g/MJ_{th}	0.00	0.00	0.00
Acidifying emissions	$g\ SO_2eq./MJ_{th}$	0.05	0.04	0.04
- of those, SO_2	g/MJ_{th}	0.00	0.00	0.00
- of those, NO_x	g/MJ_{th}	0.06	0.06	0.06
- of those, NH_3	g/MJ_{th}	0.00	0.00	0.00
Fine dust (PM_{10})	g/MJ_{th}	0.00	0.00	0.00
$PEC_{non\text{-}renewable}$	$MJ_{primary}/MJ_{th}$	1.34	1.28	1.27
Producer costs	$€_{2010}/GJ_{th}$	33.5	35.1	37.3

Source: IINAS/ÖKO 2012, data incl. auxiliary power and heat distribution.

Table 34: Characteristics of the heat production from fuel oil heating, 2010 – 2030

Indicator	Units	2010	2020	2030
η_{th}	%	85	86	87
GHG as CO_2eq	g/MJ_{th}	103.9	101.4	99.5
- of those, CO_2	g/MJ_{th}	102.8	100.5	98.8
- of those, CH_4	g/MJ_{th}	0.03	0.02	0.02
- of those, N_2O	g/MJ_{th}	0.00	0.00	0.00
Acidifying emissions	$g\ SO_2eq./MJ_{th}$	0.14	0.10	0.08
- of those, SO_2	g/MJ_{th}	0.09	0.06	0.04
- of those, NO_x	g/MJ_{th}	0.06	0.06	0.06
- of those, NH_3	g/MJ_{th}	0.00	0.00	0.00
Fine dust (PM_{10})	g/MJ_{th}	0.01	0.01	0.01
$PEC_{non\text{-}renewable}$	$MJ_{primary}/MJ_{th}$	1.38	1.35	1.33
Producer costs	$€_{2010}/GJ_{th}$	42.1	44.5	45.9

Source: IINAS/ÖKO 2012, data incl. auxiliary power and heat distribution.

As shares for the supply mix of heat, 70 % natural gas and 30 % fuel oil are assumed; the corresponding results are shown in the following table.

Table 35: Characteristics of the heat production from the mix of natural gas / fuel oil heating, 2010 – 2030

Indicator	Units	2010	2020	2030
GHG as CO_2eq	g/MJ_{th}	86.7	82.4	81.2
- of those, CO_2	g/MJ_{th}	82.2	79.6	78.3
- of those, CH_4	g/MJ_{th}	0.17	0.10	0.11
- of those, N_2O	g/MJ_{th}	0.00	0.00	0.00
Acidifying emissions	$g\ SO_2eq./MJ_{th}$	0.07	0.06	0.05
- of those, SO_2	g/MJ_{th}	0.03	0.02	0.01
- of those, NO_x	g/MJ_{th}	0.06	0.06	0.06
- of those, NH_3	g/MJ_{th}	0.00	0.00	0.00
Fine dust (PM_{10})	g/MJ_{th}	0.00	0.00	0.00
$PEC_{non\text{-}renewable}$	$MJ_{primary}/MJ_{th}$	1.35	1.30	1.29
Producer costs	$€_{2010}/GJ_{th}$	36.1	37.9	39.9

Source: IINAS/ÖKO 2012, data incl. auxiliary power and heat distribution.

As supplement for marginal analysis, heat from natural gas condensing boiler is relevant, so that this system is also presented with its indicator values.

Table 36: Characteristics of the heat production from natural gas condensing boilers, 2010 – 2030

Indicator	Units	2010	2020	2030
η_{th}	%	100	101	102
GHG as CO_2eq	g/MJ_{th}	68.5	64.9	64.9
- of those, CO_2	g/MJ_{th}	63.3	61.7	61.4
- of those, CH_4	g/MJ_{th}	0.20	0.12	0.13
- of those, N_2O	g/MJ_{th}	0.00	0.00	0.00
Acidifying emissions	g SO_2eq./MJ_{th}	0.04	0.04	0.04
- of those, SO_2	g/MJ_{th}	0.00	0.00	0.00
- of those, NO_x	g/MJ_{th}	0.05	0.05	0.05
- of those, NH_3	g/MJ_{th}	0.00	0.00	0.00
Fine dust (PM_{10})	g/MJ_{th}	0.00	0.00	0.00
$PEC_{non-renewable}$	$MJ_{primary}$/MJ_{th}	1.15	1.12	1.12
Producer costs	€$_{2010}$/GJ_{th}	36.0	37.8	39.7

Source: IINAS/ÖKO 2012, data incl. auxiliary power and heat distribution.

The values of the average consideration (mix of gas / oil) in comparison to the marginal analysis (calorific value of gas) are higher in terms of GHG emissions by 25 % and in terms of air pollutants by 50 - 90 % as well as in terms of $PEC_{non-renewable}$ by approx. 15 %. Just like for electricity, it is also important with respect to the environmental effects for the reference systems for heat to clearly distinguish between the average and the marginal analysis.

Just like for the electricity systems, it is recommended to always use the average mix as a reference system, and - time permitting - to represent the sensitivity of the results by using a marginal analysis.

8.4 Reference systems for the provision and utilisation of fuels for transport

As reference systems for the production of fuels for transport and their 100 % utilisation in a car – here, a mid-range car with gasoline or diesel engine – pure fossil petrol as well as pure fossil diesel are reviewed, whose manufacturing and import data in turn were taken from GEMIS 4.8 (IINAS/ÖKO 2012).

In the combustion of the fuels in the cars, the emissions requirements for new vehicles in accordance with the BMU project renewbility II (ÖKO/DLR-IVF/ISI 2012) are assumed.

Data of the mineral oil industry association MWV were used to determine the fossil fuel costs for the year 2010. In this, the product price (notation Rotterdam) without further revenues as well as distribution costs is to be considered as LCOE and / or producer costs at refinery. The costs for 2020 and 2030 have been calculated building upon the real price increase of crude oil (Europe, current policy scenario) based on the World Energy Outlook 2010.

Table 37: Characteristics of the production of petrol and 100 % conversion in a mid-range car with gasoline engine, 2010 – 2030

Petrol	Units	2010	2020	2030
GHG as CO_2eq	g/MJ_{fin}	86.4	89.0	88.7
- of those, CO_2	g/MJ_{fin}	85.2	87.9	87.7
- of those, CH_4	g/MJ_{fin}	0.03	0.02	0.02
- of those, N_2O	g/MJ_{fin}	0.00	0.00	0.00
Acidifying emissions	g SO_2-eq./MJ_{fin}	0.09	0.08	0.09
- of those, SO_2	g/MJ_{fin}	0.04	0.03	0.04
- of those, NO_x	g/MJ_{fin}	0.07	0.07	0.07
- of those, NH_3	g/MJ_{fin}	0.00	0.00	0.00
Fine dust (PM_{10})	g/MJ_{fin}	0.00	0.00	0.00
$PEC_{non-renewable}$	$MJ_{primary}$/MJ_{fin}	1.20	1.20	1.20
Producer costs	€ct$_{2010}$/MJ	1.26	1.85	2.12

Source: IINAS/ÖKO 2012, data ***final energy****-related (per MJ of used fuel for transport); information* ***without*** *biomass shares in the fuel for transport.*

Table 38: Characteristics of the production of diesel and 100 % conversion in a mid-range car with diesel engine, 2010 – 2030

Diesel	Units	2010	2020	2030
GHG as CO_2eq	g/MJ_{fin}	87.1	87.1	86.9
- of those, CO_2	g/MJ_{fin}	84.8	85.0	84.8
- of those, CH_4	g/MJ_{fin}	0.02	0.02	0.01
- of those, N_2O	g/MJ_{fin}	0.01	0.01	0.01
Acidifying emissions	g SO_2-eq./MJ_{fin}	0.29	0.28	0.29
- of those, SO_2	g/MJ_{fin}	0.03	0.03	0.03
- of those, NO_x	g/MJ_{fin}	0.36	0.36	0.37
- of those, NH_3	g/MJ_{fin}	0.00	0.00	0.00
Fine dust (PM_{10})	g/MJ_{fin}	0.01	0.005	0.005
$PEC_{non-renewable}$	$MJ_{primary}$/MJ_{fin}	1.14	1.14	1.14
Producer costs	€ct$_{2010}$/MJ	1.20	1.77	2.02

Source: IINAS/ÖKO 2012, data ***final energy****-related (per MJ of used fuel for transport); information* ***without*** *biomass shares in fuel for transport.*

In accordance with the EU Directive on the promotion of the use of renewable energies (EU RED 2009), for GHG balances of liquid biofuels for transport, an EU-wide "comparator" is mandatorily required for the life-cycle emissions of fossil fuels.
It amounts to 83.8 g CO_2eq/MJ_{fin} and is as such slightly lower than the GHG emissions of gasoline and diesel mentioned here.

For consistency reasons, the values presented here should be used instead of the RED comparators for comparisons with fossil systems since they include life-cycle data regarding air pollutants and primary energy use.

As supplement for a marginal assessment, in the following table the characteristics for diesel from "syncrude" are listed, i.e., for diesel obtained from Canadian oil sands. With some degree of freedom, these data can also be use for marginal assessments for petrol from **syncrude**.

Table 39: Characteristics of the provision and 100 % conversion of diesel from syncrude in a mid-range car with diesel engine, 2010 – 2030

Diesel	Units	2020-2030
GHG as CO_2eq	g/MJ_{fin}	118.5
- of those, CO_2	g/MJ_{fin}	115.9
- of those, CH_4	g/MJ_{fin}	0.02
- of those, N_2O	g/MJ_{fin}	0.01
Acidifying emissions	g SO_2-eq./MJ_{fin}	0.59
- of those, SO_2	g/MJ_{fin}	0.29
- of those, NO_x	g/MJ_{fin}	0.43
- of those, NH_3	g/MJ_{fin}	0.00
Fine dust (PM_{10})	g/MJ_{fin}	0.02
$PEC_{non-renewable}$	$MJ_{primary}/MJ_{fin}$	1.61

Source: IINAS/ÖKO 2012, data final energy-related (per MJ of used fuel for transport).

9 Research with foresight

The method handbook of the funding programme “Biomass energy use” is the result of a joint, intense discussion among the funding programme’s participants who, at the start of their work, were faced with the task of designing and harmonising their methodological approach transparently in order to make not only indicators but also cost calculations and balancing comparable.

The method handbook is intentionally aimed at the “simpler” user who does not deal with the methods presented day-in, day-out. This way, select methods for the material flow-oriented balancing of greenhouse gas effects can be applied with limited expenditure in a simple, transparent and comprehensible manner.

For further ease of use, you will also find the essential working tools used in the method handbook on the website of the funding programme, at:
www.energetische-biomassenutzung.de.

Here, you will find:

- Summary of the general framework conditions
- Most important points regarding the application of the methods
- Lists with the most important parameters
- Documentation lists to download as Excel files

For the time being, the method handbook is being applied within the funding programme and is therefore particularly tailored toward questions relating to the corresponding projects, which are assessed based on the climate protection effects achieved.

In future, too, any necessary further changes to the handbook will only be possible by means of joint discussion and adjustments carried out by the funding programme’s participants and the handbook’s users. Its further development is a continuous process that requires feedback from both experts and those applying it in practice. Partners not only within the funding programme but also above and beyond it are very welcome to provide such feedback.

10 Figures

11 Tables

12 Literature and references

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APPENDIX I: Definitions of biomass

Legal definitions

In accordance with § 2 of the Biomass Ordinance, the following fractions count as biomass:

- plants and plant components,
- energy sources (fuels) manufactured from plants or plant components, whose components and interim products were all produced from biomass in the meaning of the Biomass Ordinance,
- wastes and by-products of vegetable and animal origin from agriculture, forestry and the fishing industry,
- biowastes in the meaning of § 2 No. 1 of the Ordinance on Bio-Wastes,
- gas generated from biomass via gasification or pyrolysis and secondary and by-products resulting therefrom,
- alcohols generated from biomass.

Also considered as biomass in the meaning of the Biomass Ordinance are in accordance with § 2 Par. 3 BiomasseV [BiomassO]:

- waste wood, consisting of used wood (used products made of wood, timber material or composites with predominant share of wood) or industrial waste wood (in waste wood occurring in woodworking or wood processing businesses as well as in waste timber material occurring in businesses of the timber material industry), that occurs as waste, unless Sentence 2 of the Biomass Ordinance applies or the waste wood is excluded from recognition as biomass in accordance with § 3 No. 4,
- gas generated from waste wood, unless Sentence 3 of the Biomass Ordinance applies or the waste wood is excluded from recognition as biomass in accordance with § 3 No. 4,
- plant oil methyl ester, unless Sentence 4 of the Biomass Ordinance applies,
- flotsam from the maintenance of bodies of water, bank maintenance and the keeping clean of banks,
- biogas generated via anaerobic digestion, unless substances in accordance with § 3 No. 3, 7, 9 Biomass Ordinance were used or more than 10 percent by weight sewage sludge.

Not considered as biomass in the meaning of this ordinance are in accordance with § 3 BiomassO:

- fossil fuels as well as by-products and secondary products manufactured therefrom,
- peat,
- mixed municipal waste from private households as well as similar wastes from other areas of origin,
- waste wood:
  a) with a content of polychlorinated biphenyls (PCBs) or polychlorinated terphenyls (PCTs) in an amount of more than 0.005 percent by weight in accordance with the PCB/PCT Waste Ordinance dated 26 June 2000 (Federal Law Gazette I pg. 932),

b) with a mercury content of more than 0.0001 percent by weight,
c) other composition, its use for energy as waste for processing has been excluded due to the German Closed Substance Cycle Waste Management Act (Krw-AbfG),

- paper, paperboard, pasteboard,
- sewage sludges in the meaning of the Sewage Sludge Ordinance,
- harbour silt and other body of water sludges and sediments,
- textiles,
- animal by-products in the meaning of Article 2 Par. 1 Letter a of the Regulation (EC) No. 1774/2002 of the European Parliament and the Council of October 3, 2002 with rules of hygiene for by-products not intended for human consumption,
- landfill gas,
- sewage gas.

APPENDIX II: Data collection material and energy balancing

Subsequently compiled are the following 12 tables regarding material and energy balancing:

In the following tables, only the fields shaded in light grey have to be filled with the data of the respective system, and the remaining values have to be supplemented via calculation. The templates for the data collection sheets and documentation lists are made available on the homepage of the funding programme "Biomass energy use" at www.energetische-biomassenutzung.de. For illustrative purposes, additional examples for a completely filled-in data collection sheet and a documentation list (including plausibility check) have been given (values in blue: recorded data; values in black: calculated or transfered date). These are intended to illustrate the use of the data collection sheet and to once more emphasise the importance of the "Explanation of data origin".

Table 40: Data collection sheet - Energy and material balance for biomass gasification plants (template)

1 Data collection and presentation of results			Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters		Data	Units	Calcula-tion	Meas-urement	Assump-tion	
Biomass	Form		...					
Biomass	Origin (within a radius of)		...	km				
Biomass	Biomass demand at rated operation		...	kg_{ds}/h				
Biomass	Power of biomass							
Biomass	Inferior calorific value		...	MJ/kg_{ds}				
Biomass	Moisture content of untreated biomass		...	wt %				
Biomass	Moisture content of pre-treated biomass		...	wt %				
Auxiliary energy	Auxilaries with energy content							
Auxiliary energy	Auxiliary material 1:	...	...	kWh/L				
Auxiliary energy	Auxiliary material 2:	...	...	kWh/L				
Auxiliary energy	Auxiliary material 3:	...	...	kWh/L				
Auxiliary energy	Mass flow of auxiliary material							
Auxiliary energy	Auxiliary material 1:	...	...	L/h				
Auxiliary energy	Auxiliary material 2:	...	...	L/h				
Auxiliary energy	Auxiliary material 3:	...	...	L/h				
Auxiliary energy	Chemical power of auxiliary material							
Auxiliary energy	Auxiliary material 1:	...	...	kW	x			
Auxiliary energy	Auxiliary material 2:	...	...	kW	x			
Auxiliary energy	Auxiliary material 3:	...	...	kW	x			
Auxiliary energy	Power delivered							
Auxiliary energy	Therm. power delivered at the total plant (> 20 °C), (auxiliary energy)		...	kW				
Auxiliary energy	Electrical power delivered at the total plant (auxiliary energy)		...	kW				
Electrical energy	Electrical nominal power		...	kW				

1 Data collection and presentation of results			Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters		Data	Units	Calcu-lation	Measure-ment	Assump-tion	
By-products	By-products with energy content							
By-products	By-product 1:	...	...	kWh/kg				
By-products	By-product 2:	...	...	MJ/kg				
By-products	Mass flow of by-products							
By-products	By-product 1:	...	...	kg/h				
By-products	By-product 2:	...	...	kg/h				
By-products	Chemical power of by-products							
By-products	By-product 1:	....	...	kW	x			
By-products	By-product 2:	...	...	kW	x			
By-products	Thermal power of by-products (> 20 °C)							
By-products	By-product 1:	...	...	kW				
By-products	By-product 2:	...	...	kW				

1 Data collection and presentation of results			Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
		Parameters	Data	Units	Calcu-lation	Meas-urement	Assump-tion	
Heat	Thermal power							
	from process 1:		...	kW				
	from process 2:		...	kW				
	Drying thermal power		...	kW				
	Nominal heat		...	kW				
	Internally used thermal power without drying		...	kW				
	Useful heat		...	kW				
	Thermal utilisation factor		...	%	x			
Residues	Residues and energy content							
	Residue 1:	...	...	MJ/kg				
	Residue 2:	...	...	kWh/L				
	Mass flow of residues							
	Residue 1:	...	...	kg/h				
	Residue 2:	...	...	L/h				
	Chemical power of residues							
	Residue 1:	...	...	kW	x			
	Residue 2:	...	...	kW	x			
	Thermal power of the residues (> 20 °C), (auxiliary energy)							
	Residue 1:	...	...	kW				
	Residue 2:	...	...	kW				

1 Data collection and presentation of results		Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters	Data	Units	Calcu-lation	Meas-urement	Assump-tion	
Other assumptions	Mass flow of fuel gas after cleaning of crude gas	...	kg/h				
	Gas power of fuel gas	...	kW				
	Balanced power loss of the total system	...	kW				
	Non-balanced power loss of the total system	...	kW				
	Total amount of electricity produced	...	MJ/a	x			
	Total amount of useful heat produced	...	MJ/a	x			
	Annual biomass consumption (untreated)	...	t/a	x			
	Annual amount of residues	...	t/a	x			
	Annual amount of by-product	...	t/a	x			
	Annual operating hours	...	h				
	Methane slip (CHP)	...	g/h				
	Other methane emissions	...	g/h				

Table 41: Filled-in example for the data collection sheet - Energy and material balance for biomass gasification plants

	1 Data collection and presentation of results		Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters		Data	Units	Calcu-lation	Measure-ment	Assump-tion	
Biomass	Form		Wood shavings			x		Untreated
	Origin (within a radius of)		50.0	km			x	Supplier data
	Biomass demand at rated operation		109.0	kg$_{ds}$/h	x	x		Calculation from measured biomass flow (weighing cells) and moisture content
	Inferior alorific value		18.7	MJ/kg$_{ds}$		x		Laboratory analysis
	Moisture content of untreated biomass		30.0	wt %		x		Laboratory analysis
	Moisture content of pre-treated biomass		10.0	wt %		x		Laboratory analysis
Auxiliary energy	Auxiliaries with energy content							
	Auxiliary material 1:	Ignition oil	9.7	kWh/L			x	Bibliographical reference - Source: ...
	Auxiliary material 2:	RME	9.5	kWh/L			x	Bibliographical reference - Source: ...
	Auxiliary material 3:	Compressed air (gasifica-tion agent)	–	kWh/L				None
	Mass flow of auxiliaries							
	Auxiliary material 1:	Ignition oil	2.0	L/h		x		Measurement of the fill cycle of the ignition oil tank
	Auxiliary material 2:	RME	5.0	L/h		x		
	Auxiliary material 3:	Com-pressed air (gasifica-tion agent)	121.5	m^3_n/h		x		Measurement with orifice flowmeter, continuous
	Chemical power of auxiliary materials							
	Auxiliary material 1:	Ignition oil	19.0	kW	x			
	Auxiliary material 2:	RME	48.0	kW	x			Calculation from energy content and mass flow of auxiliary materials
	Auxiliary material 3:	Com-pressed air (gasifica-tion agent)	–	kW				
	Power delivered							
	Thermal power delivered (> 20 °C) (auxiliary energy)		–	kW				No external thermal aux-iliary energy necessary
	Electrical power delivered of the total system (auxiliary energy)		22.0	kW		x		Measurement via own meter

	1 Data collection and presentation of results		Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters		Data	Unit	Calcula-tion	Measure-ment	Assump-tion	
Electrical energy	Electrical nominal power		112.0	kW		x		Electricity meter
By-products	By-products with energy content							
	By-product 1:	Wood shavings	4.0	kWh/kg		x		From biomass processing for pellet manufacturing / analysis of external laboratory
	By-product 2:	Coke	31.0	MJ/kg		x		From gasifier, release as fuel to ... / analysis of external laboratory
	Mass flow of by-products							
	By-product 1:	Wood shavings	10.0	kg/h		x		Measurement upon emptying of receiving container
	By-product 2:	Coke	3.5	kg/h		x		Measurement upon emptying of receiving container
	Chemical power of by-products							
	By-product 1:	Wood shavings	40.0	kW	x			Calculation from energy content and mass flow of by-products
	By-product 2:	Coke	30.0	kW	x			
	Thermal power of by-products (> 20 °C)							
	By-product 1:	Wood shavings	–	kW				None
	By-product 2:	Coke	10.0	kW		x		Extraction of coke at 250 °C / measure-ment with thermo-couple at receiver

1 Data collection for balancing			Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters		Data	Units	Calcu-lation	Measure-ment	Assump-tion	
Heat	Thermal power (heat output)							
Heat	from process 1:	Gasifica-tion	56.0	kW	x			Calculation with temperatures measured at heat exchanger
Heat	from process 2:	CHP	227.0	kW		x		Heat meter at CHP
Heat	Drying thermal power		28.0	kW		x		Separating out heat downstream of gasifier for drying of fuel / suitable heat meter
Heat	Nominal heat		227.0	kW	x			Addition of all measured heat flows that are available for external utilisation
Heat	Internally used thermal power without drying		56.0	kW		x		Preheating of the gasification agent / temperature measurement of gasification agent
Heat	Useful heat		170.0	kW		x		Feeding into the heat grid / own heat meter
Heat	Thermal utilisation factor		75.0	%	x			Ratio of useful and nominal heat
Residues	Residues and energy content							
Residues	Residue 1:	Filtration dust	24.0	MJ/kg		x		Analysis at external laboratory
Residues	Residue 2:	RME with dust and tar	12.0	kWh/L			x	Bibliographical data - Source: ...
Residues	Mass flow of residues							
Residues	Residue 1:	Filtration dust	1.5	kg/h		x		Fill level measurement of receiving container continuous
Residues	Residue 2:	RME with dust and tar	6.5	L/h		x		Measurement upon emptying of receiving container
Residues	Chemical power of residues							
Residues	Residue 1:	Filtration dust	10.0	kW	x			Calculation from energy content and mass flow of the residues
Residues	Residue 2:	RME with dust and tar	78.0	kW	x			
Residues	Thermal power of the residues (> 20 °C)							
Residues	Residue 1:	Filtration dust	14.0	kW		x		Extraction of the filter dust at 150 °C / temperature measurement in receiving container
Residues	Residue 2:	RME with dust and tar	–	kW				

1 Data collection and presentation of results		Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters	Data	Units	Calcu-lation	Meas-urement	Assump-tion	
Other assumptions	Mass flow of fuel gas after cleaning of crude gas	323.0	kg/h		x		Volume flow (orifice plate) and concentration measurement at gasifier outlet
Other assumptions	Gas power of fuel gas	388.0	kW	x			Calculation from measured volume flow and composition
Other assumptions	Balanced power loss of the total system	83.0	kW	x			Addition of all losses (gasifier, cleaning of crude gas, CHP)
Other assumptions	Non-balanced power loss of the total system	0	kW				Balancing remainder between output / input energy flows
Other assumptions	Total amount of electricity produced	186.1	MJ/a	x			
Other assumptions	Total amount of rated heat produced	378.0	MJ/a	x			
Other assumptions	Annual biomass consumption	934.0	t/a	x			
Other assumptions	Annual operating hours	6,000.0	h		x		Operating hours meter
Other assumptions	Methane slip (CHP)	-	g/h				Unknown

Table 42: Documentation list - Balance indicators for biomass gasification plants (template)

2 Indicators of the balancing	Data	Units	Calculation	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
2.1 Biomass pre-treatment (system boundary > Biomass Pre-treatment in Fig 9.)						
Fuel power	...	kW				
Total rated thermal input	...	kW				
Storage and sieve losses (by-product)	...	kW				
Drying thermal heat	...	kW				
2.2 Biomass gasifier incl. gas cleaning (system boundary > Biomass Conversion I in Fig 9.)						
Gas power	...	kW				
Power of the by-products (thermal + chemical)	...	kW				
Power of residues (thermal + chemical)	...	kW				
Thermal power (gasification & gas cleaning)	...	kW				
Chemical efficiency (cold gas efficiency)	...	%	x			
2.3 CHP or synthesis plant (system boundary > Biomass Conversion II in Fig 9.)						
Electrical efficiency of prime mover (gross)	...	%	x			
Thermal efficiency of prime mover (gross)	...	%	x			
Total efficiency of prime mover (gross)	...	%	x			
Synthesis efficiency	...	%				
2.4 Overall plant / system (system boundary > Biomass Pre-treatment in Fig 9.)						
Electrical plant efficiency (net)	...	%	x			
Chemical plant efficiency (net)	...	%	x			
Thermal plant efficiency (net)	...	%	x			
Total plant efficiency (net)	...	%	x			

3 Plausibility check		Data	Units	Calculation	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
3.1 Energy balance (system boundary: ...)							
Input	Fuel power	...	kW				
Input	Power of auxiliary energy (energy delivered)	...	kW				
Input	**Energy input**	**...**	**kW**	x			
Output	Electrical plant / system power	...	kW				
Output	Therm. power of plant / system	...	kW				
Output	Power of by-products (thermal + chemical)	...	kW				
Output	Power of residues (thermal + chemical)	...	kW				
Output	Power loss of gasifier	...	kW				
Output	Power loss of gas cleaning	...	kW				
Output	Power loss of prime mover / synthesis	...	kW				
Output	**Energy output**	**...**	**kW**	x			
3.2 Material balance (system boundary: ...)							
Input	Mass flow of fuel	...	kg/h				
Input	Mass flow of auxiliaries	...	kg/h				
Input	**Input mass flow**	**...**	**kg/h**	x			
Output	Mass flow of fuel gas	...	kg/h				
Output	Mass flow of by-products	...	kg/h				
Output	Mass flow of residues	...	kg/h				
Output	Mass flow of flue gas (prime mover)	...	kg/h				
Output	**Output mass flow**	**...**	**kg/h**	x			

Table 43: Filled-in example for the documentation list - Balance indicators for biomass gasification plants

2 Indicators of the balancing	Data	Units	Calculation	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
2.1 Biomass pre-treatment (system boundary > Biomass Pre-treatment in Fig 9.)						
Fuel power	491.0	kW	x			Calculation from measured mass flow and analysis values of fuel
Total rated thermal input	512.0	kW	x			Calculation from measured mass flow and analysis values of fuel
Storage and sieve losses (by-product)	40.0	kW	x			Calculation from measured mass flow of biofuel (wood shavings) and analysis values of fuel
Drying thermal heat	28.0	kW		x		Own heat meter
2.2 Biomass gasifier incl. gas cleaning (system boundary > Biomass Conversion I in Fig 9.)						
Gas power	388.0	kW	x			Calculation from measured fuel gas volume flow and composition
Power of the by-products (thermal + chemical)	40.0	kW	x			Sum of chemical and therm. residue power of the gasifier
Power of residues (thermal + chemical)	102.0	kW	x			Sum of power of chemical and thermal by-products of the gasifier.
Thermal power (gasifier & gas cleaning)	110.0	kW	x			Calculated thermal power of gasifier (product gas volume flow and temperature at gasi-fier outlet)
Chemical efficiency (cold gas efficiency)	76.0	%	x			Calculation from gas power and total rated thermal input
2.3 CHP or synthesis plant (system boundary > Biomass Conversion II in Fig 9.)						
Electrical efficiency of prime mover (gross)	28.8	%	x			Calculation from gas & electrical power
Thermal efficiency of prime mover (gross)	58.5	%	x			Calculation from gas power & nominal heat of prime mover
Total efficiency of prime mover (gross)	87.2	%	x			Calculation from thermal & electrical efficiency of prime mover
Synthesis efficiency	–	%				No synthesis
2.4 Overall plant / system (system boundary > Biomass Pre-treatment in Fig 6.)						
Electrical plant efficiency (net)	**23.0**	%	x			Calculation from fuel power and electrical system power
Chemical plant efficiency (net)	**14.0**	%	x			Calculation from fuel power and power of biofuel
Thermal plant efficiency (net)	**46.0**	%	x			Calculation from fuel power and power of usable heat
Total plant efficiency (net)	**83.0**	%	x			Calculation from electrical, chemical / thermal plant efficiency

	3 Plausibility check	Data	Units	Calculation	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
3.1 Energy balance (system boundary: total plant, incl. CHP)							
Input	Fuel power	491.0	kW	x			Power of biomass at plant entry relative to the superior calorific value
Input	Power of auxiliary energy (energy delivered)	89.0	kW	x			Sum of the electrical and thermal auxiliary energy as well as the chemical energy of the individual auxiliaries
Input	**Energy input**	**580.0**	kW	x			Addition of all input energy flows - Balance / sboundary (plant entry)
Output	Electrical plant / system power	112.0	kW		x		Corresponds to electrical power of CHP
Output	Therm. power of plant / system	227.0	kW		x		Corresponds to nominal heat
Output	Power of by-products (chem.)	70.0	kW	x			Corresponds to the sum of the chemical power of the by-products
Output	Power of resi-dues (chemical)	88.0	kW	x			Corresponds to the sum of the chem. power of the individual residues
Output	Power loss of gasifier	15.0	kW			x	Thermal loss of gasifier - own as-sumption - includes thermal power of the by-products (10 kW)
Output	Power loss of gas cleaning	19.0	kW			x	Thermal loss of crude gas clean-ing - own assumption - includes thermal power of the residues (14 kW)
Output	Power loss of prime mover / synthesis	49.0	kW	x			Calculation via CHP efficiency (in-cludes heat losses and incomplete combustion)
Output	**Energy output**	**580.0**	kW	x			Addition of all output energy flows - Balance / system boundary (CHP gas outlet)
3.2 Material balance (system boundary: downstream of gasifier)							
Input	Mass flow of fuel	156.0	kg/h		x		Mass flow of biomass at plant entry
Input	Mass flow of auxiliaries	152.0	kg/h		x		Sum of mass flows of the indi-vidual auxiliaries
Input	**Input mass flow**	**308.0**	kg/h	x			Addition of all input mass flows - balance / system boundary (plant entry)
Output	Mass flow of fuel gas	287.0	kg/h	x			Mass flow at exit of the crude gas cleaning upstream of CHP
Output	Mass flow of by-products	14.0	kg/h		x		Sum of mass flows of the indi-vidual biofuels
Output	Mass flow of residues	7.0	kg/h		x		Sum of the mass flows of the individual residues
Output	Mass flow of flue gas (prime mover)	–	kg/h				Mass flow downstream of CHP and flue gas cleaning
Output	**Output mass flow**	**308.0**	kg/h	x			Addition of all output mass flows - Balance / system boundary (CHP gas inlet)

Table 44: Data collection sheet - Energy and material balance for ADs (template)

1 Data collection for balancing		Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters	Data	Units	Calculation	Measure-ment	Assump-tion	
Biomass 1	Substrate 1	...					
	Origin (within a radius of)	...	km			x	
	Biomass demand at rated operation	...	t_{fm}/d	x		x	
	Power of biomass:						
	Superior calorific value	...	MJ/kg_{fm}	x	x	x	
	Dry substance content	...	wt %		x	x	
	Organic dry solids	...	wt %		x	x	
	Biogas yield	...	m^3/t_{fm}	x	x	x	
	Methane content	...	%	x	x	x	
Biomass 2	Substrate 2	...					
	Origin (within a radius of)	...	km			x	
	Biomass demand at rated operation	...	t_{fm}/d	x		x	
	Power of biomass:						
	Superior calorific value	...	MJ/kg_{fm}	x	x	x	
	Dry substance contents	...	wt %		x		
	Organic dry solids	...	wt %		x		
	Biogas yield	...	m^3/t_{fm}	x	x	x	
	Methane content	...	%	x	x	x	
Auxiliary energy	Thermal power delivered of the total plant as annual average	...	kW	x			
	Electrical power delivered of the total plant as annual average	...	kW	x			
Electrical energy	Electrical nominal power	...	kW	x		x	
	Electrical rated power	...	kW	x			

1 Data collection for balancing		Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters	Data	Units	Calculation	Meas-urement	Assump-tion	
By-products	Energy content of by-products						
	By-product 1: ...	...	MJ/kg				Digestate to be taken into consideration, here, if utilisation for energy takes place, otherwise to be entered under residues
	Mass flow of by-products						
	By-product 1: ...	...	kg/h			x	
	Chemical power of by-products						
	By-product 1: ..	...	kW	x			
Heat	Thermal power						
	Nominal heat output	...	kW			x	
	Internally used thermal power	...	kW	x		x	
	Useful heat output	...	kW	x		x	
	Thermal utilisation factor	...	%	x		x	
Residues	Residues and energy content						
	Residue 1: ...	...	MJ/kg	x			
	Residue 2: ...	...	MJ/kg	x			
	Mass flow of residues						
	Residue 1: ...	...	t_{fm}/d	x			
	Residue 2: ...	...	t_{fm}/d	x			
Losses	Methane slip (CHP)	...	g/h	x		x	
	Residual methane potential	...	m^3/t_{fm}			x	
	Other methane emissions	...	g/h			x	
Other information	Volume flow of biogas	...	m^3/h	x			
	Methane content	...	%	x			
	Hydrogen sulphide content in crude gas	...	ppm			x	
	Gas power of biogas	...	kW	x			
	Total amount of electricity produced	...	MWh/a		x		
	Total amount of nominal heat produced	...	MWh/a		x		
	Annual biomass consumption (untreated)	...	t/a	x			
	Annual amount of residues	...	t/a	x			
	Annual amount of by-product	...	t/a	x			
	Annual operating hours CHP	...	h/a			x	
	Annual full load hours CHP	...	h/a	x			
	Annual operating hours of the excess gas burner system	...	h/a			x	

Table 45: Hypothetical plant example for the data collection sheet - Energy and material balance for ADs

	1 Data collection and presentation of results	Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters	Data	Units	Calcu-lation	Measure-ment	Assump-tion	
Biomass 1	Substrate 1	Cattle manure					Operator information
	Origin (within a radius of)	0	km			x	Livestock buildings on-site
	Biomass demand at rated operation	21.0	kg_{fm}/d	(x)		x	Operator information, alternatively calculation via number of animals
	Power of biomass:						
	Superior calorific value	14.0	MJ/kg_{fm}			x	ECN database
	Dry substance contents	10.0	wt %			x	KTBL database
	Organic dry solids	8.0	wt %			x	Often reference to oDS
	Biogas yield	30.0	m^3/t_{fm}			x	KTBL database
	Methane content	55.0	%			x	KTBL database
Biomass 2	Substrate 2	Maize silage					Operator information
	Origin (within a radius of)	5.4	km			x	Operator information
	Biomass demand at rated operation	21.0	t_{fm}/d			x	Operator information
	Power of biomass:						
	Superior calorific value	17.0	MJ/kg_{fm}			x	ECN database
	Dry substance contents	35.0	wt %			x	KTBL database
	Organic dry solids	33.3	wt %			x	KTBL database
	Biogas yield	261.0	m^3/t_{fm}			x	KTBL database
	Methane content	52.0	%			x	KTBL database
Auxiliary energy	Thermal power delivered of the total plant as annual average	–	kW				Generally not received from external
	Electrical power delivered of the total plant as annual average	37.0	kW	x			Calculation based on own consumption of electricity of ~8 %, here, coverage by own production
Electrical energy	Electrical nominal power	500.0	kW			x	Operator information CHP plant
	Electrical rated power	457.0	kW	x			Taking into consideration of the theoretical number of full load hours

	1 Data collection and presentation of results	Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters	Data	Units	Calcula-tion	Measure-ment	Assump-tion	
By-products	Energy content of by-products (Digestate to be taken into consideration, here, if utilisation for energy takes place, otherwise to be entered under residues)						
	By-product 1: ...	...	MJ/kg				Calorimetric determination necessary
	Mass flow of by-products						
	By-product 1: ...	...	kg/h				Operator information, e.g. in plant gate balance
	Chemical power of by-products						
	By-product 1: ...	...	kW				Calculation based on mass flow and superior calorific value
Heat	Thermal power						
	Nominal heat output	577.0	kW			x	Gross thermal power of the CHP based on manufacturer's information
	Internally used thermal power	105.0	kW			x	Values from literature
	Useful heat output	202.0	kW			x	Values from literature
	Thermal utilisation factor	35.0	%			x	Based on minimum heat utilisation in accordance with REL 2012
Residues	Residues and energy content						
	Residue 1: Digestate	16.9.0	MJ/kg		x		Calorimetric determination necessary
	Residue 2: ...	...	MJ/kg				No further residue
	Mass flow of residues						
	Residue 1: Digestate	33.0	t_{fm}/d	x			Calculation based on the substrates used
	Residue 2: ...	...	kg/h				Calculation from balancing (e.g. plant gate balance)
Losses	Methane slip (CHP)	812.0	g/h	x		(x)	Calculation based on the total methane content with 1 % methane slip
	Residual methane potential	5.1	m^3/t_{fm}			x	Value from literature for multi-stage plants
	Other methane emissions	1,211.0	g/h			x	Estimated value for 1.5 % methane slip, to be recorded plant-specific

	1 Data collection and presentation of results	Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters	Data	Units	Calculation	Measurement	Assumption	
Other information	Volume flow of biogas	215	m^3/h	x			Calculation based on the theoretical biogas yield
	Methane content	52	%	x			Calculated via calculation of the ratios of the individual substrates
	Hydrogen sulphide content in crude gas	500	ppm			x	Plant-specific measured value
	Gas power of biogas	1,241	kW	x			Addition of individual yields of the substrates
	Total amount of electricity produced	4,000	MWh/a		x		Addition of the daily / monthly values from the operations diary
	Total amount of nominal heat produced	4,616	MWh/a		x		Addition of the daily / monthly values from the operations diary
	Annual biomass consumption (untreated)	15,330	t/a	x			Sum of the individual substrates based on the operations diaries
	Annual amount of residues	11,948	t/a	x			Estimated calculation based on the gas yields at a biogas density of 1.25 kg/m^3
	Annual amount of by-product	...	t/a				Information from balancing (e.g. plant gate balance)
	Annual operating hours CHP	8,500	h/a			x	To be captured system / plant-specifically
	Annual full load hours CHP	8,000	h/a	x			Calculatory determination based on the amount of electricity produced and the nominal power (rated power)
	Annual operating hours of the excess gas burner system	50	h/a			x	To be captured system / plant-specifically

Table 46: Documentation list - Balance indicators for ADs (template)

2 Indicators of the balancing	Data	Units	Calculation	Measurement	Assumption	Explanation of data origin: Measuring method, calculation path, source of the assumption
2.1 Biomass pre-treatment (system boundary > Biomass Pre-treatment in Figure 10.)						
Substrate power (related to superior calorific value)	...	kW	x			
Storage losses	...	%			x	
2.2 Anaerobic digestion (system boundary > Biomass Conversion I in Figure 10.)						
Gas power	...	kW	x			
Power digester heating	...	kW	x		x	
Losses (thermal + chemical)	...	kW			x	
Chemical efficiency	...	%	x			
2.3 Gas utilisation of CHP plant (system boundary > Biomass Conversion II in Figure 10.)						
Electrical efficiency of prime mover (gross)	...	%			x	
Thermal efficiency of prime mover (gross)	...	%			x	
Total efficiency of prime mover (gross)	...	%	x			
Nominal heat output	...	kW			x	
Electrical nominal power	...	kW			x	
2.4 Total plant (system boundary > Biomass Conversion II in Figure 10.)						
Electrical plant efficiency (net)	...	%	x			
Thermal plant efficiency (net)	...	%	x			
Total system / plant efficiency (net)	...	%	x			

3 Plausibility check		Data	Units	Calculation	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
3.1 Energy balance (system boundary: ...)							
Input	Substrate power	...	kW	x			
	Power of auxiliary energy (energy delivered)	...	kW	x			
	Energy input	**...**	kW	x			
Output	Electrical plant power	...	kW	x			
	Thermal plant power	...	kW	x			
	Power by-products	...	kW	x			
	Losses (thermal + chemical)	...	kW	x			
	Energy output	**...**	**kW**	x			
3.2 Material balance (system boundary: ...)							
Input	Mass flow of substrate	...	t/d	x			
	Mass flow of auxiliaries	...	t/d	x			
	Input mass flow	**...**	**t/d**	x			
Output	Mass flow of biogas	...	t/d	x			
	Mass flow of by-products	...	t/d	x			
	Mass flow of residues	...	t/d	x			
	Mass flow rate losses (residues)	...	t/d	x			
	Output mass flow	**...**	**t/d**	x			

Table 47: Filled-in example for the documentation list - Balance indicators for ADs

2 Indicators of the balancing	Data	Units	Calculation	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calcula-tion path, source of the assumption
2.1 Biomass pre-treatment (system boundary > Biomass Pre-treatment in Figure 10.)						
Substrate power (related to superior calorific value)	1,718	kW	x			
Storage losses	12.0	%			x	
2.2 Anaerobic digestion (system boundary > Biomass Conversion I in Figure 10.)						
Gas power	1,241	kW	x			
Power digester heating	105.0	kW	x		(x)	A lump sum of 35 % of the heat extraction
Losses (thermal + chemical)	–	kW			(x)	Not measurable
Chemical efficiency	72.2	%	x			
2.3 Gas utilisation of CHP plant (system boundary > Biomass Conversion II in Figure 10.)						
Electrical efficiency of prime mover (gross)	39.0	%			x	
Thermal efficiency of prime mover (gross)	45.0	%			x	
Total efficiency of prime mover (gross)	84.0	%	x			
Nominal heat output	577.0	kW			x	
Electrical nominal power	500.0	kW			x	
2.4 Total plant (system boundary > Biomass Conversion II in Figure 10.)						
Electrical plant efficiency (net)	24.5	%	x			
Thermal plant efficiency (net)	10.7	%	x			Heat output minus on-site consumption
Total plant efficiency (net)	35.2	%	x			

	3 Plausibility check	Data	Units	Calculation	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
3.1 Energy balance (system boundary: AD plant incl. CHP)							
Input	Substrate power	1,718	kW	x			
Input	Power of auxiliary energy (energy delivered)	0	kW				
Input	**Energy input**	**1,718**	**kW**	x			
Output	Electrical plant power	**457.0**	kW	x			At 8,000 h/a full load; corre-sponds to the rated power
Output	Thermal plant power	**527.0**	kW	x			At 8,000 h/a full load
Output	Power By-products	0	kW				None
Output	Losses (thermal + chemical)	0	kW	x			None; unused energy poten-tial from digestate + losses
Output	**Energy output**	**984.0**	**kW**	x			In the example, only sum of electrical and thermal power of plant / system
3.2 Material balance (system boundary: AD plant incl. CHP)							
Input	Mass flow of substrate	42.0	t/d	x	(x)		Sum of the substrates
Input	Mass flow of auxiliaries	0	t/d	x			Sum of auxiliaries, e.g. for desulphurisation, trace ele-ments, etc.
Input	**Input mass flow**	**42.0**	**t/d**	x			
Output	Mass flow of biogas	6.5	t/d	x			Calculation at a density of 1.25 kg/m³
Output	Mass flow of by-products	–	t/d				No by-products
Output	Mass flow of resi-dues (losses)	32.7	t/d	x			Volume of fermenter residue incl. condensate
Output	**Output mass flow**	**35.2**	**t/d**	x			

Table 48: Data collection sheet - Energy and material balance for small-scale furnaces (template)

1 Data collection for balancing			Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters		Data	Units	Calculation	Measure-ment	Assump-tion	
Fuel	Type (wood, pellets, briquette)		...					
Fuel	Fuel consumption		...	kg_{ds}/h		x		
Fuel	Inferior calorific value		...	MJ/kg_{ds}			x	
Fuel	Moisture content		...	wt %			x	
Auxiliary energy	Electricity		...	MJ/kg			x	
Heat	Nominal heat output		...	kW			x	
Heat	Drying thermal power		...	kW				
Heat	Total rated thermal input		...	kW	x			
Heat	Thermal plant efficiency		...	%	x			
Heat	Boiler efficiency		...	%	x			
Losses	Energy content:	Exhaust gas / flue gas	...	MJ/kg		x		
Losses	Mass flow:	Exhaust gas / flue gas	...	kg/h		x		
Losses	Chemical power:	Exhaust gas / flue gas	...	kW	x			
Losses	Thermal power:	Exhaust gas / flue gas	...	kW				
Residues	Energy content:	Residue (ash)	...	MJ/kg		x		
Residues	Mass flow:	Residue (ash)	...	kg/h		x		
Residues	Chemical power:	Residue (ash)	...	kW	x			
Residues	Thermal power:	Residue (ash)	...	kW				
Miscellaneous	Annual full load hours		...	h	x		x	

Table 49: Hypothetical plant example for the data collection sheet - Energy and material balance for small-scale furnaces

1 Data collection for balancing		Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
	Parameters	Data	Units	Calculation	Measure-ment	Assump-tion	
Fuel	Type (wood, pellets, briquette)	Wood pellets					DIN + pellets
	Fuel consumption	10.00	kg_{ds}/h		x		Gravimetric determination (continuous)
	Inferior calorific value	17.28	MJ/ kg_{ds}			x	Value from literature
	Moisture content	10.00	wt %			x	This value is estimated, it is not atypical for e.g. wood pellets (no analysis possible)
Auxiliary energy	Electricity	50.00	W			x	This value is estimated, it is not atypical for small-scale furnaces
Heat	Nominal heat output	45.00	kW			x	Label
	Drying thermal power	0.00	kW				No drying upstream of the boiler
	Total rated thermal input	48.00	kW	x			Calculation from heating value (external analysis) and continuously measured mass flow at fuel delivery
	Thermal plant efficiency	93.75	%	x			Calculation from thermal power of the plant and fuel power
	Boiler efficiency	93.75	%	x			

1 Data collection for balancing			Data collection		Data origin (check as applicable)			Explanation of data origin: e.g. measuring method, calculation path, source of the assumption
		Parameters	Data	Units	Calculation	Measure-ment	Assump-tion	
Losses	Energy content:	Exhaust gas / flue gas	0.1	MJ/kg		x		Measurement of gas composition
	Mass flow:	Exhaust gas / flue gas	100.0	kg/h		x		Measurement of the volume flow with orifice flow-meter with density determination from measured gas composition
	Chemical power:	Exhaust gas / flue gas	0.3	kW	x			
	Thermal power:	Exhaust gas / flue gas	0	kW				No measurement of thermal power possible
Residues	Energy content:	Residue (ash)	0.1	MJ/kg		x		Analysis at external laboratory
	Mass flow:	Residue (ash)	0.5	kg/h		x		Continuous weighing out
	Chemical power:	Residue (ash)	55.6	kW	x			Calculation from mass flow and inferior calorific value (heating value)
	Thermal power:	Residue (ash)	0	kW				Ash is retrieved cold after operation
Miscellaneous	Annual full load hours		3,000	h	(x)		x	Calculation from annual graphs or counter or estimation

Table 50: Documentation list - Balance indicators for small-scale furnaces (template)

2 Indicators of the balancing	Data	Units	Calcula-tion	Meas-urement	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
2.1 Biomass pre-treatment (system boundary > Biomass Pre-treatment in Fig 8.)						
Thermal input of the fuel	...	kW	x			
Total rated thermal input	...	kW	x			
Storage and sieve loss	...	kW				
Drying thermal power	...	kW				
2.2 Biomass conversion I (system boundary > Biomass Conversion I in Fig. 8.)						
Power of residues (thermal + chemical)	...	kW	x			
Boiler efficiency	...	%	x			
2.3 Total plant						
Thermal plant efficiency	...	%	x			

3 Plausibility check		Data	Units	Calcula-tion	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
3.1 Energy balance (system boundary: ...)							
Input	Fuel power	...	kW	x			
Input	Power of auxiliaries (energy delivered)	...	kW				
Input	**Energy input**	**...**	**kW**	x			
Output	Therm. power of plant / system	...	kW				
Output	Power of residues (thermal + chemical)	...	kW				
Output	**Energy output**	**...**	**kW**	x			
3.2 Material balance (system boundary: ...)							
Input	Mass flow of fuel	...	kg/h				
Input	Mass flow of auxiliaries	...	kg/h				
Input	**Input mass flow**	**...**	**kg/h**	x			
Output	Mass flow of residues	...	kg/h				
Output	Mass flow of exhaust gas / flue gas	...	kg/h				
Output	**Output mass flow**	**...**	**kg/h**	x			

Table 51: Filled-in example for the documentation list - Balance indicators for small-scale furnaces

2 indicators of the balancing	Data	Units	Calculation	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
2.1 Biomass pre-treatment (system boundary > Biomass Pre-treatment in Fig 8.)						
Thermal input of the fuel	48.0	kW	x			Calculation from heating value (external analysis) and continuously measured mass flow at fuel delivery
Total rated thermal input	48.0	kW	x			Calculation from heating value (external analysis) and continuously measured mass flow at boiler entry
Storage and sieve loss	0	kW				No sieving and storage loss upstream of small firing
Drying thermal power	0	kW				No external drying upstream of small firing
2.2 Biomass conversion I (system boundary > Biomass Conversion I in Fig. 8.)						
Power of residues (thermal + chemical)	3.0	kW	x			Chemical power of combustion ash – Calculation from measured heating value and mass flow of ash
Boiler efficiency	93.8	%	x			Calculation from thermal power of the plant and fuel power
2.3 Total plant						
Thermal plant efficiency	93.8	%	x			Calculation from thermal power of the plant and fuel power

	3 Plausibility check	Data	Units	Calculation	Measure-ment	Assump-tion	Explanation of data origin: Measuring method, calculation path, source of the assumption
3.1 Energy balance (system boundary: ...)							
Input	Fuel power	48.0	kW	x			Calculation from inferior calorific value (external analysis) and continuously measured mass flow at fuel delivery
Input	Power of auxiliaries (energy delivered)	0.05	kW			x	Electrical auxiliary energy of boiler - assumption based on device designation
Input	**Energy input**	**48.0**	**kW**	x			
Output	Thermal power of plant / system	45.0	kW			x	Thermal power of the boiler that is used externally (usable heat) - read from name plate
Output	Power of residues (thermal + chemical)	3.0	kW	x			Chemical power of the combustion ash – Calculation from measured heating value and mass flow of ash
Output	**Energy output**	**48.0**	**kW**	x			
3.2 Material balance (system boundary: ...)							
Input	Mass flow of fuel	10.0	kg/h		x		Throughput of a typical log wood firing. Measurement via weighing unit at the boiler
Input	Mass flow of auxiliaries	91.0	kg/h		x		Auxiliaries, such as for ignition, are not taken into consideration. Only the necessary combustion air. Measurement via rotameter
Input	**Input mass flow**	**101.0**	**kg/h**	x			
Output	Mass flow of residues	101.0	kg/h		x		Exhaust gas (measurement via orifice flowmeter) + residue (ash) (gravimetric determination)
Output	Mass flow of exhaust gas / flue gas	0	kg/h				Mass flow of the exhaust gases / flue gases already captured at the residues.
Output	**Output mass flow**	**101.0**	**kg/h**	x			

APPENDIX III: Methodology for GHG accounting

Part I – Methodology for greenhouse gas accounting in accordance with EU Directive 2009/28/EC for bioliquids and biofuels

Part II – Methodology for the calculation of greenhouse gas emissions due to land use changes

Part III – Methodology for greenhouse gas accounting in accordance with the recommendations of the EU COM for solid and gaseous biomass for the generation of energy

Part I – Methodology for greenhouse gas accounting in accordance with EU Directive 2009/28/EC for bioliquids and biofuels

C. *Methodology*

1. Greenhouse gas emissions from the production and use of transport fuels, biofuels and bioliquids shall be calculated as:

   $$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee},$$

   where

   E = total emissions from the use of the fuel;

   e_{ec} = emissions from the extraction or cultivation of raw materials;

   e_l = annualised emissions from carbon stock changes caused by land-use change;

   e_p = emissions from processing;

   e_{td} = emissions from transport and distribution;

   e_u = emissions from the fuel in use;

   e_{sca} = emission saving from soil carbon accumulation via improved agricultural management;

   e_{ccs} = emission saving from carbon capture and geological storage;

   e_{ccr} = emission saving from carbon capture and replacement; and

   e_{ee} = emission saving from excess electricity from cogeneration.

   Emissions from the manufacture of machinery and equipment shall not be taken into account.

2. Greenhouse gas emissions from fuels, E, shall be expressed in terms of grams of CO_2 equivalent per MJ of fuel, gCO_{2eq}/MJ.

3. By derogation from point 2, for transport fuels, values calculated in terms of gCO_{2eq}/MJ may be adjusted to take into account differences between fuels in useful work done, expressed in terms of km/MJ. Such adjustments shall be made only where evidence of the differences in useful work done is provided.

4. Greenhouse gas emission saving from biofuels and bioliquids shall be calculated as:

   $$SAVING = (E_F - E_B)/E_F,$$

   where

   E_B = total emissions from the biofuel or bioliquid; and

   E_F = total emissions from the fossil fuel comparator.

5. The greenhouse gases taken into account for the purposes of point 1 shall be CO_2, N_2O and CH_4. For the purpose of calculating CO_2 equivalence, those gases shall be valued as follows:

   CO_2: 1

   N_2O: 296

   CH_4: 23

6. Emissions from the extraction or cultivation of raw materials, e_{ec}, shall include emissions from the extraction or cultivation process itself; from the collection of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation. Capture of CO_2 in the cultivation of raw materials shall be excluded. Certified reductions of greenhouse gas emissions from flaring at oil production sites anywhere in the world shall be deducted. Estimates of emissions from cultivation may be derived from the use of averages calculated for smaller geographical areas than those used in the calculation of the default values, as an alternative to using actual values.

7. Annualised emissions from carbon stock changes caused by land-use change, e_l, shall be calculated by dividing total emissions equally over 20 years. For the calculation of those emissions the following rule shall be applied:

$e_l = (CS_R - CS_A) \times 3{,}664 \times 1/20 \times 1/P - e_B$ (1),

where

e_l = annualised greenhouse gas emissions from carbon stock change due to land-use change (measured as mass of CO_2-equivalent per unit biofuel energy);

CS_R = the carbon stock per unit area associated with the reference land use (measured as mass of carbon per unit area, including both soil and vegetation). The reference land use shall be the land use in January 2008 or 20 years before the raw material was obtained, whichever was the later;

CS_A = the carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit area, including both soil and vegetation). In cases where the carbon stock accumulates over more than one year, the value attributed to CS_A shall be the estimated stock per unit area after 20 years or when the crop reaches maturity, whichever the earlier;

P = the productivity of the crop (measured as biofuel or bioliquid energy per unit area per year); and

e_B = bonus of 29 gCO_{2eq}/MJ biofuel or bioliquid if biomass is obtained from restored degraded land under the conditions provided for in point 8.

8. The bonus of 29 gCO_{2eq}/MJ shall be attributed if evidence is provided that the land:

(a) was not in use for agriculture or any other activity in January 2008; and

(b) falls into one of the following categories:

(i) severely degraded land, including such land that was formerly in agricultural use;

(ii) heavily contaminated land.

The bonus of 29 gCO_{2eq}/MJ shall apply for a period of up to 10 years from the date of conversion of the land to agricultural use, provided that a steady increase in carbon stocks as well as a sizable reduction in erosion phenomena for land falling under (i) are ensured and that soil contamination for land falling under (ii) is reduced.

9. The categories referred to in point 8(b) are defined as follows:

(a) 'severely degraded land' means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded;

(b) 'heavily contaminated land' means land that is unfit for the cultivation of food and feed due to soil contamination.

Such land shall include land that has been the subject of a Commission decision in accordance with the fourth subparagraph of Article 18(4).

10. The Commission shall adopt, by 31 December 2009, guidelines for the calculation of land carbon stocks drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories — volume 4. The Commission guidelines shall serve as the basis for the calculation of land carbon stocks for the purposes of this Directive.

11. Emissions from processing, e_p, shall include emissions from the processing itself; from waste and leakages; and from the production of chemicals or products used in processing.

In accounting for the consumption of electricity not produced within the fuel production plant, the greenhouse gas emission intensity of the production and distribution of that electricity shall be assumed to be equal to the average emission intensity of the production and distribution of electricity in a defined region. By derogation from this rule, producers may use an average value for an individual electricity production plant for electricity produced by that plant, if that plant is not connected to the electricity grid.

12. Emissions from transport and distribution, e_{td}, shall include emissions from the transport and storage of raw and semi-finished materials and from the storage and distribution of finished materials. Emissions from transport and distribution to be taken into account under point 6 shall not be covered by this point.

13. Emissions from the fuel in use, e_u, shall be taken to be zero for biofuels and bioliquids.

(1) The quotient obtained by dividing the molecular weight of CO_2 (44,010 g/mol) by the molecular weight of carbon (12,011 g/mol) is equal to 3,664.

14. Emission saving from carbon capture and geological storage e_{ccs}, that have not already been accounted for in e_p, shall be limited to emissions avoided through the capture and sequestration of emitted CO_2 directly related to the extraction, transport, processing and distribution of fuel.

15. Emission saving from carbon capture and replacement, e_{ccr}, shall be limited to emissions avoided through the capture of CO_2 of which the carbon originates from biomass and which is used to replace fossil-derived CO_2 used in commercial products and services.

16. Emission saving from excess electricity from cogeneration, e_{ee}, shall be taken into account in relation to the excess electricity produced by fuel production systems that use cogeneration except where the fuel used for the cogeneration is a co-product other than an agricultural crop residue. In accounting for that excess electricity, the size of the cogeneration unit shall be assumed to be the minimum necessary for the cogeneration unit to supply the heat that is needed to produce the fuel. The greenhouse gas emission saving associated with that excess electricity shall be taken to be equal to the amount of greenhouse gas that would be emitted when an equal amount of electricity was generated in a power plant using the same fuel as the cogeneration unit.

17. Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products (co-products), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by lower heating value in the case of co-products other than electricity).

18. For the purposes of the calculation referred to in point 17, the emissions to be divided shall be $e_{ec} + e_l$ + those fractions of e_p, e_{td} and e_{ee} that take place up to and including the process step at which a co-product is produced. If any allocation to co-products has taken place at an earlier process step in the life-cycle, the fraction of those emissions assigned in the last such process step to the intermediate fuel product shall be used for this purpose instead of the total of those emissions.

In the case of biofuels and bioliquids, all co-products, including electricity that does not fall under the scope of point 16, shall be taken into account for the purposes of that calculation, except for agricultural crop residues, including straw, bagasse, husks, cobs and nut shells. Co-products that have a negative energy content shall be considered to have an energy content of zero for the purpose of the calculation.

Wastes, agricultural crop residues, including straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials.

In the case of fuels produced in refineries, the unit of analysis for the purposes of the calculation referred to in point 17 shall be the refinery.

19. For biofuels, for the purposes of the calculation referred to in point 4, the fossil fuel comparator E_F shall be the latest available actual average emissions from the fossil part of petrol and diesel consumed in the Community as reported under Directive 98/70/EC. If no such data are available, the value used shall be 83,8 gCO_{2eq}/MJ.

For bioliquids used for electricity production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator E_F shall be 91 gCO_{2eq}/MJ.

For bioliquids used for heat production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator E_F shall be 77 gCO_{2eq}/MJ.

For bioliquids used for cogeneration, for the purposes of the calculation referred to in point 4, the fossil fuel comparator E_F shall be 85 gCO_{2eq}/MJ.

Part II – Methodology for the calculation of greenhouse gas emissions due to land use changes

E_l (see EU RED formula) are the annualised emissions due to carbon stock changes as a result of land use changes (c.f. No. 15, Table 3). A land use change to be taken into consideration in the calculation of GHG emissions exists if the carbon stock of the cultivated area has changed since the reference point in time. This is in particular the case, if after the reference point in time:

- Grassland areas that are not grassland with a high biological diversity are turned into areas with annual crops or perennial crops,
- Contiguously wooded areas with a canopy degree of 10 to 30 % are turned into areas with annual crops or perennial crops,
- Areas with perennial crops are turned into areas with annual crops,
- Contiguously wooded areas that due to the type of forestry management feature long-term a high canopy degree (e.g. > 80 %) are turned, due to a change in the type of management, into areas that long-term a significantly lower canopy degree (e.g. 40 %) (land use change within the area category of contiguously wooded areas with a canopy degree of more than 30 %). A reduction of the canopy degree by more than 20 % is to be considered a significant change, and also if
- permanently saturated wetlands are dewatered for the cultivation of biomass such that they are only saturated with water for a considerable part of the year.

The interface, the operation or the permanent facility determines the annualised GHG emissions as a result of land use changes e'_l by even distribution of the greenhouse gas emissions caused thereby over 20 years, utilising the data transmitted by the farming enterprise, based on the following formula:

$$e'_l\left[\frac{kgCO_2}{kgyield}\right] = \frac{CS_R\left[\frac{kgC}{ha}\right] - CS_A\left[\frac{kgC}{ha}\right]}{yield_{mainproduct}\left[\frac{kg}{ha \cdot yr}\right] \cdot 20[yr]} \cdot 3{,}664 - \frac{e_b}{AF \cdot CF}$$

AF, CF	=	Product-specific conversion factors for the calculation of the mass-related values of the greenhouse gas emissions
e_b	=	Bonus of 29 g CO_2eq/MJ of liquid biomass in case of cultivation on restored degraded areas. To be eligible for the bonus e_B for the cultivation on restored degraded areas, the business documents that the respective area:

- Was not used agriculturally or for other purposed at the reference point in time, and
- Is not a severely degraded area, or
- Is not a severely polluted area.

The bonus e_b applies for a period of up to 10 years from the point in time of the conversion of the area into an area for agricultural use, if:

- A continuous increase of the carbon stock and a significant reduction of the erosion exists on severely degraded areas, and
- The soil pollution on severely polluted areas is reduced.

Severely polluted areas are areas that are not suitable for the cultivation of foodstuffs and feedstuffs, due to soil pollution. The carbon stock of the area is the amount of carbon in the soil and vegetation per unit of area.

CS_R is the carbon stock per unit of area (measured as mass of carbon per unit of area in soil and vegetation) associated with the reference area or 20 years prior to the extraction of the feedstock, depending on which point in time was later.

CS_A is the carbon stock per unit of area (measure as mass of carbon per unit of area in soil and vegetation) associated with the actual land use. If the carbon stock increases over the course of more than one year, the estimated carbon stock after 20 years or at the point in time of maturity of the plants shall be considered as CS_A value, depending on which point in time occurs sooner.

Areas on which cultivation is accordance with §§ 4 to 7 is permissible can be converted under the provision that the GHG emissions incurred by the land use changes are calculated and added to the other emissions values. It has to be determined to which land use category the arable area belonged at the reference point in time.

If if has been proven that no land use change took place since the reference point in time, i.e., if the arable area at the reference point in time belonged to the land use category "arable land", then e'_l = zero.

Part III – Methodology for greenhouse gas accounting in accordance with the recommendations of the EU COM for solid and gaseous biomass for the generation of energy

1a. Greenhouse gas emissions from the production of solid and gaseous biomass fuels, before conversion into electricity, heating and cooling, shall be calculated as:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr},$$

where

E = total emissions from the production of the fuel before energy conversion;

e_{ec} = emissions from the extraction or cultivation of raw materials;

e_l = annualised emissions from carbon stock changes caused by land use change;

e_p = emissions from processing;

e_{td} = emissions from transport and distribution;

e_u = emissions from the fuel in use, that is greenhouse gases emitted during the combustion of solid and gaseous biomass;

e_{sca} = emission savings from soil carbon accumulation via improved agricultural management;

e_{ccs} = emission savings from carbon capture and geological storage, and;

e_{ccr} = emission savings from carbon capture and replacement.

Emissions from the manufacture of machinery and equipment shall not be taken into account.

1b. Greenhouse gas emissions from the use of solid and gaseous biomass in producing electricity, heating or cooling including the energy conversion to electricity and/ or heat or cooling produced shall be calculated as follows:

For energy installations delivering only useful heat:

$$EC_h = \frac{E}{\eta_h}$$

For energy installations delivering only electricity:

$$EC_{el} = \frac{E}{\eta_{el}}$$

For energy installations delivering only useful cooling:

$$EC_c = \frac{E}{\eta_c}$$

Where:

EC_h = Total greenhouse gas emissions from the final energy commodity, that is heating.

EC_{el} = Total greenhouse gas emissions from the final energy commodity, that is electricity.

EC_c = Total greenhouse gas emissions from the final energy commodity, that is cooling

η_{el} = The electrical efficiency, defined as the annual electricity produced divided by the annual fuel input.

η_h = The thermal efficiency, defined as the annual useful heat output, that is heat generated to satisfy an economically justifiable demand for heat, divided by the annual fuel input.

η_c = The thermal efficiency, defined as the annual useful cooling output, that cooling generated to satisfy an economically justifiable demand for cooling, divided by the annual fuel input.

Economically justifiable demand shall mean the demand that does not exceed the needs of heat or cooling and which would otherwise be satisfied at market conditions.

For the electricity coming from energy installations delivering useful heat:

$$EC_{el} = \frac{E}{\eta_{el}}\left(\frac{C_{el}\cdot\eta_{el}}{C_{el}\cdot\eta_{el} + C_h\cdot\eta_h}\right)$$

For the useful heat coming from energy installations delivering electricity:

$$EC_h = \frac{E}{\eta_h}\left(\frac{C_h\cdot\eta_h}{C_{el}\cdot\eta_{el} + C_h\cdot\eta_h}\right)$$

Where:

C_{el} = Fraction of exergy in the electricity, or any other energy carrier other than heat, set to 100 % (C_{el} = 1).

C_h = Carnot efficiency (fraction of exergy in the useful heat).

Carnot efficiency, C_h, for useful heat at different temperatures:

$$C_h = \frac{T_h - T_0}{T_h}$$

Where:

T_h = Temperature, measured in absolute temperature (kelvin) of the useful heat at point of delivery as final energy

T_0 = Temperature of surroundings, set at 273 kelvin (equal to 0 °C)

For T_h < 150 °C (423 kelvin), C_h is defined as follows:

C_h = Carnot efficiency in heat at 150 °C (423 kelvin), which is: 0.3546

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