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Life Cycle Assessment of Burning Different Solid Biomass Substrates

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Für den Inhalt und die Schlussfolgerungen sind ausschliesslich die Autoren dieses Berichts verantwortlich

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Imprint

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Abstract

Biomass from agriculture, crop residues, forestry, landscape management, and wastes from industry and households can be used for energy recovery. In order to obtain useful energy carriers from the different biomass substrates, they can be fermented for a conversion into biogas, they can be converted into biofuels or they can be burnt directly in order to receive heat or to generate electricity.

In this project a life cycle assessment (LCA) of the direct combustion of different non-wood biomass substrates is performed. For that purpose the life cycle inventory (LCI) data are collected and modelled according to the present guidelines of ecoinvent data v2.2. The final product is useful heat provided by the combustion process.

A survey of the potential biomass substrates for direct combustion mentioned in literature was conducted, which gave an overview of these substrates covering pomaces, kernels, shells, by-products from industry, oil from oil seeds, and other products and wastes.

Based on the overview of potential biomass substrates for combustion and the availability of data, life cycle inventory data for burning the following five substrates are collected:

- Olive dry pomace
- Coffee ground pellets
- Horse dung & wood chips co-combustion
- Poultry litter pellets
- Slurry solids & wood chips co-combustion

The life cycle impact assessment shows that the combustion of the biomass substrates has the highest environmental impact, followed by the disposal of the ash generated by the combustion process. In general the biomass substrates perform worse compared to the combustion of wood from an environmental point of view. The burning of biomass substrates generates higher particulate and nitrogen oxide emissions than the combustion of wood or wood pellets. The combustion of coffee ground pellets, poultry litter pellets and horse dung mixed with wood chips show similar environmental impacts as the combustion of wood logs in a small furnace.

The study shows the improvement potentials regarding reduction of air emissions and disposal routes for ashes. These have to be further evaluated and measurements on key pollutants are necessary in order to finally judge about the possibilities and environmental impacts of using biomass wastes in direct combustion processes.

Abbreviations

C	Carbon
CH	Switzerland
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
GWP	Global warming potential
H	Hydrogen
IPCC	Intergovernmental panel on climate change
kW	Kilo watt
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LHV	Lower heating value
MJ	Mega joule
MSWI	Municipal solid waste incineration
MW	Mega watt
N_2O	Dinitrogen monoxide
NMVOC	Non-methane volatile organic carbon
NO_x	Nitrogen oxides
O	Oxygen
PM	Particulate matter
S	Sulphur
SO_x	Sulphur oxides
TSP	Total suspended solids
UHV	Upper heating value
VOC	Volatile organic carbon

Life Cycle Assessment of Burning Different Solid Biomass Substrates

1. Introduction

Biomass from agriculture, crop residues, forestry, landscape management, and wastes from industry and households can be used for energy recovery. In order to obtain useful energy carriers from the different biomass substrates, they can be fermented for a conversion into biogas, they can be converted into biofuels or they can be burnt directly in order to receive heat or to generate electricity. Detailed life cycle assessments (LCA) of the use of wood as energy source have been carried out by Bauer (2007), whereas the direct combustion of other biomass substrates has not yet been evaluated for the ecoinvent database. Hence, in this project an LCA of the direct combustion of different non-wood biomass substrates is performed. For that purpose the life cycle inventory (LCI) data are collected and modelled according to the ecoinvent guidelines (Frischknecht et al. 2007; Jungbluth et al. 2007a).

2. Goal and scope of the LCA study

2.1. Key questions

The combustion of different types of biomass is assessed within the study. The analysis focuses on the following points.

- What are the environmental impacts of biomass combustion?
- How can these impacts be compared to other types of heat provision also from fossil resources?
- What are the main emissions and impacts from an environmental point of view?
- Which influence has the type of substrate and the combustion technology?

The data investigated in this project should facilitate others works on LCA. Examples are the labelling of renewable energy with the naturemade star label (Jungbluth et al. 2010) and a comparison of different disposal routes of such biomass wastes.

Furthermore, with this evaluation we also would like to highlight possible further research questions for the investigation of such biomass substrates.

In order to assess the environmental performance of burning different biomass substrates, data about different types of technology and biomass substrates are necessary. Data regarding production of the biomass substrates, heat generation, as well as regarding emissions from the combustion process have to be collected and modelled in a LCI.

If the purpose of the substrate production is the generation of heat from burning the biomass, the full production process has to be allocated to the environmental impact of burning the biomass substrate. However, substrates are often by-products of multi-output processes. In such processes, the environmental impact of the production process is allocated using the price of the different products as allocation factor. If burning biomass substrates that are wastes with no economic value, no environmental impacts from the substrate production need to be allocated to the generated heat.

The disposal of the ashes generated by the combustion of the biomass substrates is completely allocated to the combustion processes. The replacement of artificial fertilizer, when using the ashes of the biomass substrates instead of artificial fertilizers, is not considered.

In addition to the substrate supply chain, the emissions from the combustion of the biomass have to be considered. The most important emissions are nitrogen oxides, particulates, and carbon dioxide. However, the combustion of biomass in different furnaces leads to many other specific emissions, which are dependent on the applied technology and composition of the substrate.

For the accomplishment of the goals the following information is needed:

- LCI data of substrate production
- Actual market prices for substrates and co-substrates
- Calorific value of different substrates

- Emission data from burning the biomass substrates

2.2. Functional unit

The functional unit is one MJ useful heat for heating systems. The LCA is modelled for the situation in Switzerland with the most recent data available.

2.3. Geographical boundaries

The inventory for the combustion of olive pomace is modelled for a typical production area for olives in the Lythrodontas region in Cyprus. The inventory for the disposal of the ash generated by the combustion of olive pomace is modelled for municipal incineration in Switzerland and for a sanitary landfill according to Swiss legislation built in Switzerland. The technology mix for municipal incineration corresponds to the technology mix encountered in Switzerland in the year 2000 and is comparable to modern incineration practices in Europe, North America or Japan. The sanitary landfill for the disposal of the ash includes a base seal, leachate collection and treatment of the leachate in a municipal wastewater treatment plant.

The inventories for the combustion of coffee ground pellets, poultry litter pellets, horse dung and pig slurry solids are modelled for pilot plants in Switzerland. No adjustments have been made to the emission factors in order to account for the measurements in pilot plants. The inventory for the disposal of the ash generated by the combustion is modelled for the same geographical boundaries as the disposal of ash generated by the combustion of olive pomace.

2.4. Overview of potential biomass substrates for combustion

As a first step a survey of the potential biomass substrates for direct combustion mentioned in literature is conducted. Tab. 1 gives an overview of these substrates covering pomaces, kernels, shells, by-products from industry, oil from oil seeds, and other products and wastes. For the green marked substrates, data that could be used for an LCI are available, such as calorific values, typical moisture or elemental composition.

Tab. 1 Overview of potential biomass substrates for direct combustion

	English	Deutsch
Pomace		
	Canola pomace	Rapskuchen
	Sunflower pomace	Sonnenblumenpresskuchen
	Olive Pomace	Olivenpresslinge (Rückstände)
	Castor cake	Rizinuskuchen
Kernel		
	Palm kernel	Palmenkerne
	Oliven kernel	Olivenkerne
	Cherry stones	Kirschenkerne
	Plum stones	Zwetschgenkerne
	Grape seeds	Traubenkerne
Shells		
	Sunflower shells	Sonnenblumenschalen
	Canola shells	Rapsschalen
	Buckwheat shells	Buchweizenschalen
	Nut shells	Nusschalen
	Peanut shells	Erdnusschalen
	Almond shells	Mandelschalen
	Coconut shells	Kokosnusschalen
	Rice shells	Reisschalen
	Soybean shells	Sojaschalen
By-products		
	By-products of cellulose factories	Nebenprodukte aus Zellulosefabrik
	Draff (by-product from beer production)	Biertreber (Nebenprodukt Bierproduktion)
	Residues from malt processing	Rückstände aus der Malzverarbeitung
	Bagasse (from sugarcane processing)	Bagasse (aus Zuckerrohrverarbeitung)
Oil from oil seeds		
	Canola oil	Rapsöl
	Jatropha oil	Jatropha-Öl
	Palm oil	Palmöl
	Sunflower oil	Sonnenblumenöl
	Castor oil	Rizinusöl
	Soybean oil	Sojaöl
	Plant oils in general	Pflanzenöle allg.
	Animal fat	Tierfett

Other products and wastes	English	Deutsch
	Heating cereals	Heizgetreide
	Triticale (cereals)	Triticale (Getreide)
	Biowaste	Grüngut
	Paper	Papier
	Paper fibre residues	Papierfaserreststoff
	Textiles	Textilien
	Coffee grounds	Coffee grounds / Waste
	Roasting wastes	Röstereiabfälle
	Sugarcane	Zuckerrohr
	Palm leaves	Palmblätter
	Miscanthus	Chinaschilf (Miscanthus)
	Thistle (*Cynara cardunculus*)	Distel (*Cynara cardunculus*)
	Other plant leaves	andere Pflanzenblätter
	Gylcerine	Glyzerin
	Straw	Stroh
	Grass	Gras
	Reed canary grass	Reed canary grass
	Needles (spruce)	Tannennadeln
	Horse dung with wood shavings litter + wood chips	Pferdemist mit Hobelspäneinstreu + Holzschnitzel
	Horse dung with wood shavings litter + cereal briquettes	Pferdemist mit Hobelspäneinstreu + Holzschnitzel
	Horse dung with straw litter + reed cutting	Pferdemist mit Stroheinstreu + Riedflächenstreu
	Poultry litter	Hühnermist
	Corn cob	Maiskolben
	Cotton residues	Baumwollreste
	Beet chips	Rübenschnitzel
	Sludge	Klärschlamm
	Animal meal	Tiermehl
	Fungi mycelium / fungi compost + wood chips	Pilzmyzel / Pilzkompost + Holzschnitzel
	Cereal briquette	Getreideabgang
	Residues from cereal harvesting	Rückstände der Getreideernte
	Cutting of reed areas	Schnitt von Riedflächen
	Fermentation substrate from food wastes	Gärsubstrat aus Speiseabfällen
	Solids from biowaste collection	Feststoffe von Grüngutsammlungen
	Slurry solids	Güllefeststoff

In Tab. 2 the available data for an LCI of burning biomass substrates are shown.

Tab. 2 **Data availability for LCI of burning biomass** substrates (√ means that corresponding data are available**)**

	technology	calorific value	moisture	density	fuel composition	emissions to air	ash content	ash composition	source
Olive dry pomace	boiler furnace in oil mill	√	√	√	√	CO_2, CO, CH_4, C_2H_6, ethylene, 1,3-Butadiene, n-Hexane, Benzene, Napthalene, Anthracene	√	√	Jauhiainen et al. (2005), van Loo & Koppejan (2007)
Palm kernel		-	-	-	-	-	√	-	van Loo & Koppejan (2007)
Sunflower shells		√	-	-	-	CO_2	-	-	Hackl & Mauschitz (2007)
Bagasse	in boiler furnace in sugar mill	√	√	-	√	PM, PM_{10}, CO_2, NO_x, POM,	√	-	EPA (1993)
Triticale (cereals)		√	√	√	√	-	√	√	van Loo & Koppejan (2007)
Paper fibre residues		√	-	-	-	CO_2	-	-	Hackl & Mauschitz (2007)
Coffee grounds	in 25 kW industrial furnace, in large industrial furnace, and in a open fireplace	√	√	√	√	CO, NO_2, dust	√	-	SGS-Institut-Fresenius (2008), Waelti & Keller (2009)
Miscanthus	in grate furnace, in bale furnace, in Bioflox IDDEA©	√	√	-	√	CO, NO_x, dust	√	√	van Loo & Koppejan (2007), Schmid & Gaegauf2008, agricultural production investigated in Jungbluth *et al.* (2007b)
Thistle (Cynara cardunculus)		-	-	-	√	-	√	-	Llorente & Garcia (2006)
Straw	e.g. in cigar burner or straw furnaces	√	√	√	√	NO_x, dust	√	√	van Loo & Koppejan (2007), Llorente & Garcia (2006), Allica et al. (2001),

	technology	calorific value	moisture	density	fuel composition	emissions to air	ash content	ash composition	source
									Hersener et al. (1997)
Grass	in grate furnace, in bale furnace	√	√	√	√	NO$_x$, dust	-	-	van Loo & Koppejan (2007), Hersener et al. (1997)
Horse dung with wood shaving litter and wood chips	500-600 kW grate furnace	√	√	√	√	dust, SO$_2$, CO, NO$_x$, HC, NH$_3^-$, Cl, CO$_2$	-	-	Bühler et al. (2005), Bühler et al (2007)
Horse dung with wood shaving litter and cereal briquettes	500-600 kW grate furnace	√	√	√	√	dust, SO$_2$, CO, NO$_x$, HC, NH$_3$	-	-	Bühler et al. (2005), Bühler et al (2007)
Horse dung with straw litter + wood chips + reed cutting	500-600 kW grate furnace	-	√	-	√	dust, SO$_2$, CO, NO$_x$, HC, NH$_3$	-	√	Bühler et al (2007)
Poultry litter	250-350 kW grate furnace	√	√	√	√	dust, SO$_2$, CO, NO$_x$, HC, NH$_3$	√	(√)	Salerno et al. (2001), van Loo & Koppejan (2007),
Fungi mycelium / fungi compost + wood chips	500-600 kW grate furnace	√	√	√	(√)	dust, SO$_2$, CO, NO$_x$, HC, NH$_3$	-	-	Bühler et al. (2005)
Cereal briquette	500-600 kW grate furnace	√	√	√	(√)	dust, SO$_2$, CO, NO$_x$, HC, NH$_3$	-	-	Bühler et al. (2005)
Cutting of reed areas	500-600 kW grate furnace	-	√	-	√	dust, SO$_2$, CO, NO$_x$, HC, NH$_3$	√	√	Bühler et al (2007)
Slurry solids	900 kW grate furnace	√	√	-	√	dust, SO$_2$, CO, NO$_x$, HC, NH$_3$	-	(√)	Hersener & Bühler (1998), Hersener & Meier (2002)

2.4.1. Olive dry pomace

Olive pomace is the solid remains of olives after pressing olive oil. It contains the skins, pulp, seeds, and stems of the fruit. In the European Union, olive pomace is burned mainly in olive oil mills in order to heat up water for the oil mills. In a demonstration project of the European Commission and the University of Cyprus detailed LCI data with regard to emissions, ash composition, calorific value etc. of the olive dry pomace are published (Avraamides & Fatta 2006, Jauhiainen et al. 2005).

2.4.2. Bagasse

Bagasse is the fibrous residue remaining after sugarcane or sorghum stalks are crushed to extract their juice. Bagasse is often used as a primary fuel source for sugar mills, where it is often used in cogeneration in order to provide both heat energy, used in the mill, and electricity, which is typically sold on to the grid. The island Mauritius generates 30 % of its electricity from combustion of Bagasse. The U.S. Environmental Protection Agency (EPA 1993) reports emission factors and other useful LCI figures of the bagasse combustion in a boiler furnace in a sugar mill. The combustion of bagasse in order to generate electricity is already included in ecoinvent (Jungbluth et al. 2007a).

2.4.3. Coffee grounds

The Swiss 3R Company[1] sells briquettes made from coffee grounds that can be used for barbecuing, in open fire places and in wood furnaces. We made contact with Dr. Harald Jenny, the director of the 3R Company, who informed us about their activities with regard to collection of data that can be used for LCI. According to Dr. Jenny, they already measured the emissions from fuelling a 25 kW industrial furnace with coffee grounds briquettes, and further analysis with open fire places and a large industrial furnace are planned. The 3R company showed high attendance to share their data with ESU-services Ltd. in order to enable an implementation in ecoinvent. They provided us with data regarding the elemental composition of the coffee grounds fuel (SGS-Institut-Fresenius 2008) as well as regarding carbon monoxide, nitrogen dioxide and particle emissions from the combustion in a 25 kW industrial furnace (Waelti & Keller 2009).

2.4.4. Horse dung

The technically feasible potential of energy from horse dung in Switzerland is about 2 PJ per year (Hersener & Meier 1999). However, as yet no horse dung is used energetically in Switzerland. Horse dung is usually mixed with litter, such as shavings or straw. Still, this combination cannot be burned by itself and needs another fuel, such as wood chips. The combustion of horse dung (with shavings or straw litter) as a co-fuel with wood chips, cereal briquettes, or reed cutting, was analysed in (Bühler et al. 2005; 2007). LCI data regarding calorific value, moisture, density, fuel composition, and emissions are published, however with a lack of data regarding the ash content and ash composition.

2.4.5. Grass and cereals

Several publications report LCI data of the combustion of grass, straw, hay, cereals, miscanthus, or reed cutting. The current technically feasible potential of energy from agricultural halm crops (miscanthus, hemp etc.) in Switzerland is about 0.7 PJ per year, the one of energy from compensating areas (grass, hedges etc.) is about 3.9 PJ per year, the one of energy from cuttings from landscape conservation is about 1 PJ per year, and the one of energy from straw is 11 PJ per year (Hersener & Meier 1999). As yet, grasses and cereals are not used energetically in Switzerland.

Van Loo and Koppejan (2007) report the moisture content, the calorific value and the density of high pressure grass bales, triticale, and straw, as well as elemental concentrations in straw, miscanthus, hay, triticale, and grass. They also declare the ash content of miscanthus, straw and cereals as well as the elemental composition of the ashes from cereal straw, miscanthus, and canary reed grass. However, they do not present emission factors of burning biomass substrates.

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[1] http://www.3rcompany.com/

Schmid & Gaegauf (2008) report dust, CO, and NOx emission factors of burning miscanthus pellets in an improved boiler. In addition they also declare typical elemental compositions of cereal and miscanthus pellets.

The cultivation of grass, wheat, and cereals as well as the production of hay and straw is already implemented in ecoinvent.

2.4.6. Poultry litter

Data of the combustion of poultry litter are presented by Salerno et al. (2001) whose study considers the combustion in a 250-350 kW grate furnace. Conventionally, poultry litter is used as a fertiliser in agriculture.

Ecoinvent already contains an LCI of dried poultry manure as a commercial fertiliser covering the energy demand required for further-processing (i.e. drying and granulation), process emissions, waste production, infrastructure, and transports (Nemecek et al. 2007).

2.4.7. Slurry solids

Slurry solids from liquids/solids separation of crude animal slurry can be used energetically as fuel in biomass furnaces. The technically feasible energy potential of the total slurry solids in Switzerland is about 2 PJ per year, which corresponds to 10'000 tons per year of solids from slurry separation (Hersener & Meier 1999). However, as yet slurry solids are not used energetically in Switzerland. Data of the combustion of slurry solids are reported by Hersener & Bühler (1998) and Hersener & Meier (2002).

2.5. Selection of the biomass substrates

Based on the overview of potential biomass substrates for combustion and the availability of data, LCAs of the following five substrates are established:

- **Olive dry pomace**: drying out process of pomace and combustion of dry pomace in a small-scale boiler furnace generating heat for an olive oil mill in Cyprus. Since olive dry pomace can be considered as a waste product, no emissions from the olive cultivation need to be allocated to the pomace and therefore it is not necessary to include the olive supply chain into the LCI.
- **Coffee grounds**: production of coffee ground briquettes and combustion of briquettes in a 25 kW industrial furnace generating useful heat. The coffee ground in the considered briquettes is a waste product from Nespresso© capsules and therefore the coffee production and processing does not need to be considered in the LCI.
- **Horse dung & wood chips**: co-combustion of 67 % unmodified horse dung (including wood shaving litter) and 33 % construction residual wood chips (ecoinvent dataset) in a grate furnace with a nominal boiler heat capacity of 500-600 kW generating heat for drying fruits in a farm and heating buildings. Horse dung is a waste product with no environmental burden from its formation. However, the environmental impacts from the wood chips production need to be taken into account and can be included with ecoinvent datasets.
- **Poultry litter**: Production of poultry litter pellets and combustion in a 250-250 kW grate furnace generating useful heat for apartments and hen houses. Poultry litter is a waste product with no environmental burden from its formation. Production of pellets is included in the analysis.
- **Slurry solids & wood chips**: separation of solid components from slurry and mixing and co-combustion of 15.5 % slurry solids with 71.7 % bark (ecoinvent dataset) and 12.8 % other components (mainly wood shavings) in a 1 MW bark furnace. Slurry solids are a waste product with no environmental burden from their formation. For the bark fuel ecoinvent data sets are available and the wood shavings can be approximated with similar ecoinvent dataset.

In Fig. 1 the process chain of the combustion of the five different substrates is shown. Because the fuels are considered as waste products the process chain starts with the preparation of the fuel for the combustion. No environmental burden is allocated to the biomass substrates.

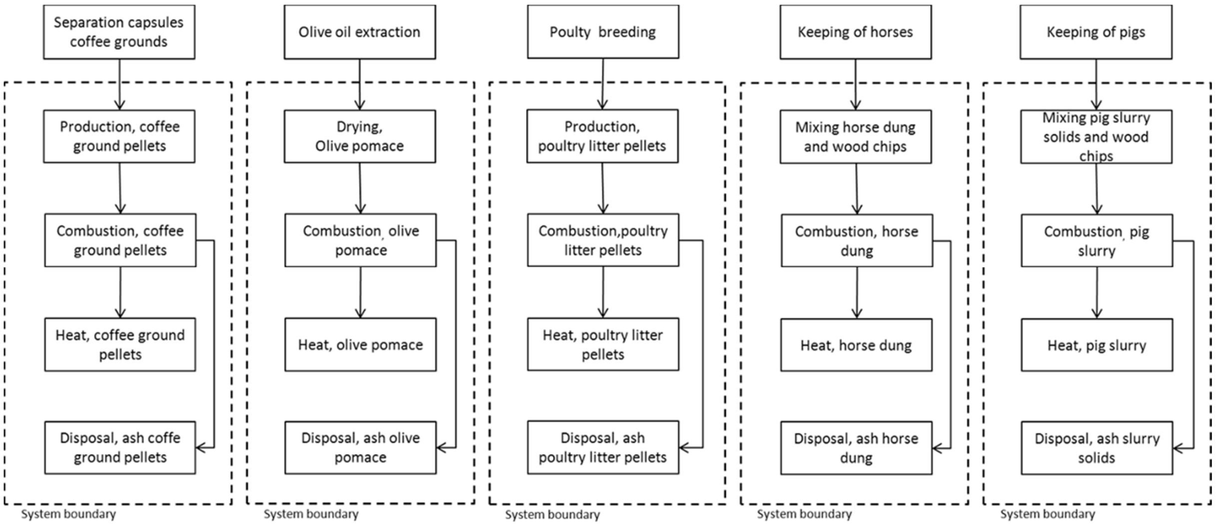


Fig. 1: **Sketch of the process chain of the different biomass substrates**

The five process chains in Fig. 1 are very similar. They all include four processes. The first process describes the preparation of the biomass fuel for combustion. The second process is the combustion of biomass fuel. The third process describes the heat generation and the fourth process describes the disposal of the ash generated by the combustion.

2.6. Properties of the substrates

Tab. 3 shows the elemental composition of the biomass substrates. The elemental composition of the different substrates was derived from literature. The known fractions of different elements were combined with estimates of the unknown fractions to fit the higher and the lower heating values shown in Tab. 4. The formulas (1) and (2) have been used to compute the higher and the lower heating values.

Tab. 3: **Elemental composition and effective moisture of the different biomass substrates**

Elemental composition	**Olive pomace**	**Coffee ground pellets**	**Poultry litter pellets**	**Horse dung & wood chips**	**Pig slurry solids & bark chips**
Unit	kg/kg	kg/kg	kg/kg	kg/kg	kg/kg
Carbon C	0.470	0.512	0.400	0.480	0.465
Hydrogen H	0.057	0.055	0.065	0.055	0.055
Oxygen O	0.384	0.404	0.355	0.373	0.350
Nitrogen N	0.011	-	0.038	0.002	0.022
Sulphur S	0.001	-	-	-	0.004
Ash content	0.077	0.029	0.142	0.090	0.104
Total dry mass	1.000	1.000	1.000	1.000	1.000
Moisture content	0.140	0.146	0.150	0.450	0.610

If there was no data available for the elemental composition of the fuel, the formulas (1) and (2) were used to fit the elemental composition to the known heating values shown in Tab. 4.

$$H_U = 34.8 \cdot C + 93.9 \cdot H - 10.8 \cdot O + 6.3 \cdot N - 2.44 \cdot w \qquad (1)$$

$$H_O = 33.9 + 121.4 \cdot \left(H - \frac{O}{8}\right) + 22.6 \cdot H + 10.5 \cdot S \qquad (2)$$

C: Carbon in kg per kg fuel H: Hydrogen in kg per kg fuel
O: Oxygen in kg per kg fuel N: Nitrogen in kg per kg fuel
S: Sulphur in kg per kg fuel w: Water content in kg per kg fuel

Tab. 4 shows the lower heating value, the lower heating value dry base and the higher heating value of the different substrates. The heating values calculated according to the formulas (1) and (2) are highlighted with grey colour.

Tab. 4: Heating values of the different biomass substrates

Heating value	**Olive pomace**	**Coffee ground pellets**	**Poultry litter pellets**	**Horse dung & wood chips**	**Pig slurry solids & bark chips**
Unit	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg
Lower heating value LHV	14.8	15.5	13.6(3	8.7(4	5.4
Lower heating value LHV dry base	17.6(1	18.6	16.4	17.9	17.8(5
Upper heating value UHV	18.4	19.1(2	17.8	18.5	18.6

1) Jauhiainen et al. 2005
2) SGS-Institut-Fresenius 2008
3) Salerno et al. 2001
4) Bühler et al. 2005
5) Hersener & Bühler 1998

Tab. 5 shows the particle density and the bulk density of the different biomass substrates. The particle and the bulk density of coffee ground pellets are assumed to be equal to the particle and bulk density of wood (Bauer 2007).

Tab. 5: Density and bulk density of the different biomass substrates

Density	**Olive pomace**	**Coffee ground pellets**	**Poultry litter pellets**	**Horse dung & wood chips**	**Pig slurry solids & bark chips**
particle density in kg/m3	-	1100(1	850(2	-	1519(4
bulk density in kg/m3	-	650(1	500	312(3	300(4

1) Bauer 2007
2) Salerno et al. 2001
3) Bühler et al. 2005
4) Hersener & Bühler 1998

2.7. Technical specifications of the furnace

In Tab. 6 a short description of the furnace used for the combustion of the biomass substrates is shown. The furnace used for the combustion of slurry solids and bark chips is considered the oldest technology. The furnace type hobag used for the combustion of coffee ground pellets is a fully automatic heating system as the furnaces used for the combustion of poultry litter pellets, horse dung and slurry solids. The hobag heating system does not use a grate firing but instead uses a die cutter in order to compress the fuel before the combustion. For the larger furnaces used for the combustion of poultry litter pellets, horse dung and slurry solids the same technology is used. These three fuels are burned in a grate firing. For the combustion of the olive pomace only data of a laboratory scale experiment using a tubular reactor are available.

Tab. 6: General description of the device used for the combustion of the biomass substrates

general description	furnace	comment
olive pomace(1	batch laboratory scale horizontal tubular reactor	experiment in lab
coffee ground pellets(2	furnace type hobag 25kW	device for combustion of wood waste
poultry litter pellets(3	rotating grate furnace 250-350kW, post-combustion chamber	pilot plant
horse dung and wood chips(4	grate furnace 500-600kW	device for combustion of wood waste
slurry solids and bark chips(5	grate furnace 1MW	device for combustion of wood waste

1) Jauhiainen et al. 2005
2) Waelti & Keller 2009
3) Salerno et al. 2001
4) Bühler et al. 2005
5) Hersener & Bühler 1998

Tab. 7 shows the measures for air pollution control used during the combustion of different biomass substrates. An electrostatic filter to clean the exhaust gas was only used in the case of horse dung, but the filter did not work properly. According to Bühler et al. (2005) the electrostatic filter only removed 50% of the expected amount of particles. In Bühler et al. (2007) corona-quenching and a too high electric resistance are named as reasons for the lower separation rate.

Tab. 7: Measures for air pollution control for the different biomass substrates

air pollution control	cyclone	electrostatic filter	comment
olive pomace(1	no	no	lab scale
coffee ground pellets(2	no	no	-
poultry litter pellets(3	yes	no	-
horse dung and wood chips(4	yes	yes	electrostatic filter did not work properly during the measurements
slurry solids and bark chips(5	no	no	-

1) Jauhiainen et al. 2005
2) Waelti & Keller 2009
3) Salerno et al. 2001
4) Bühler et al. 2005
5) Hersener & Bühler 1998

3. Life cycle inventory: summary

3.1. Fuel-mixture preparation

3.1.1. Drying of the olive pomace

The olive pomace as a residue of the olive oil production has a moisture content of about 50 w% (Vlyssides et al. 2004). In order to burn the pomace, it has to be dried. The moisture has to be reduced from 50 %w to 14 %w in order to enable the combustion of the olive pomace in a furnace. This corresponds to 0.72 kg of water per kg of dried olive pomace that has to be removed.

3.1.2. Pellet production

Pellets are produced for coffee grounds and poultry litter. The LCI data for pellet production infrastructure and drying infrastructure are taken from wood pellet production (ecoinvent Centre 2010). The bulk density of the pellets is shown in Tab. 5. The moisture of the coffee grounds is reduced from 50 %w to 15 %w and the moisture of the poultry litter is reduced from 43 %w to 13 %w in order to enable the pellet production. This corresponds to 0.7 kg of water that has to be removed per kg of coffee ground pellets and 0.57 kg of water that has to be removed per kg of poultry litter pellets The energy consumption for the drying processes before the pellet production is estimated to be 3.78 MJ per kilogram water evaporated (Hässig-Schellhorn 2007).

There are two possibilities to produce the pellets. Either the pellets are produced in a factory using fossil fuels for the drying process or the pellets are produced on site using heat and waste heat from the combustion processes. In addition to the savings of fossil fuels the pellets do not have to be transported, if they are produced on site. These two scenarios for the pellet production are evaluated in section 4.3.3.

3.1.3. Preparation of the fuel-mixture

Two of the biomass substrates, namely horse dung and slurry solids, are mixed with wood or bark chips. These two biomass fuels have high moisture and the mixing with a dryer fuel is needed to guarantee an efficient combustion. The mixture for horse dung consists of 67 % horse dung and 33 % wood chips. The mixture for slurry solids consists of 15.5 % slurry solids and 84.5 % bark chips.

3.2. Combustion of the biomass substrates

Compared to the different combustion datasets of wood in the ecoinvent database, there is only little data available for the different biomass substrates. Especially the air emissions of the combustion are not sufficiently documented in literature. In order to estimate the undocumented emissions the ecoinvent data sets for wood combustion are used. The furnace power is considered when completing the data sets.

Tab. 8 shows the emission factors for air emissions from the combustion for all substrates. For the coffee ground pellets, the poultry litter pellets, the horse dung and the slurry solids there are only concentration measurements in the exhaust gas available. Based on these concentrations the total flux was calculated using the total volume of the exhaust gas derived from the elemental composition of the substrates.

Tab. 8: **Emission factors for the air emissions of the different biomass substrates, extrapolated emission factors are highlighted with grey colour**

Emission factors	**Olive pomace(1**	**Coffee ground pellets(2**	**Poultry litter pellets(3**	**Horse dung & wood chips(4**	**Pig slurry solids & bark chips(5**
Unit	kg/MJ	kg/MJ	kg/MJ	kg/MJ	kg/MJ
Carbon dioxide CO2	1.16E-01	1.21E-01	1.08E-01	2.09E-01	3.14E-01
Carbon monoxide CO	2.12E-03	5.55E-04	5.16E-06	9.10E-05	1.41E-04
Nitrogen oxides NOx als NO2	-	3.33E-04	1.35E-04	2.39E-04	6.67E-04
Sulphur oxide SO2	-	-	4.17E-04	1.71E-04	6.50E-05
Hydrocarbons HC als C	-	-	1.88E-06	1.71E-05	-
Hydrogen chloride	-	-	4.83E-05	3.18E-05	2.11E-06
Ammonia NH3	-	-	-	7.96E-06	-
Ash	4.47E-03	1.59E-03	8.88E-03	5.50E-03	7.46E-03
Particulates TSP	-	6.34E-05	1.61E-04	2.27E-04	9.92E-04
Particulates PM <2.5um(6	-	5.70E-05	1.45E-04	2.05E-04	8.93E-04
Particulates PM 2.5 -10um(6	-	3.17E-06	8.07E-06	1.14E-05	4.96E-05
Particulates PM >10um(6	-	3.17E-06	8.07E-06	1.14E-05	4.96E-05

1) Jauhiainen et al. 2005
2) Waelti & Keller 2009
3) Salerno et al. 2001
4) Bühler et al. 2005
5) Hersener & Bühler 1998
6) extrapolated, Berdowski et al. 2001

The air emissions for the combustion of olives are taken from Jauhiainen et al. (2005) and completed with the ecoinvent data set "logs, mixed, burned in wood heater 6kW, CH". The air emissions for the combustion of coffee ground pellets are taken from Waelti & Keller (2009) and completed with the ecoinvent data set "pellets, mixed, burned in furnace 15kW, CH".

The air emissions for the combustion of poultry litter pellets are taken from Salerno et al. (2001) and completed with the ecoinvent data set “wood chips, from forest, mixed, burned in furnace 300kW, CH”. The air emissions for the combustion of horse dung are taken from Bühler et al. (2005) and completed with the ecoinvent data set “wood chips, from forest, mixed, burned in furnace 1000kW, CH”. The air emissions for the combustion of slurry solids are taken from Hersener & Bühler (1998) and completed with the ecoinvent data set “wood chips, from forest, mixed, burned in furnace 1000kW, CH”.

If measurements of the emissions from the combustion are available these measurements are used. For the most important pollutants like particles, nitrogen oxides and sulphur oxides measurements are documented in literature. The numbers for particles, NO_x and SO_x are missing for the combustion of olive pomace. For the coffee ground pellets only the SO_x emissions are missing.

3.2.1. Disposal ash from combustion

There are three different ways considered to dispose the ash generated by the combustion process, namely the disposal in landfarming, the disposal to municipal incineration or the disposal to a sanitary landfill For the small furnaces below a threshold of 30 kW it is assumed that 50 % of the ash are disposed in landfarming and 50 % are disposed in municipal solid waste incineration. For bigger furnaces above 30 kW it is assumed that 50 % of the ash is disposed in a sanitary land fill, 25 % of the ash is disposed in landfarming and 25 % is disposed in municipal solid waste incineration. These disposal scenarios are the same as used for disposal of wood ash in the ecoinvent data set for wood combustion (Bauer 2007).

3.2.2. Particulate matter emissions

For the particulate emissions only data for the total suspended particulate matter (TSP) were available. The distribution of the size of the particles had to be estimated. It was assumed that the distribution of the size of the particles for biomass combustion corresponds to the distribution of the particles for wood combustion determined within the CEPMEIP project

(Berdowski et al. 2001). The distribution of the particle emissions of wood and wood waste combustion according to CEPMEIP project is shown in Tab. 9.

Tab. 9: Distribution of the total suspended particulate matter to the different classes of particulates for non-industrial combustion plants according to Berdowski et al. 2001

Emissionfactors Wood and wood waste	**Low**	**Fraction**	**Medium**	**Fraction**	**Medium-High**	**Fraction**	**High**	**Fraction**
Non-industrial combustion plants	Mg/PJ	%	Mg/PJ	%	Mg/PJ	%	Mg/PJ	%
TSP	150.0	100.0%	300.0	100.0%	300.0	100.0%	300.0	100.0%
Particulates, < 2.5 um	135.0	90.0%	270.0	90.0%	270.0	90.0%	270.0	90.0%
Particulates, > 2.5 um, and < 10um	8.0	5.3%	15.0	5.0%	15.0	5.0%	15.0	5.0%
Particulates, > 10 um	7.0	4.7%	15.0	5.0%	15.0	5.0%	15.0	5.0%

3.3. Heat generation

The efficiency factor of the furnace used for the combustion of the olive pomace and the efficiency factor of the furnace used for the combustion of coffee ground pellets are estimated to be equal to 0.85.

The efficiency factor of the grate furnace used for the combustion of poultry litter pellets is 0.94 (Salerno et al. 2001). The efficiency factors for grate furnace and the bark furnace used for the combustion of the other substrates no information was available and an efficiency factor of 0.85 was assumed.

3.4. Disposal of the ashes

The elemental composition of the ash is taken from literature and the missing values are taken from the elemental composition of wood ash documented in the ecoinvent data set "disposal, wood ash mixture, pure, 0% water, to landfarming, CH, kg". Tab. 10 shows the elemental composition of the ash of the different biomass fuels.

The ash composition of the ash generated by the combustion of olive pomace is taken from Jauhiainen et al. (2005). The ash composition of the ash generated by the combustion of coffee ground pellets is taken from SGS-Institut-Fresenius (2008). The ash composition of the ash generated by the combustion of poultry litter pellets is taken from Salerno et al. (2001) and the composition of the ash generated by the combustion of horse dung is taken from Bühler et al. (2007). The ash composition of the ash generated by the combustion of slurry solids is taken from Hersener & Bühler (1998).

The natural concentration of heavy metals in wood and the natural concentration in the analysed biomass substrates are similar, but the ash formation when burning biomass substrates is ten times higher compared to the ash formation when burning wood. If 90% of the heavy metals are transferred to the residual ash, the concentration of the heavy metals in the wood ash is considerably higher than the concentration of the heavy metals in the ash generated by the combustion of the biomass substrates. To account for the higher ash formation the adopted values for the concentration of heavy metals taken from wood ash are reduced by a factor of 10 in the case of olive pomace, poultry litter and horse dung and by a factor of 3 in the case of coffee ground pellets. Without this correction the heavy metal content of the ash generated by biomass combustion is assumed to be overestimated.

Tab. 10: Elemental composition of the ash generated by the combustion process for the different biomass fuels (kg/kg waste)

Fuel		ash olive pomace	ash coffee ground pellets	ash poultry litter pellets	ash horse dung and wood chips	ash slurry solids and bark chips
Water content	H2O	n.a.	n.a.	n.a.	n.a.	n.a.
Oxygen (without O from H2O)	O	0.38554	0.4012	0.2875	0.4909	0.4909
Hydrogen (without H from H2O)	H	n.a.	n.a.	n.a.	n.a.	n.a.
Carbon (enter share of biogenic C below)	C	0.14853	0.012	0.012	0.012	0.012
Sulfur	S	0.00987	0.0092	0.0092	0.0092	0.0092
Nitrogen	N	n.a.	n.a.	n.a.	n.a.	n.a.
Phosphor	P	0.01705	0.0098	0.112	0.00392	0.00392
Boron	B	n.a.	n.a.	n.a.	n.a.	n.a.
Chlorine	Cl	0.00305	0.0032	0.0032	0.000204	0.000204
Bromium	Br	n.a.	n.a.	n.a.	n.a.	n.a.
Fluorine	F	n.a.	n.a.	n.a.	n.a.	n.a.
Iodine	I	n.a.	n.a.	n.a.	n.a.	n.a.
Silver	Ag	n.a.	n.a.	n.a.	n.a.	n.a.
Arsenic	As	n.a.	0.0000067	0.0000067	0.0000067	0.0000067
Barium	Ba	n.a.	n.a.	n.a.	n.a.	n.a.
Cadmium	Cd	n.a.	1.03448E-05	0.00000022	0.000005	0.000005
Cobalt	Co	n.a.	3.44828E-05	0.0000018	0.0000018	0.0000018
Chromium	Cr	n.a.	3.44828E-05	0.0000195	0.0000195	0.0000195
Copper	Cu	n.a.	0.001034483	0.000426	0.000103	0.000103
Mercury	Hg	n.a.	0.000000033	0.00000001	0.00000001	0.00000001
Manganese	Mn	n.a.	0.002172414	0.02	0.02	0.02
Molybdenum	Mo	n.a.	0.0000037	0.0000037	0.0000037	0.0000037
Nickel	Ni	n.a.	6.89655E-05	0.000059	0.00000552	0.00000552
Lead	Pb	n.a.	0.000172414	0.0000065	0.000016	0.000016
Antimony	Sb	n.a.	0.000206897	n.a.	n.a.	n.a.
Selenium	Se	n.a.	n.a.	n.a.	n.a.	n.a.
Tin	Sn	n.a.	0.001172414	n.a.	n.a.	n.a.
Vanadium	V	n.a.	3.44828E-05	0.0000395	0.0000395	0.0000395
Zinc	Zn	n.a.	0.002965517	0.00091	0.00102	0.00102
Beryllium	Be	n.a.	n.a.	n.a.	n.a.	n.a.
Scandium	Sc	n.a.	n.a.	n.a.	n.a.	n.a.
Strontium	Sr	n.a.	n.a.		n.a.	n.a.
Titanium	Ti	0.00065	0.00138	0.00138	0.00138	0.00138
Thallium	Tl	n.a.	n.a.	n.a.	n.a.	n.a.
Tungsten	W	n.a.	n.a.	n.a.	n.a.	n.a.
Silicon	Si	0.06982	0.0826	0.0826	0.0826	0.0826
Iron (enter share of metallic iron below)	Fe	0.02528	0.0228	0.0228	0.0228	0.0228
Calcium	Ca	0.06675	0.284	0.284	0.284	0.284
Aluminium	Al	0.0241	0.079310345	0.0208	0.0208	0.0208
Potassium	K	0.21518	0.0545	0.099	0.01886	0.01886
Magnesium	Mg	0.03023	0.0321	0.044	0.0321	0.0321
Sodium	Na	0.00395	n.a.	n.a.	n.a.	n.a.
sum wet mass		**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

3.4.1. Landfarming

One possibility to dispose the ash generated by the combustion of the biomass substrates is the disposal in landfarming. Landfarming means the spreading of the ashes on arable land. The environmental impact of the spreading of the ashes is allocated to 100 % to the combustion of the biomass. The use of ashes as fertilisers is not considered despite the high content of alkali metals and phosphorus in the ashes. The disposal of the ash in landfarming was modelled as a direct flux of the elements shown in Tab. 10 to agricultural soil.

3.4.2. Municipal incineration

A second possibility to dispose the ashes is the disposal in municipal incineration. The disposal of the ash to municipal incineration was modelled according to Doka (2007). The same elemental composition of the ash, which is shown in Tab. 10, was used for the calculations. This includes the combustion of the ash in municipal incineration and the landfilling of the residual waste.

3.4.3. Sanitary landfill

The third possibility to dispose the ashes is the disposal of the ashes to a sanitary landfill. The disposal of the ashes to a sanitary landfill was modelled according to Doka (2007). The same elemental composition of the ash, which is shown in Tab. 10, was used for the calculations. This includes the construction of the sanitary landfill and the treatment of the sewage sludge from the wastewater treatment.

3.5. Coffee grounds in municipal incineration

For the coffee ground a second way of energy recovery was modelled, namely the combustion of the wet coffee grounds in municipal incineration instead of the drying and pelletising of the coffee grounds. The heat and electricity generation was modelled according to Doka (2007). The same elemental composition for the moist fuel as shown in Tab. 3 was used for the calculations.

For the analysis the net benefit of the combustion of coffee grounds in municipal incineration is computed. The net benefit is calculated as the difference between the avoided environmental impact of energy generation and the environmental impact of the combustion of one kilogram of coffee grounds in municipal incineration. The combustion of 1 kg of coffee grounds in municipal incineration generates 0.53 kWh electricity and 3.92 MJ of useful heat according to Doka (2007).

For the substitution of the energy generation two possibilities for electricity generation and heat production are analysed resulting in a minimal net benefit and a maximal net benefit. This minimum-maximum analysis is performed to cover the range of the different technologies for energy generation (Zah et al. 2007).

As substitution processes for electricity generation the process „electricity, natural gas, at combined cycle plant, best technology, RER“ is chosen for the minimal net benefit and for the maximal net benefit the electricity import mix shown in Tab. 11.

Tab. 11: Unit process raw data of the electricity import mix used for the calculation of the maximal net benefit of the electricity generation

	Name	Location	InfrastructureProces	Unit	electricity mix, import FR/DE/IT	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				kWh			
product	electricity mix, import FR/DE/IT	CH	0	kWh	1			
technosphere	electricity mix	FR	0	kWh	9.17E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); Leuenberger M. and Frischknecht R. (2010) Life Cycle Assessment
	electricity mix	IT	0	kWh	1.92E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); Leuenberger M. and Frischknecht R. (2010) Life Cycle Assessment of Swiss Electricity Mixes. implemented in ecoinvent data v2.3
	electricity mix	DE	0	kWh	6.41E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); Leuenberger M. and Frischknecht R. (2010) Life Cycle Assessment of Swiss Electricity Mixes. implemented in ecoinvent data v2.4

As substitution process for heat generation the process “heat, light fuel oil, at industrial furnace 1MW, CH” is chosen for the maximal net benefit and the process “heat, natural gas, at industrial furnace >100kW, RER” for the minimal net benefit.

3.6. Data quality

All the measurements were performed in pilot plants. Therefore the measurements are not comparable to a continuous operation of the plants. No adjustments have been made to the emission factors in order to account for the measurements in pilot plants.

For all substrates only the total amount of suspended particulate matter (TSP) in the flue gas was measured. The particle distribution had to be extrapolated from other measurements (Berdowski et al. 2001). This resulted in a fraction of 90% of the TSP belonging to the smallest category of the particulate matter (PM) smaller than 2.5 um. Because the combustion process of the biomass is worse compared to the combustion of wood, it is expected that the amount of small particles is smaller for the biomass fuels than for the wooden fuels, but there was no data available to prove this assumption. Therefore the same particle distribution as for the combustion of wooden fuels was used. This might lead to a higher environmental impact because the environmental impact of smaller particles is higher than the environmental impact of bigger particles.

Because of the availability, the up-to-dateness and the quality of the data an inclusion in the ecoinvent data base is only recommended for the data sets for coffee ground pellets, poultry litter pellets and horse dung mixed with wood chips.

3.6.1. Olive pomace

Data quality for olives pomace is debatable. The ash composition and the air emissions during the combustion are documented in Jauhiainen et al. (2005), but in the measurements of Jauhiainen et al. (2005) no heavy metals emissions, no nitrogen oxide emissions and no particle emissions into air are reported, as well as there are no heavy metals detected in the ash after combustion. Because the heavy metal emissions and the heavy metal content of the ash have a high impact on the result of the ecological scarcity method 2006 it is recommended to consider this fact when comparing the olive pomace with the other substrates, especially in case of the disposal of the ash.

3.6.2. Coffee grounds

For coffee grounds there are measurements for the nitrogen oxides, carbon monoxides and particle emissions from the combustion in Waelti & Keller (2009) as well as the metal content of the fuel (SGS-Institut-Fresenius 2008). This covers the factors with the highest impact on the result of the ecological scarcity method 2006. Because of the recent measurements and the emissions measured, the air emission data quality for coffee grounds is sound.

For the ash composition of the coffee grounds there was no information available, but there was detailed information on the composition of the fuel regarding metals and heavy metals in SGS-Institut-Fresenius (2008). In order to estimate the transfer of the heavy metals to the ash, the heavy metal balance of the combustion process was calculated, assuming that all heavy metals which are not emitted into air during the combustion are transferred to the ash. This calculation provides a reliable estimate for the heavy metal content in the ash.

3.6.3. Poultry litter

The data quality for poultry litter is considered as sound. The measurements took place in 2001 (Salerno et al. 2001) and as for coffee grounds the key emissions into, namely nitrogen oxides, sulphur oxides, particulate matter and carbon monoxide are measured. The other emissions are again taken from the data sets for wood combustion.

For the ash composition there is information on the potassium, phosphorus, magnesium, cadmium, copper, nickel and zinc content of the ash in Salerno et al. (2001). This selection covers the most important metals except of lead in case of the heavy metals.

3.6.4. Horse dung

The most important air emissions generated by the combustion of horse dung regarding environmental impact are measured in Bühler et al. (2005). This includes the emissions of nitrogen oxides, sulphur oxides and particulate matter. The basis of the data regarding air emissions is considered as sound.

For the ash composition there is information on the content of phosphorus, potassium, lead, zinc, copper and cadmium in Bühler et al (2007). This covers most of the elements with a high environmental impact

3.6.5. Pig slurry solids

For pig slurry there was only information available on the air emissions in Hersener & Bühler (1998). Again the most important air emissions are measured. For the ash composition there was no data available , but there was information on the composition of the fuel regarding metals and heavy metals in Hersener & Bühler (1998). In order to estimate the transfer of the heavy metals to the ash, the heavy metal balance of the combustion process was calculated, assuming that all heavy metals which are not emitted into air during the combustion are transferred to the ash.

Because the measurements for pig slurry took place in 1998 and because of the missing data regarding ash composition the data quality for pig slurry solids is considered as the lowest among these five biomass substrates. Further the fuel mixture for slurry solids mainly consists of wood (about 85%, cf. Tab. 14) and rather represents the co-combustion of a small fraction of slurry solids with wood.

4. Life cycle impact assessment

The five data sets for the heat generation are evaluated with the methods ecological scarcity 2006 (Frischknecht et al. 2009) and IPCC Global Warming Potential (Solomon et al. 2007) and the mass fluxes for selected substances are analysed. In addition the energy recovery from coffee grounds in municipal incineration is analysed.

4.1. Ecological Scarcity 2006

The ecological scarcity method (Frischknecht et al. 2009) evaluates the inventory results on a distance to target principle. The calculation of the eco-factors is based on one hand on the actual emissions (actual flow) and on the other hand on Swiss environmental policy and legislation (critical flow). These goals are:

- Ideally mandatory or at least defined as goals by the competent authorities,
- formulated by a democratic or legitimised authority, and
- preferably aligned with sustainability.

The weighting is based on the goals of the Swiss environmental policy; global and local impact categories are translated to Swiss conditions, i.e. normalised. Environmental impacts are shown separately for the main environmental compartments such as air, soil, surface water, ground water, waste, natural and energy resources. The method is applicable to other regions as well. Eco-factors were also developed for the Netherlands, Norway, Sweden (Nordic Council of Ministers 1995, Tab. A22 / A23), Belgium (SGP 1994) and Japan (Miyazaki et al. 2004).

The ecological scarcity method allows for an optimisation within the framework of a country's environmental goals.

The environmental and political relevance is essential for the choice of substances. The environmental policy does by far not define goals for all substances. Thus the list of eco-factors is limited. This particularly applies to substances with low or unknown environmental relevance in Switzerland and Europe (e.g. sulphate emissions in water bodies).

Fig. 2 shows the absolute and the relative contribution of the different stages to the result of ecological scarcity method 2006. The combustion of natural gas has the lowest environmental impact to generate 1 MJ of useful heat followed by the combustion of wood and the combustion of oil. The biomass substrates perform significantly worse than the fossil and the wooden fuels. The combustion of the biomass substrates performs even worse than a small and inefficient combustion (wood logs mixed 6 kW).

Overall, the burning of biomass releases more pollutants into the environment than the combustion of wood, oil or natural gas. Especially the combustion of olive pomace and pig slurry solids causes a high environmental impact.

The emissions caused by the combustion process have the highest fraction for all fuels. The supply of the fuel has a higher environmental impact in case of the fossil fuels and the pelletized fuels. The drying of the olive pomace also causes a higher environmental impact for the supply with fuel. The disposal of the ashes just has an impact to the heat generation using biomass fuels. For all the biomass substrates except olive pomace the disposal of the ash has a higher impact on the result of the ecological scarcity method than for the wooden fuels. Based on Fig. 2 one can say that the combustion process itself has the highest influence on the result, followed by the provision of the fuel and the disposal of the ashes in case of the biomass substrates. A clean and complete combustion of the fuel and an appropriate disposal of the ash have the highest priority in order to minimise the environmental impacts of the heat generation.

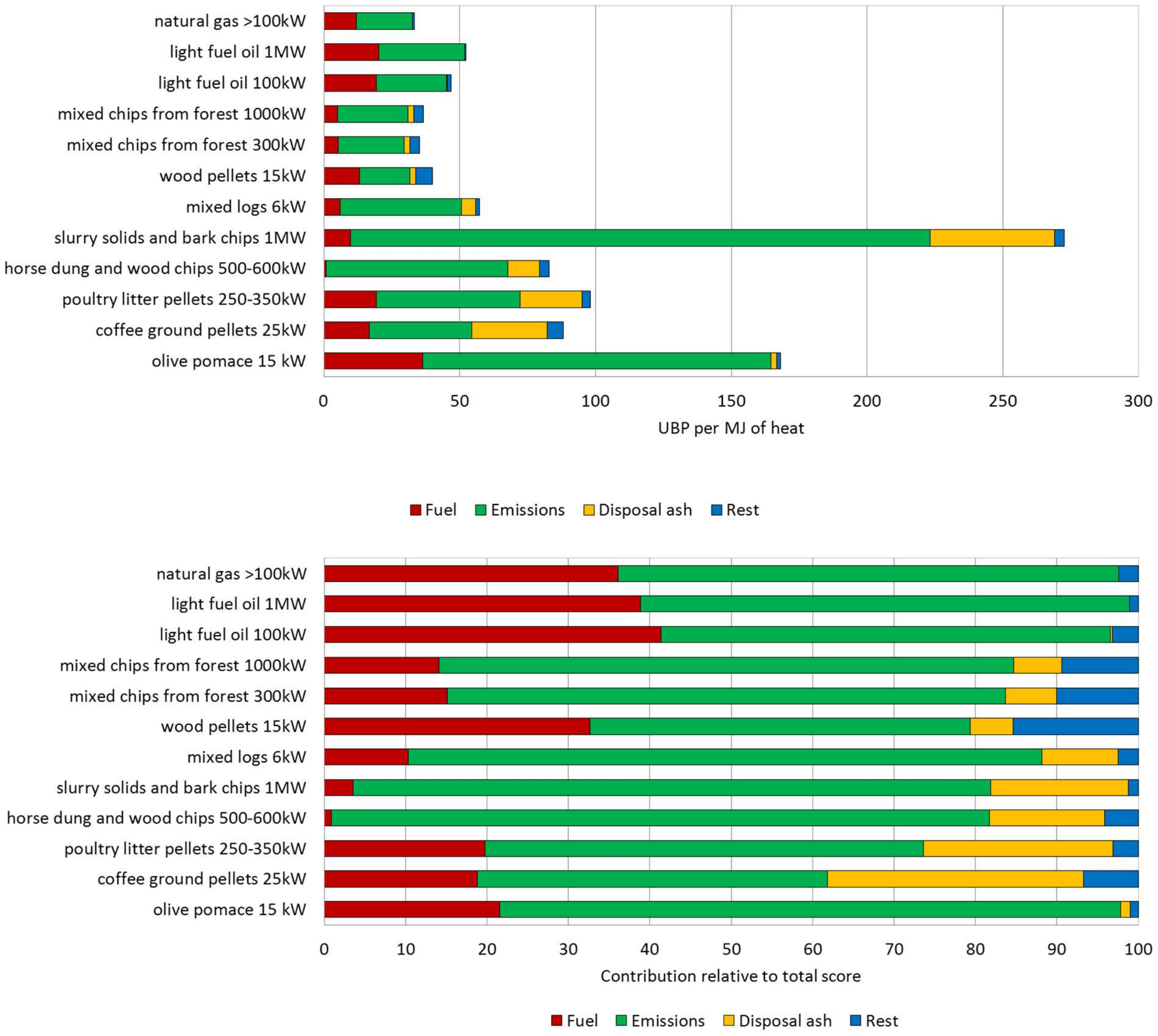


Fig. 2: **Total score (top) and the relative contribution (bottom) to the total score calculated with the method ecological scarcity 2006 per MJ of heat generated by the combustion of the different fuels split into contribution from the provision of the fuel, the direct emissions from combustion, disposal of the ashes and the rest**

Fig. 3 shows the environmental impact of the burning of biomass substrates and wooden and fossil fuels grouped according to the different environmental compartments and resources distinguished in the environmental scarcity method. The combustion of slurry solids and bark chips has the highest environmental impact regarding emissions into air, into ground water and into top soil. Further the combustion of pig slurry solids consumes the most energy resources because of the high amount of bark chips that has to be mixed with the slurry solids in order to enable the combustion (cf. 3.1.3) and causes a high depletion of natural resources. The combustion of poultry litter pellets causes the highest emissions into surface water and produces a high amount of waste that has to be deposited.

The high moisture of the slurry solids demands a high amount of an additional, dryer fuel, namely bark chips, in order to enable the combustion. In case of the combustion of pig slurry solids the depletion of energy resources is even higher than in case of the fossil fuels.

Without an overall weighting of the environmental impacts the ranking would differ for the different environmental compartments, but the combustion of slurry solids causes also the highest environmental impact in five of the seven categories.

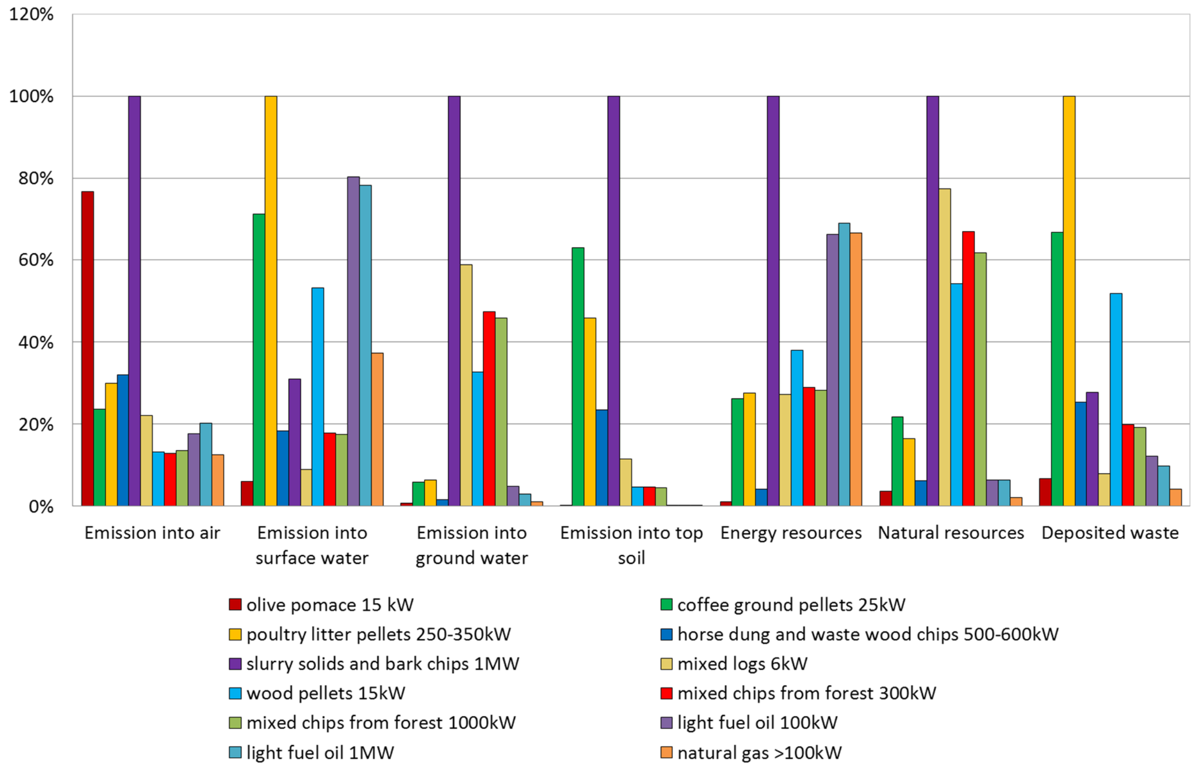


Fig. 3: **Environmental impact of the burning of the different biomass substrates, wood and fossil fuels relative to the highest score per environmental compartment**

Fig. 4 shows the absolute and the relative contribution of the different environmental compartments to the result of ecological scarcity method 2006. The highest percentage of the result is determined by the emissions into air and the emissions into top soil. The emissions in these two environmental compartments are analysed in more detail in the sections 4.1.1 and 4.1.2.

For all the biomass fuels the relative contribution of the different environmental compartments is similar. The emissions into air and the emissions into top soil account for the highest fraction of the total results. The sum of the points for the emissions into air and the emissions into top soil cover more than 90% of the environmental impact of the biomass fuels according to the ecological scarcity method 2006.

The total score is determined to a large extent by the air emissions. This shows the importance of the combustion process and the combustion technology. All the other environmental compartments have a considerably lower contribution to the result.

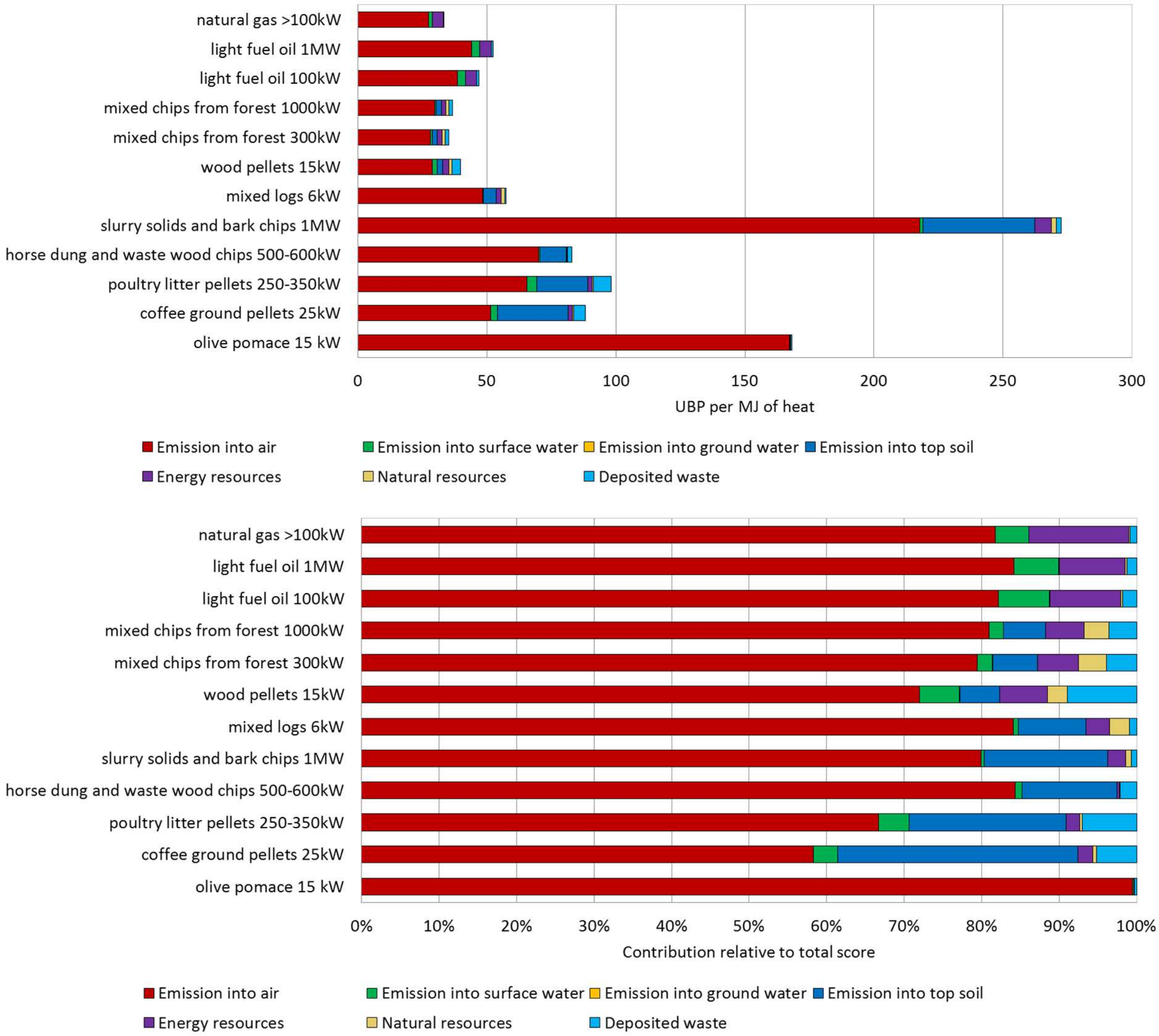


Fig. 4: **Total score (top) and the relative contribution (bottom) to the total score calculated with the method ecological scarcity 2006 per MJ of heat generated by the combustion of the different fuels split into environmental compartments**

4.1.1. Emissions into air

Fig. 5 shows the contribution of the different air pollutants to the total score of the air emissions as absolute values and relative to the total score. The environmental impact of the air emissions is mainly caused by the emission of benzene, particles, nitrogen oxides, methane, lead, dinitrogen oxide, cadmium, dioxin, sulphur oxide, NMVOC and fossil CO_2.

The reported benzene emissions per MJ of heat generated by the combustion of olive pomace are about 20 times higher than the benzene emissions into air generated by the combustion of the other substrates. The composition of the olive pomace seems to boost the formation of aromatic hydrocarbons during and after the combustion. The most important airborne emissions in case of the combustion of biomass substrates are particle emissions, emissions of nitrogen oxides and emissions of benzene, but there are considerable differences in the contribution of the different air pollutants to the total score across the different fuels.

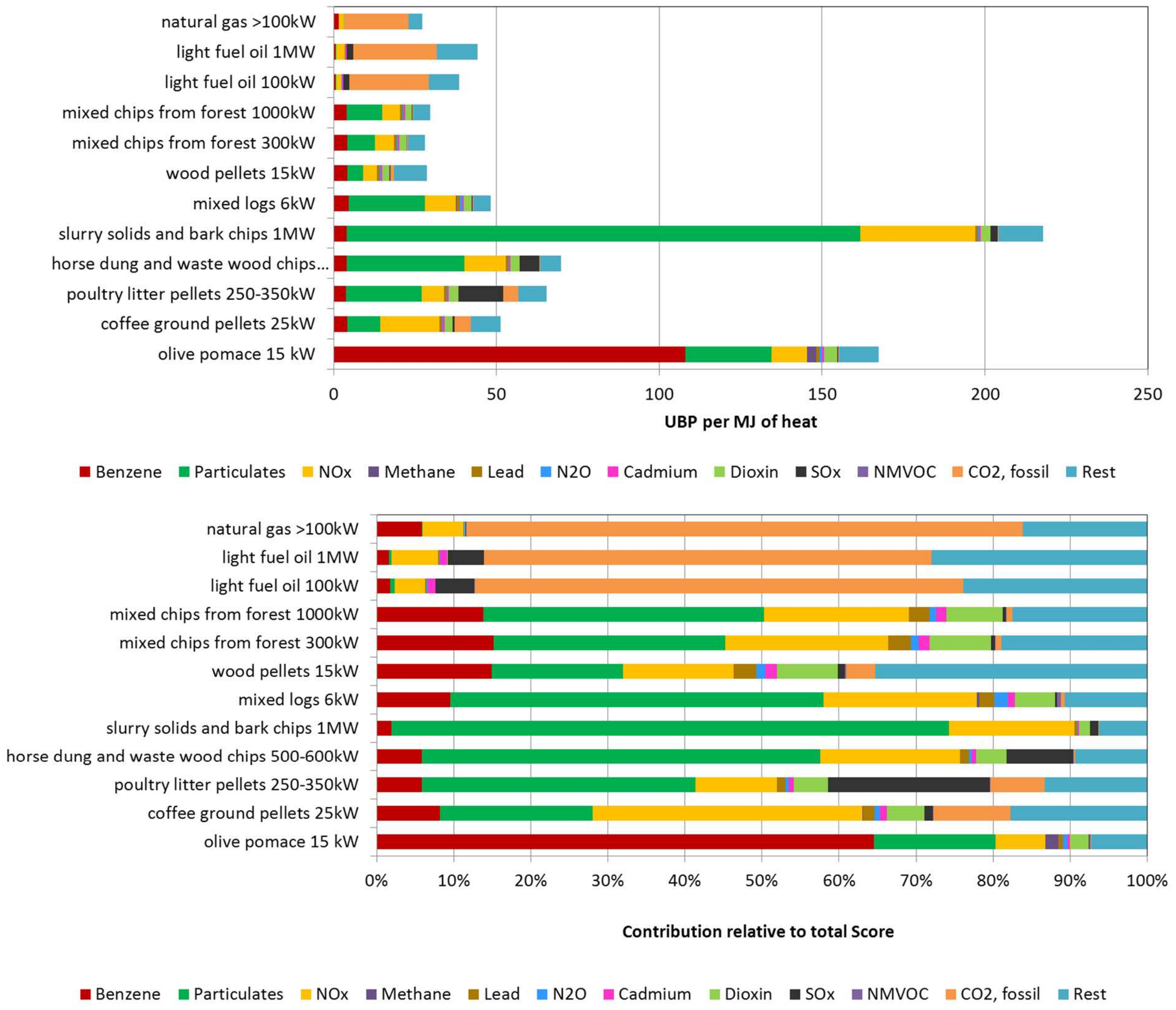


Fig. 5: **Total score (top) and the relative contribution (bottom) to the total score for air emissions calculated with the method ecological scarcity 2006 per MJ of heat generated by the combustion of the different biomass substrates and the combustion of wood**

Between the biomass substrates and the wooden fuels there is only a small difference in the contribution of the different pollutants to the total score. For the fossil fuels the total score for the air emissions is mainly determined by the emissions of fossil carbon dioxide.

Because of the high benzene emissions when burning olive pomace, the NMVOC emissions for the burning of olive pomace are higher than all other fuels (cf. figure Fig. 6). For the other fuels the NMVOC emissions are in the same order of magnitude, except for light fuel oil. The nitrogen oxide emissions are in the same range for all fuels but slightly higher for the biomass substrates. Astonishing are the low nitrogen oxide emissions for horse dung and poultry litter. For these substrates high nitrogen oxide emissions are expected because of the elemental composition of the dung like in the case of slurry solids.

The particulate emissions are very high for the burning of biomass substrates (cf. Fig. 6). In the case of the burning of the slurry solids one has to say that the particle measurements are taken from a pilot plant, which does not fulfil the Swiss legislation regarding particle emissions (LRV 2009). The particle concentration of 564 mg/m^3 (Hersener & Bühler 1998) in the flue gas exceeds the threshold of 20 mg/m^3 by more than a factor of 25. In addition the distribution of the particle size had to be estimated for all the biomass substrates, because only the mass of the total suspended solids in the exhaust gas was measured (cf. Tab. 9). The total amount of suspended solids in the exhaust gas of the biomass combustion is higher than the total amount of suspended solids from which the distribution was extrapolated. More detailed information about the distribution of the particles emitted from the combustion of the biomass substrates is needed in order to assess the environmental impact of the particle emissions.

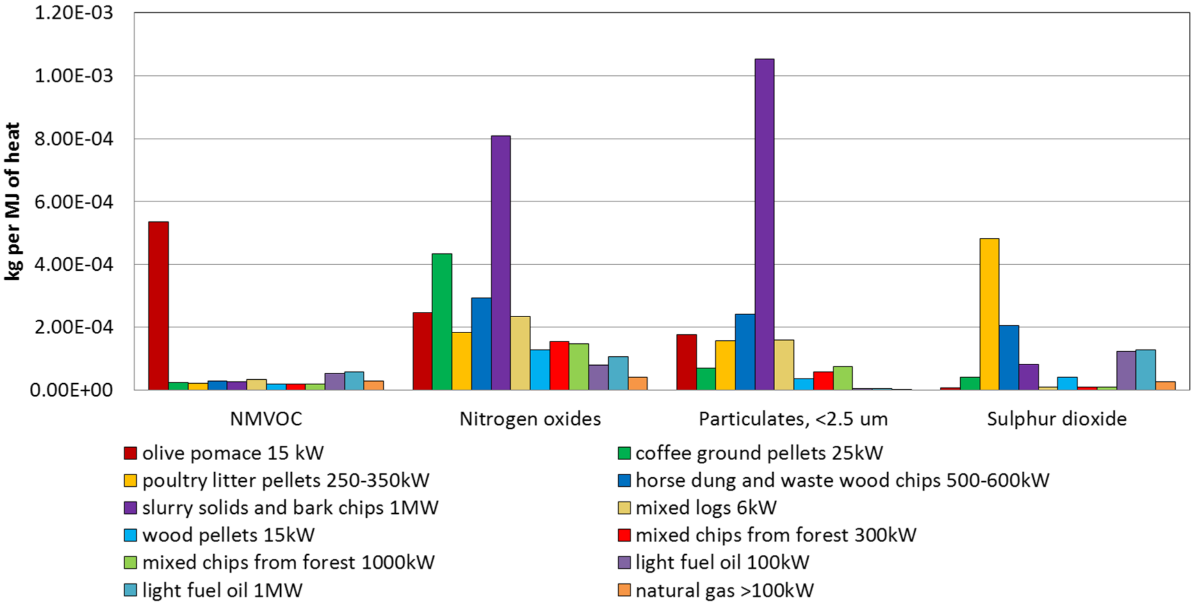


Fig. 6: **NMVOC emissions, nitrogen oxide emissions, particulate emissions and sulphur dioxide emissions caused by the generation of 1 MJ of useful heat for different substrates**

When looking at Fig. 6 the high the amount of emissions compared to the other substrates is clearly visible, the total mass of particles emitted and the total mass of nitrogen oxides emissions have to be reduced by at least a factor of 2 in order to be in the same range as the emissions caused by the combustion of wooden fuels.

4.1.2. Emissions into soil

Fig. 7 shows the environmental impacts caused by the emissions into top soil in detail. The heavy metal emissions account for the highest fraction of the environmental impact. The sum of the environmental impact of Zinc, Cadmium, Copper and Lead determines about 90% of the environmental impact assessed with the method of the ecological scarcity 2006. The combustion of pig slurry solids mixed with bark chips causes the highest heavy metal emissions into soil, followed by coffee ground pellets and poultry litter pellets.

The heavy metal flux into agricultural soil per MJ of heat generated in the case of the biomass fuels is considerably higher than the heavy metal flux per MJ of heat generated in case of the wooden fuels. The disposal of the ash as fertiliser on agricultural soil has a high environmental impact.

Because there are no heavy metals in the ash of burned olive pomace (cf. Tab. 10), the emissions into top soil are rated considerably lower in case of olive pomace compared to the other biomass substrates and even compared to the wooden fuels.

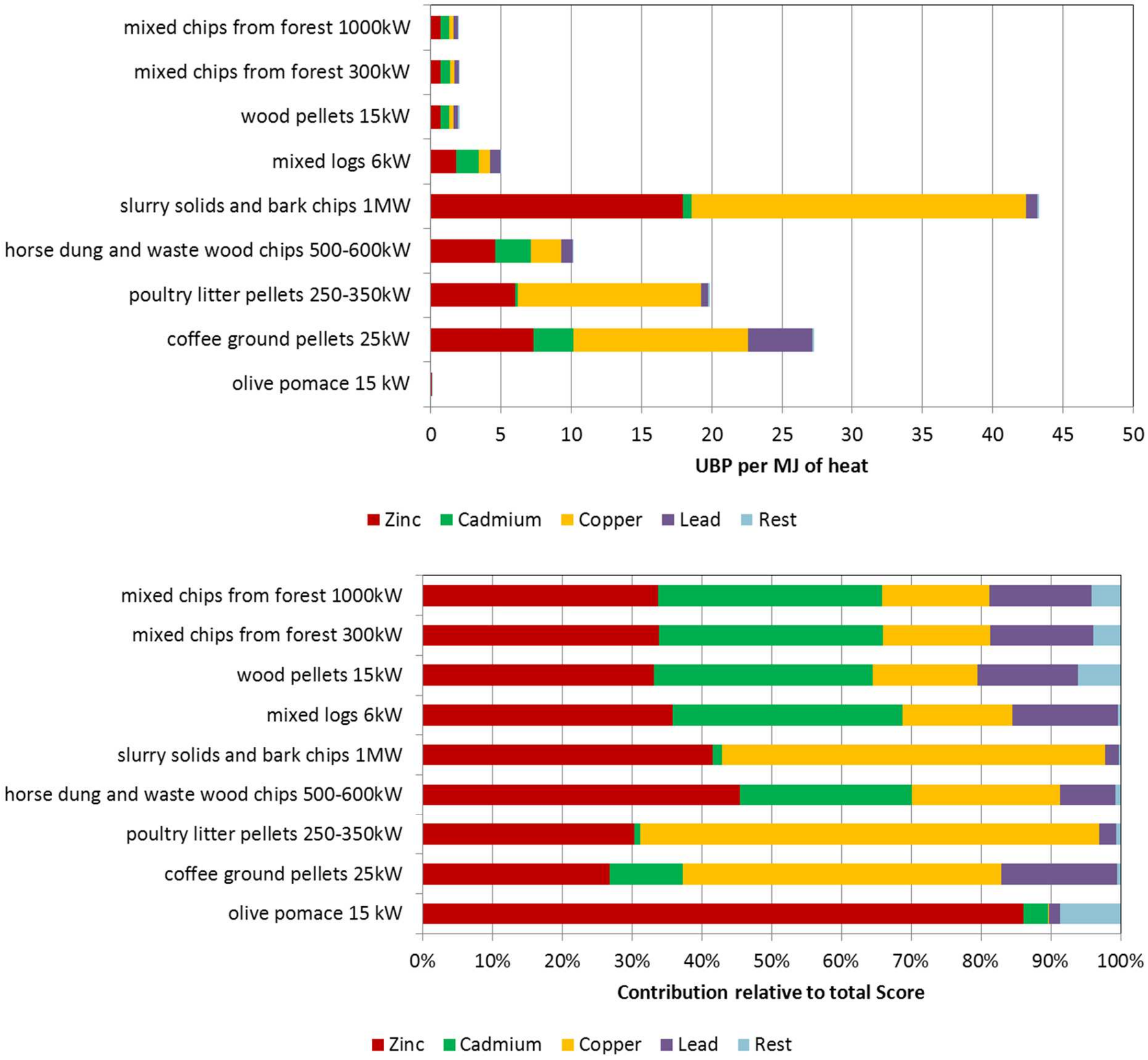


Fig. 7: **Total score (top) and the relative contribution (bottom to the total score of emissions into top soil calculated with the method ecological scarcity 2006 per MJ of heat generated by the combustion of different biomass substrates and wooden fuels**

Fig. 8 shows the absolute mass fluxes of the heavy metals copper, zinc, cadmium and lead into agricultural soil. The copper emissions are very high for pig slurry solids followed by coffee ground pellets and poultry litter pellets. The zinc emissions into top soil are considerably higher for the biomass substrates compared to the wooden fuels except olive pomace. Again the zinc emissions caused by the combustion of pig slurry solids are the highest.

The cadmium emissions into top soil are in the same range, but again higher for the biomass substrates compared to the wooden fuels except for olive pomace and poultry litter pellets.

The lead emissions into top soil are in a similar range except the emission caused by the disposal of the ash of coffee ground pellets. The lead emissions for poultry litter pellets and horse dung are between the values of wood logs and wood chips.

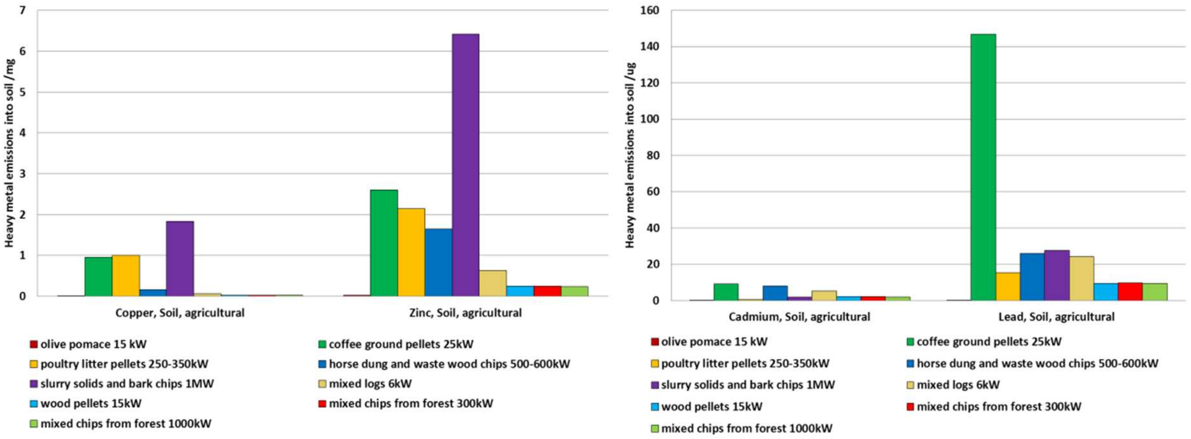


Fig. 8: **Heavy metal flux into top soil for the heavy metals copper and zinc in mg on the left and for cadmium and lead in ug on the right**

4.2. Greenhouse gases

All substances, which contribute to climate change, are included in the global warming potential (GWP) indicator according to IPCC (Solomon et al. 2007). The residence time of the substances in the atmosphere and the expected immission design are considered to determine the global warming potentials. The potential impact of the emission of one kilogram of a greenhouse gas is compared to the potential impact of the emission of one kilogram CO_2 resulting in kg CO_2-equivalents. The global warming potentials are determined applying different time horizons (20, 100 and 500 years). The short integration period of 20 years is relevant because a limitation of the gradient of change in temperature is required to secure the adaptation ability of terrestrial ecosystems. The long integration time of 500 years is about equivalent with the integration until infinity. This allows monitoring the overall change in temperature and thus the overall sea level rise, etc..

In this study a time horizon of 100 years is chosen, which is also used in the Kyoto protocol.

Fig. 9 shows the IPCC global warming potential for the different fuels. It is pointed out that the composition of the biomass substrates and the wood fuels is different to the composition of the fossil fuels. The combustion of oil and natural gas causes high emissions of fossil carbon dioxide, which results in a high global warming potential. All the biomass substrates cause a lower global warming potential than the fossil fuels.

The pelletised fuels have a higher global warming potential but the GWP is still way below the GWP caused by the combustion of fossil fuels. Further the drying of the pelletised fuels is modelled with the use of fossil fuels for the heat generation. The impact on the GWP can be lowered if waste heat or heat generated by the combustion of the biomass substrate itself is used.

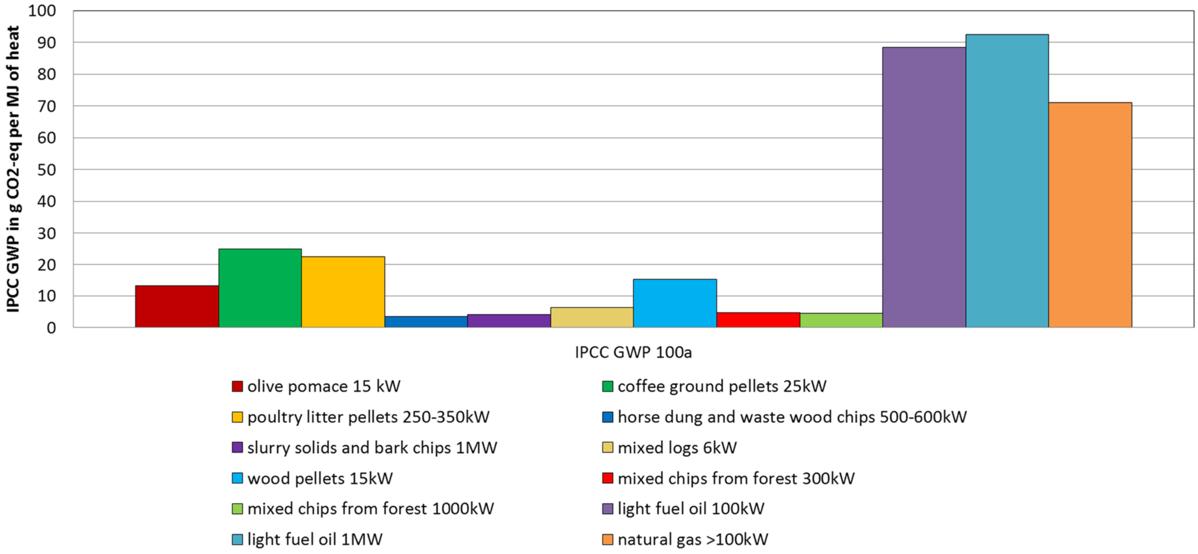


Fig. 9: **IPCC global warming potential for the generation of 1 MJ of useful heating using the different biomass substrates or wooden fuels**

Fig. 10 shows the fractions of the different greenhouse gases contributing to the total global warming potential. For olive pomace the non-CO_2 emissions and the emission of biogenic methane accounts for about 90% of the global warming potential. For all the other substrates the GWP is mainly caused by CO_2 emissions. The GWP is considerably lower for all the biomass substrates and wooden fuels compared to the combustion of fossil fuels.

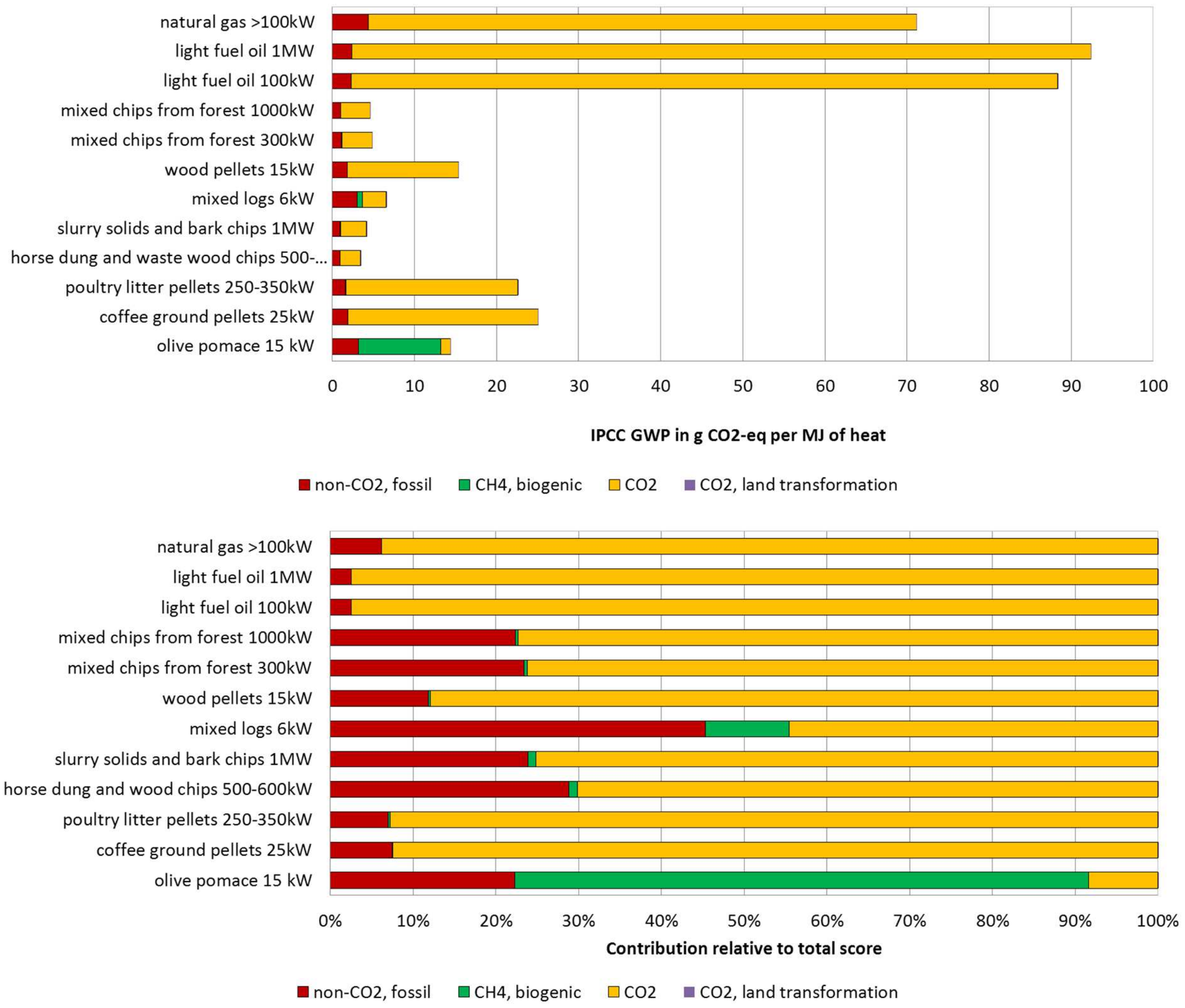


Fig. 10 **GWP in CO_2-eq per MJ of heat generated with different substrates in absolute values (top) and relative to the total score (bottom)**

4.3. Scenario analysis

4.3.1. Coffee grounds in municipal incineration

Fig. 11 shows the net benefit (Zah et al. 2007) of the combustion of coffee grounds in municipal incineration.

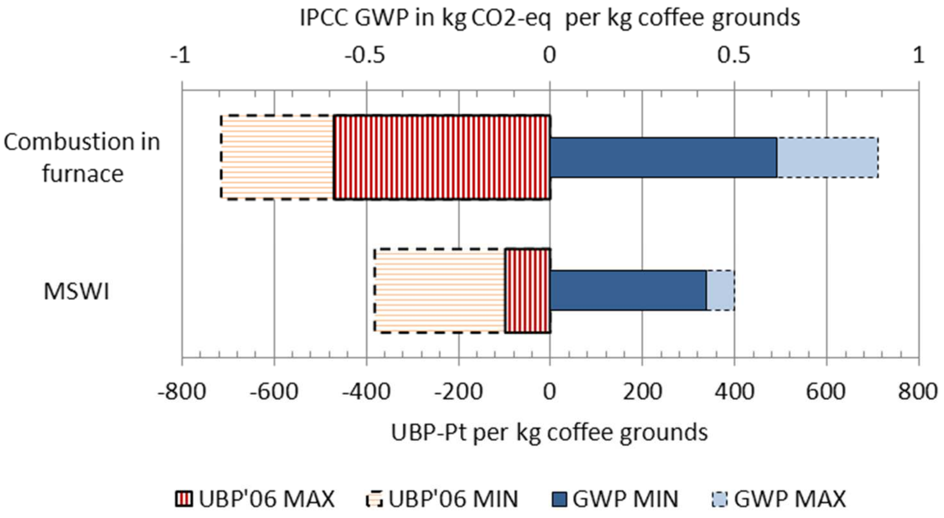
The combustion of coffee grounds in municipal incineration leads to a reduction of the GWP for the minimal net benefit as wells as for the maximal net benefit. This is the case because fossil fuels are replaced by the non-fossil fuel coffee ground. The combustion of the coffee grounds in form of pellets in a furnace has a minimal net benefit of 0.6 kg CO2-eq/kg and is higher than the maximal net benefit for the combustion in municipal incineration.

The net benefit for the combustion of coffee grounds calculated with the ecological scarcity method 2006 reveals that the minimal and the maximal net benefit are negative. This means that the substitution processes for the minimal and the maximal net benefit have a lower environmental impact according to the ecological scarcity method 2006.

The energy recovery in municipal incineration and the direct combustion of the coffee grounds are options to reduce the greenhouse gas emissions, but these options may not be environmentally friendlier, when looking at other emissions than greenhouse gases. Regarding the overall environmental impact the combustion of the coffee grounds in municipal incineration is the better solution than the direct combustion but the reduction of the GWP is slightly lower.

The net benefit in Fig. 11 also shows the trade-off between the reduction of the GWP and the increase of the environmental impact according to the ecological scarcity method 2006.

Fig. 11 **f material**



4.3.2. Ash disposal

In order to evaluate the impact of the disposal of the ash generated by the combustion different scenarios for the disposal of the ash are compared. In the *reference scenario* (REF) the ash is disposed to 50 % in landfarming and to 50 % in municipal incineration for olive pomace and coffee ground pellets. The ashes from poultry litter pellets, horse dung and slurry solids are disposed to 25 % in landfarming, to 25 % in municipal incineration and to 50 % to a sanitary landfill in the reference scenario (REF). The reference scenario is described in section 3.2.1. and is used for the life cycle impact assessment.

In the *scenario disposal in landfarming* (LAND) all the ash is disposed in landfarming. The disposal in landfarming is described in section 3.4.1. In the *scenario disposal to municipal incineration* (MSWI) all the ash is disposed to municipal incineration and in the *scenario disposal to sanitary landfill* (MSWLF) all the ash is disposed to a sanitary landfill.

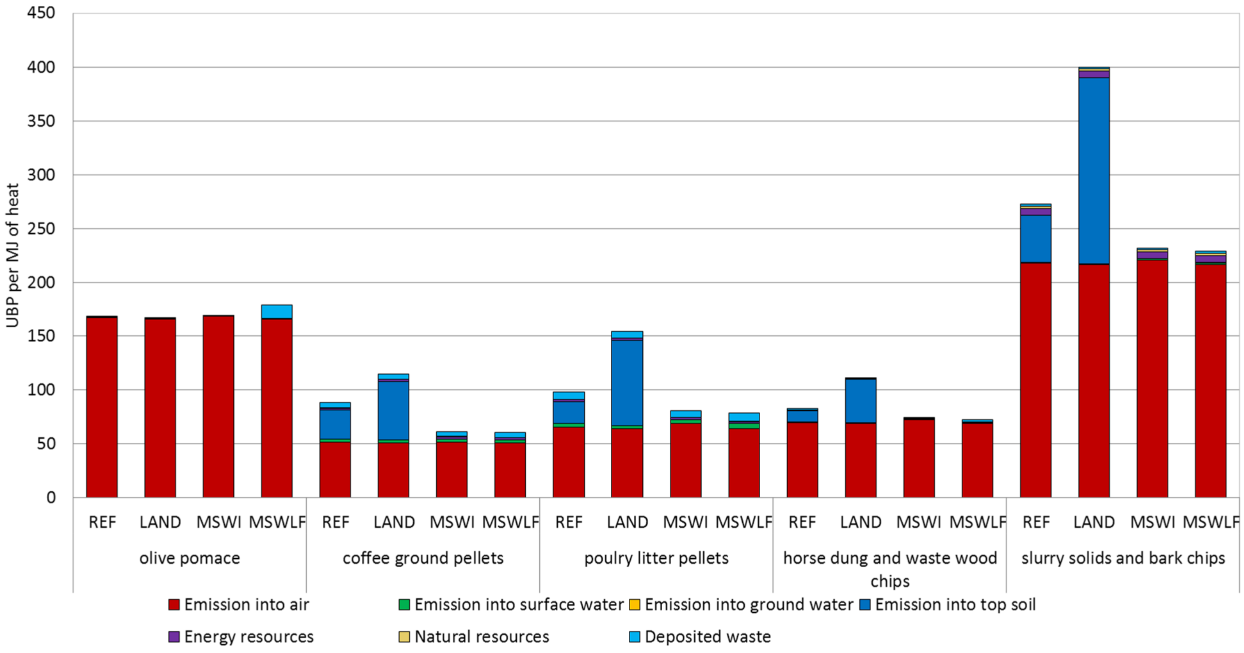


Fig. 12 **Comparison of the different possibilities for the disposal of the ash generated by the combustion of the biomass fuels for the reference scenario (REF), the disposal in landfarming (LAND), the disposal to municipal incineration (MSWI) and the disposal to sanitary landfill (MSWLF)**

The different scenarios for the disposal evaluate the impact of the disposal strategy on the result of the ecological scarcity method 2006. For the olive pomace the disposal of the ash has only a small influence on the result. Because there are no heavy metals in the ash (cf. Tab. 10) the disposal of the ash from the combustion of olive pomace in landfarming has only low environmental impacts.

The different scenarios show that the disposal of the ash has a considerable influence on the result for all the biomass substrates except olive pomace. The environmental impact can be lowered when disposing the ash to municipal incineration or to a sanitary landfill.

4.3.3. Pellet production

In order to evaluate the importance of the energy source for the drying of the biomass, two possibilities for the drying process are modelled here. The first scenario assumes that the biomass is dried using fossil fuels and stored in a regional storage centre after the pelletising process. This is scenario is named *regional storage*. This is the worst case regarding use of fossil fuels because fossil fuels are used for the heat generation in the drying process and for the transportation of the pellets to the regional storage centre. This scenario describes the situation if pellets are sold to external users.

The second scenario assumes the production of the pellets on site and the direct use of the heat generated by the combustion of the pellets for the drying process. This is the best case with a minimal use of fossil fuels because of the minimised transport distances and use of non-fossil fuels to dry the biomass substrates. But, it would not allow for using the pellets at another place.

Fig. 13 shows the comparison of the different scenarios for coffee ground pellets and poultry litter pellets. The environmental impact calculated with the method ecological scarcity 2006 slightly increases when using the biomass substrates in a closed loop in order to dry the wet biomass. This is mainly the case because of the high airborne emissions caused by the combustion of the biomass substrates.

The GWP can be reduced by 50 % when using the biomass substrates for the drying process instead of fossil fuels and when producing the pellets on site. However, there is a trade-off between reduction of the greenhouse gas emissions and the increase of other airborne emissions like particles and nitrogen oxides. Without an improvement of the combustion technology or a treatment of the flue gas the production of the pellets on site does not have a smaller environmental impact.

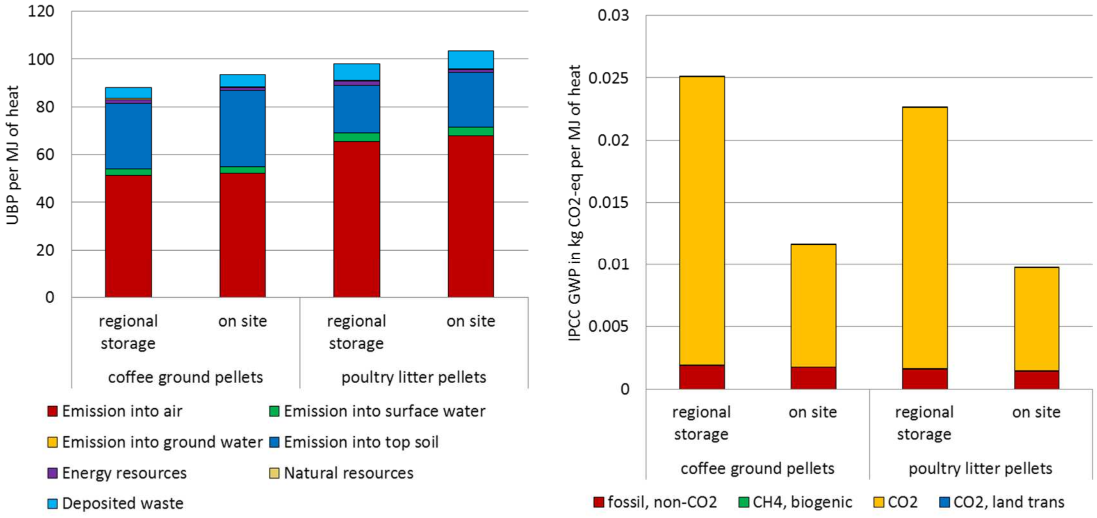


Fig. 13: **Total score calculated with the method ecological scarcity 2006 on the left and GWP according to IPCC on the right for the different scenarios for the drying of the biomass substrates during pelletizing process**

5. Interpretation

Biomass from agriculture, forestry or landscape management as well as waste from industry or households can be used for energy recovery. In this project an LCA performed for the direct combustion of five different wastes, namely olive pomace, coffee grounds, poultry litter, horse dung and pig slurry solids.

The LCA shows, that the direct emissions from combustion into air and the emissions from ash disposal into top soil turn out to cause the most important environmental impacts. The burning of olive pomace and pig slurry solids has the severest environmental impacts (cf. Fig. 3 and Fig. 4). The combustion of olive pomace causes high emissions of volatile organic carbons, mainly benzene and methane and the combustion of pig slurry solids causes high particle emissions.

The benzene emissions resulting from the combustion of olive pomace are high compared to the benzene emissions resulting from the combustion of the other substrates (cf. Fig. 5). The benzene emissions are taken from Jauhiainen et al. (2005). The lowest benzene emissions reported by Jauhiainen et al. (2005) were taken for the this study. It has to be considered that even higher benzene emissions are possible for the combustion of olive pomace when the conditions for the combustions are suboptimal. Especially because Conesa et al. (2009) report even higher benzene emissions than Jauhiainen et al. (2005). However, the investigations of Jauhiainen et al. (2005) show that the combustion can be optimised in order to reduce the benzene emissions.

The pelletising of the biomass substrates reduces the particle emissions. The combustion of poultry litter pellets, coffee ground pellets and wood pellets causes lower particle emissions among the different biomass substrates (cf. Fig. 5 and Fig. 6). However, the biomass substrates in general perform significantly worse compared to the particle emissions generated by the combustion of wooden fuels and even worse when compared to fossil fuels. In order to reduce the environmental impact of the combustion of the biomass substrates the combustion process has to be optimised in order to minimise the particle emissions or a treatment of the flue gas with a particle filter is necessary to reduce the particle emissions.

The fuel with the highest particle emissions were the slurry solids mixed with wood chips. This fuel has high moisture of more than 60 w% (cf. Tab. 3). A drying procedure before the combustion, like in the case of the pelletised fuels could help to reduce the particle emissions. Because of the high moisture of the pig slurry, the slurry solids have to be mixed with a dryer fuel in order to enable the combustion. This mixing leads to a high use of energy resources and natural resources. Despite the mixing with a dryer fuel for co-combustion the pig slurry solids have a low heating value (cf. Tab. 4) and the combustion of pig slurry solids has the highest environmental impact among the different biomass substrates according to the ecological scarcity method 2006. The direct combustion of slurry solids as described in Hersener & Bühler (1998) is not a valuable disposal strategy.

The influence of the used technology is difficult to determine, because the used technology is identical for the bigger furnaces with a high rated power (cf. Tab. 6). Procedural differences have not been investigated because the furnaces with a rated power above 250 kW all use the grate furnace technology. The used technology for the combustion of olive pomace is not comparable to the other furnaces, because the olive pomace is burned in a lab scale experiment. The fully automatic heating system type hobag used for the combustion of coffee ground pellets seems to be suitable for biomass combustion and even without treatment of the flue gas the particle emissions are low compared to the other fuels. Because of the lower rated power of only 25 kW compared to the other furnaces with a rated power of 250 kW or more, the automatic heating system type hobag is not compared to the technologies used for the other biomass substrates. For further investigations regarding combustion technology data from other furnaces using different technologies are needed Based on the results one can say that drier fuels cause less particle emissions and that a treatment of the flue gas is necessary in order to reduce the particle emissions.

Heavy metal emissions are very low for olive pomace (cf. Fig. 7). The heavy metal content has to be approved with further literature research or new measurements. The high heavy metal content of the ash from the combustion of biomass substrates has severe consequences for the disposal of the ash. The disposal of the ash of the biomass substrates in landfarming leads to a considerably higher flux of heavy metals into top soil than the disposal of the ash of wooden fuels. A disposal of the ash for biomass fuels to municipal incineration or to a sanitary landfill has to be considered in order to minimise the heavy metal fluxes into top soil and the environmental impacts.

The low global warming potential of the burning of horse dung and slurry solids matches the expectations for biomass substrates, as there are no environmental burdens allocated to the fuel itself, the global warming potential is supposed to be low. The high global warming potential for the other biomass substrates is astonishing, especially for olive pomace, because the combustion of the fuel itself does not emit fossil CO_2.

The higher global warming potential of pelletised fuels originates from the preparation of the fuel. The original substrates coffee ground and poultry litter are wet and have to be dried in order to enable the pelletising process. The drying process is modelled with a heating system using fossil fuels, which leads to the higher GWP for coffee ground pellets and poultry litter pellets. The higher global warming potential of the pelletised biomass substrates is caused by the higher moisture of the biomass compared to wood.

The other biomass substrates, namely horse dung and slurry solids, also have high moisture, but they do not have to be dried. Horse dung and slurry solids are mixed with a drier fuel and burnt with high moisture. In this way there is no additional energy demand as for the pelletised fuels, which results in the lower global warming potential. However the overall environmental impact is difficult to assess because the pelletising seems to lower the particle emissions during combustion but needs more energy for the preparation.

The high GWP resulting from the combustion of olive pomace is caused by the high emissions of methane. These high methane emissions may be caused by the used combustion technology. In order to be able to judge energy recovery from olive pomace the combustion process and the methane emissions have to be measured in more detail

6. Conclusion and outlook

In this project the environmental impact of the direct combustion of five different biomass substrates, namely olive pomace, coffee grounds, poultry litter, horse dung and pig slurry solids, is assessed with an LCA. The main environmental impacts of the combustion of the different biomass substrates are high particle and nitrogen oxide emissions into air and high heavy metal emissions into soil.

The biomass fuels perform worse than their wooden and fossil counterparts when using the ecological scarcity method 2006. When using the IPCC GWP the biomass fuels perform better than the fossil fuels but not better than wooden fuels. For the heat generation using biomass substrates that means a trade-off between a reduction of the greenhouse gas emissions and an increase of other airborne pollutants like particles and nitrogen oxides.

In the case of olive pomace the combustion process need to be optimised in order to guarantee a complete combustion of the fuel and to lower the benzene and methane emissions. The high benzene and methane emissions are responsible for the high impacts in case of the ecological scarcity 2006 and the IPCC global warming potential.

For slurry solids, poultry litter pellets and horse dung a treatment of the flue gas is necessary in order to limit the particle emissions. The importance of particle emissions causes the considerably higher environmental impact for the biomass substrates compared to the wooden fuels. For all the pilots plants considered for this study only two had some kind of flue gas treatment (cf. Tab. 7). Therefore, there is a potential to reduce the air emissions, especially particles, with measures like cyclones or electro filters. Regarding electro filters the experiences from Bühler et al. (2005, 2007) should be considered.

The wet biomass fuels are prone to cause high particle emissions. With adequate technology, either to avoid the particles due to a better combustion or to clean the exhaust gas, these emissions can be significantly reduced.

The environmental impact of the disposal of the ash in landfarming is completely allocated to the disposal of the ashes. The replacement of the artificial fertiliser is not considered. If the environmental impact also would be allocated partly to the fertilisation of the agricultural land, the environmental impact of the disposal of the ash would be reduced.

The different scenarios (cf. Fig. 12) show that environmental impact can be reduced by disposing the ash generated by the combustion to municipal incineration or to a sanitary landfill. Regarding the heavy metal content of olive pomace there is additional measurement needed to consolidate the low heavy metal content in the fuel and the ash.

According to the life cycle impact assessment with the Swiss ecological scarcity method the combustion of biomass fuels is not an environmentally valuable alternative to the combustion of fossil fuels and wooden fuels, but with adjustments in the combustion technology and the disposal of the ash the combustion of biomass is able to compete with the combustion of wood. A cleaning and filtering of the exhaust gas and good conditions for a complete combustion are requirements for the energy recovery from biomass substrates.

When these requirements are fulfilled these biomass substrates can be a valuable alternative to fossil and wooden fuels and with the combustion of biomass fuels instead of fossil fuels the greenhouse gas emissions can be reduced.

For the improvement of the data sets, more detailed data on the air emissions, especially the particle distribution and the data regarding the heavy metal content of olive pomace is needed.

7. Appendix: life cycle inventory

The EcoSpold files elaborated in this project can be downloaded on http://www.esu-services.ch/ourservices/lci/public-lci-reports/ or http://www.lc-inventories.ch/. They have not been validated according to the ecoinvent guidelines.

7.1. Fuel-mixture preparation

7.1.1. Drying of the olive pomace

The olive pomace as a residue of the olive oil production has a moisture content of about 50 w% (Vlyssides et al. 2004). In order to burn the pomace, it has to be dried. The moisture has to be reduced from 50 %w to 14 %w in order to enable the combustion of the olive pomace in a furnace. This corresponds to 0.72 kg of water per kg of dried olive pomace that has to be removed.

Tab. 12: Unit process raw data for the drying of olive pomace

	Name	Location	InfrastructureProcess	Unit	olive pomace, dried, at oil mill	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CY			
	InfrastructureProcess				0			
	Unit				kg			
product	olive pomace, dried, at oil mill	CY	0	kg	1			
technosphere	heat, olive pomace, at boiler furnace, in oil mill	CY	0	MJ	2.72E+0	1	1.33	(1,3,2,1,3,5,BU:1.05); Own calculations: 3.78 MJ required for drying one kg water; 0.72 kg water removed from olive pomace

7.1.2. Pellet production

Pellets are produced for coffee grounds and poultry litter. The LCI data for pellet production infrastructure and drying infrastructure are taken from wood pellet production (ecoinvent Centre 2010). The bulk density of the pellets is shown in Tab. 5. The moisture of the coffee grounds is reduced from 50 %w to 15 %w and the moisture of the poultry litter is reduced from 43 %w to 13 %w in order to enable the pellet production. This corresponds to 0.7 kg of water that has to be removed per kg of coffee ground pellets and 0.57 kg of water that has to be removed per kg of poultry litter pellets The energy consumption for the drying processes before the pellet production is estimated to be 3.78 MJ per kilogram water evaporated (Hässig-Schellhorn 2007).

The basis of the drying process is the ecoinvent process “sawn timber, softwood, raw, kiln dried, u=10%, at plant, RER, m3”. The basis for the pellet production is the ecoinvent process “wood pellets, u=10%, at storehouse, RER, m3” (ecoinvent Centre 2010).

There are two possibilities to produce the pellets. Either the pellets are produced in a factory using fossil fuels for the drying process or the pellets are produced on site using heat and waste heat from the combustion processes. In addition to the savings of fossil fuels the pellets do not have to be transported, if they are produced on site. These two scenarios for the pellet production are evaluated in section 4.3.3. The unit process raw data for pellet production is shown in Tab. 13.

Tab. 13: Unit process raw data for the production of coffee ground and poultry litter pellets

	Name	Location	InfrastructureProcess	Unit	coffee ground pellets, at regional storehouse	coffee ground pellets, on site	UncertaintyType	StandardDeviation95%	GeneralComment	poultry litter pellets, at regional storehouse	poultry litter pellets, on site	Uncertainty-Type	Standard-Deviation-95%	GeneralComment
	Location				CH	CH				CH	CH			
	InfrastructureProcess				0	0				0	0			
	Unit				m3	m3				m3	m3			
product	coffee ground pellets, at regional storehouse	CH	0	m3	1	0				0	0			
	poultry litter pellets, at regional storehouse	CH	0	m3	0	0				1	0			
	coffee ground pellets, on site	CH	0	m3	0	1				0	0			
	poultry litter pellets, on site	CH	0	m3	0	0				0	1			
technosphere	electricity, medium voltage, at grid	CH	0	kWh	1.64E+2	1.64E+2	1	1.33	(1,3,3,3,3,5,BU:1.05); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"	1.64E+2	1.64E+2	1	1.33	(1,3,3,3,3,5,BU:1.05); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"
	heat, light fuel oil, at boiler 100kW, non-modulating	CH	0	MJ	1.72E+3	0	1	2.09	(4,5,2,3,3,5,BU:2); Own calculations: 3.78 MJ required for drying one kg water; bulk density coffee pellets 650 kg/m3; 0.7 kg water removed from coffee ground	1.00E+3	0	1	2.09	(4,5,2,3,3,5,BU:2); Own calculations: 3.78 MJ required for drying one kg water; bulk density poultry litter pellets 500 kg/m3; 0.57 kg water removed from poulty litter;
	heat, coffee ground pellets, in wood furnace 25kW	CH	0	MJ	0	1.72E+3	1	2.09	(4,5,2,3,3,5,BU:2); Own calculations: 3.78 MJ required for drying one kg water; bulk density coffee pellets 650 kg/m3; 0.7 kg water removed from coffee ground	0	0	1	2.09	(4,5,2,3,3,5,BU:2); Own calculations: 3.78 MJ required for drying one kg water; bulk density poultry litter pellets 500 kg/m3; 0.57 kg water removed from poulty litter;
	heat, poultry litter pellets, in rotating grate furnace 250-350kW	CH	0	MJ	0	0	1	2.09	(4,5,2,3,3,5,BU:2); Own calculations: 3.78 MJ required for drying one kg water; bulk density coffee pellets 650 kg/m3; 0.7 kg water removed from coffee ground	0	1.00E+3	1	2.09	(4,5,2,3,3,5,BU:2); Own calculations: 3.78 MJ required for drying one kg water; bulk density poultry litter pellets 500 kg/m3; 0.57 kg water removed from poulty litter;
	transport, freight, rail	RER	0	tkm	1.64E+2	0	1	2.09	(4,5,na,na,na,na,BU:2); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"	1.64E+2	0	1	2.09	(4,5,na,na,na,na,BU:2); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"
	transport, lorry >16t, fleet average	RER	0	tkm	3.58E+1	0	1	2.09	(4,5,na,na,na,na,BU:2); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"	3.58E+1	0	1	2.09	(4,5,na,na,na,na,BU:2); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"
	technical wood drying, infrastructure	RER	1	unit	1.83E-5	1.83E-5	1	3.36	(4,5,2,3,4,5,BU:3); Based on econinvent dataset "sawn timber, softwood, raw, kiln dried, u=10%, at plant, RER, [m3]"	1.83E-5	1.83E-5	1	3.36	(4,5,2,3,4,5,BU:3); Based on econinvent dataset "sawn timber, softwood, raw, kiln dried, u=10%, at plant, RER, [m3]"
	wood pellet manufacturing, infrastructure	RER	1	unit	1.00E-8	1.00E-8	1	3.36	(4,5,2,3,4,5,BU:3); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"	1.00E-8	1.00E-8	1	3.36	(4,5,2,3,4,5,BU:3); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"
emission air, unspecified	Heat, waste	-	-	MJ	5.91E+2	5.91E+2	1	1.33	(1,3,3,3,3,5,BU:1.05); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"	5.91E+2	5.91E+2	1	1.33	(1,3,3,3,3,5,BU:1.05); Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"

7.1.3. Preparation of the fuel-mixture

Two of the biomasse substrates, namely horse dung and slurry solids, are mixed with wood or bark chips. These two biomass fuels have high moisture and the mixing with a dryer fuel is needed to guarantee an efficient combustion.

The mixture horse dung and wood chips consists of 67 % horse dung and 33% wood chips (Bühler et al. 2005). This mixture has a lower heating value of 8.4 MJ/kg and bulk density of 315 kg/m3 (cf. Tab. 4 and Tab. 5). The mixture slurry solids and bark chips consists of 15.5% pig slurry solids and 84.5% bark chips (Hersener & Bühler 1998). This mixture has a lower heating value of 5.4 MJ/kg and bulk density of 300 kg/m3 (cf. Tab. 4 and Tab. 5).

Tab. 14: Unit process raw data for the mixtures “horse dung and wood chips” and “slurry solids and bark chips”

	Name	Location	Infrastructure-Process	Unit	horse dung and waste wood chips, at farm	slurry solids and bark chips, at farm	UncertaintyType	Standard-Deviation-95%	GeneralComment
	Location				CH	CH			
	InfrastructureProcess				0	0			
	Unit				m3	m3			
product	horse dung and waste wood chips, at farm	CH	0	m3	1	0			
	slurry solids and bark chips, at farm	CH	0	m3	0	1			
technosphere	waste wood chips, mixed, from industry, u=40%, at plant	CH	0	m3	3.30E-1	0	1	1.16E+0	(1,4,2,1,1,4,BU:1.05); Composition: (Bühler et al., 2005)
	bark chips, softwood, u=140%, at forest road	RER	0	m3	0	8.45E-1	1	1.26E+0	(1,4,4,1,1,4,BU:1.05); Composition: (Hersener et al., 1998)

7.2. Combustion of the biomass substrates

Compared to the different combustion datasets of wood in the ecoinvent database, there is only little data available for the different biomass substrates. Especially the air emissions of the combustion are not sufficiently documented in literature. In order to estimate the undocumented emissions the ecoinvent data sets "logs, mixed, burned in wood heater 6kW, CH, MJ", "pellets, mixed, burned in furnace 15kW, CH, MJ", “wood chips, from forest, mixed, burned in furnace 300kW, CH, MJ” and “wood chips, from forest, mixed, burned in furnace 1000kW” are used. The engine power is considered when completing the data sets.

Tab. 15 shows the emission factors for air emissions from the combustion for all substrates. For the coffee ground pellets, the poultry litter pellets, the horse dung and the slurry solids there are only concentration measurements in the exhaust gas available. Based on these concentrations the total flux was calculated using the total volume of the exhaust gas derived from the elemental composition of the substrates.

Tab. 15: Emission factors for the air emissions of the different biomass substrates

Emission factors	**Olive pomace(1**	**Coffee ground pellets(2**	**Poultry litter pellets(3**	**Horse dung & wood chips(4**	**Pig slurry solids & bark chips(5**
Unit	kg/MJ	kg/MJ	kg/MJ	kg/MJ	kg/MJ
Carbon dioxide CO2	1.16E-01	1.21E-01	1.08E-01	2.09E-01	3.14E-01
Carbon monoxide CO	2.12E-03	5.55E-04	5.16E-06	9.10E-05	1.41E-04
Nitrogen oxides NOx als NO2	-	3.33E-04	1.35E-04	2.39E-04	6.67E-04
Sulphur oxide SO2	-	-	4.17E-04	1.71E-04	6.50E-05
Hydrocarbons HC als C	-	-	1.88E-06	1.71E-05	-
Hydrogen chloride	-	-	4.83E-05	3.18E-05	2.11E-06
Ammonia NH3	-	-	-	7.96E-06	-
Ash	4.47E-03	1.59E-03	8.88E-03	5.50E-03	7.46E-03
Particulates TSP	-	6.34E-05	1.61E-04	2.27E-04	9.92E-04
Particulates PM <2.5um	-	5.70E-05	1.45E-04	2.05E-04	8.93E-04
Particulates PM 2.5 -10um	-	3.17E-06	8.07E-06	1.14E-05	4.96E-05
Particulates PM >10um	-	3.17E-06	8.07E-06	1.14E-05	4.96E-05

1) Jauhiainen et al. 2005
2) Waelti & Keller 2009
3) Salerno et al. 2001
4) Bühler et al. 2005
5) Hersener & Bühler 1998

If measurements of the emissions of the combustion are available these measurements are used. For the most important pollutants like particles, nitrogen oxides and sulphur oxides measurements are documented in literature. The figures for particles, NOx and SOx are missing for the combustion of olive pomace. For the coffee ground pellets only the SOx emissions are missing. In Tab. 16 and Tab. 17 the values taken from wood data sets are marked with a dark green.

The unit process raw data for the combustion of olive pomace and coffee ground pellets are shown in Tab. 16 and the unit process raw data for the combustion of poultry litter pellets, horse dung and slurry solids are shown in Tab. 17. The air emissions for the combustion of olives are taken from Jauhiainen et al. (2005) and completed with the ecoinvent data set "logs, mixed, burned in wood heater 6kW, CH, MJ". The air emissions for the combustion of coffee ground pellets are taken from Waelti & Keller (2009) and completed with the ecoinvent data set "pellets, mixed, burned in furnace 15kW, CH, MJ".

The air emissions for the combustion of poultry litter pellets are taken from Salerno et al. (2001) and completed with the ecoinvent data set “wood chips, from forest, mixed, burned in furnace 300kW, CH, MJ”. The air emissions for the combustion of horse dung are taken from Bühler et al. (2005) and completed with the ecoinvent data set “wood chips, from forest, mixed, burned in furnace 1000kW, CH, MJ”. The air emissions for the combustion of slurry solids are taken from Hersener & Bühler (1998) and completed with the ecoinvent data set “wood chips, from forest, mixed, burned in furnace 1000kW, CH, MJ”.

Tab. 16: Unit process raw data for the combustion of olive pomace and coffee ground pellets

	Name	Location	InfrastructureProc	Unit	olive pomace, burned in boiler furnace, at oil mill	UncertaintyType	StandardDeviatio	GeneralComment	coffee ground pellets, burned in wood furnace 25kW	Uncertainty-Type	Standard-Deviati	GeneralComment
	Location				CY		Legende		CH		Legende	
	InfrastructureProcess				0	🟩	taken from ecoinvent data sets for combustion of wood		0	🟩	taken from ecoinvent data sets for combustion of wood	
	Unit				MJ	🟦	taken from literature		MJ	🟦	taken from literature	
product	olive pomace, burned in boiler furnace, at oil mill	CY	0	MJ	1				0			
	coffee ground pellets, burned in wood furnace 25kW	CH	0	MJ	0				1			
technosphere	olive pomace, dried, at oil mill	CY	0	kg	6.74E-2	1	1.26	(1,4,2,1,3,4,BU:1.05); heating value dry base: 17.8 MJ/kg, Jauhiainen et al. 2005	0	1	1.26	(1,4,2,1,3,4,BU:1.05);
	coffee ground pellets, at regional storehouse	CH	0	m3	0	1	1.26	(1,4,1,1,3,4,BU:1.05);	8.84E-5	1	1.26	(1,4,1,1,3,4,BU:1.05); density: 650 kg/m3, assumed to be equal to wood pellets; LHW 17.3 MJ/kg, Prüfbericht 544946, SGS Institut Fresenius, 2008
	furnace, pellets, 15kW	CH	1	unit	0	1	3.34	(1,4,4,5,4,5,BU:3); uncertainty on lifetime	4.82E-7	1	3.34	(1,4,4,5,4,5,BU:3); uncertainty on lifetime
	furnace, logs, mixed, 6kW	CH	1	unit	1.74E-6	1	3.34	(1,4,4,5,4,5,BU:3); uncertainty on lifetime	0	1	3.34	(1,4,4,5,4,5,BU:3); uncertainty on lifetime
	disposal, ash olive pomace, to landfarming	CY	0	kg	2.23E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Elemental composition: tab. 1, Jauhiainen et al. 2005	0	1	1.60	(1,4,3,1,4,5,BU:1.05);
	disposal, ash olive pomace, to municipal incineration	CH	0	kg	2.23E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Elemental composition: tab. 1, Jauhiainen et al. 2005	0	1	1.60	(1,4,3,1,4,5,BU:1.05);
	disposal, ash olive pomace, to sanitary landfill	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05); Elemental composition: tab. 1, Jauhiainen et al. 2005	0	1	1.60	(1,4,3,1,4,5,BU:1.05);
	disposal, ash coffee ground pellets, to landfarming	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	7.97E-4	1	1.60	(1,4,3,1,4,5,BU:1.05); Ash content: Prüfbericht 544946, SGS Institut Fresenius, 2008
	disposal, ash coffee ground pellets, to municipal incineration	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	7.97E-4	1	1.60	(1,4,3,1,4,5,BU:1.05); Ash content: Prüfbericht 544946, SGS Institut Fresenius, 2008
	disposal, ash coffee ground pellets, to sanitary landfill	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	0	1	1.60	(1,4,3,1,4,5,BU:1.05); Ash content: Prüfbericht 544946, SGS Institut Fresenius, 2008
	electricity, low voltage, at grid	CH	0	kWh	0	1	1.65	(1,4,4,5,4,5,BU:1.05); general assumption	4.17E-3	1	1.65	(1,4,4,5,4,5,BU:1.05); general assumption
	transport, tractor and trailer	CH	0	tkm	6.44E-4	1	2.35	(1,4,4,5,4,5,BU:2); general assumption	0	1	2.35	(1,4,4,5,4,5,BU:2); general assumption
	transport, lorry 20-28t, fleet average	CH	0	tkm	0	1	2.35	(1,4,4,5,4,5,BU:2); general assumption	5.87E-3	1	2.35	(1,4,4,5,4,5,BU:2); general assumption
emission air, high population density	Acetaldehyde	-	-	kg	6.10E-8	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	6.10E-8	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Ammonia	-	-	kg	1.73E-6	1	1.70	(1,4,4,5,4,5,BU:1.2); extrapolation, based on measuring data of other emissions	1.73E-6	1	1.70	(1,4,4,5,4,5,BU:1.2); extrapolation, based on measuring data of other emissions
	Anthracene	-	-	kg	4.72E-6	1	3.02	(1,4,2,2,1,3,BU:3); Emissions to air from tab. 2, Jauhiainen et al. 2005	0	1	3.02	(1,4,2,2,1,3,BU:3); Emissions to air from tab. 2, Wälti & Keller, 2009
	Arsenic	-	-	kg	1.00E-9	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	1.00E-9	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Benzene	-	-	kg	1.89E-5	1	3.02	(1,4,2,2,1,3,BU:3); Emissions to air from tab. 2, Jauhiainen et al. 2005	9.10E-7	1	3.02	(1,4,2,2,1,3,BU:3); Emissions to air from tab. 2, Wälti & Keller, 2009
	Benzene, ethyl-	-	-	kg	3.00E-8	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions	3.00E-8	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions
	Benzene, hexachloro-	-	-	kg	7.20E-15	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions	7.20E-15	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions
	Benzo(a)pyrene	-	-	kg	5.00E-10	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions	5.00E-10	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions
	Bromine	-	-	kg	6.00E-8	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	6.00E-8	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Butadiene	-	-	kg	4.79E-6	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Jauhiainen et al. 2005	0	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Wälti & Keller, 2009
	Cadmium	-	-	kg	7.00E-10	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	7.00E-10	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Calcium	-	-	kg	5.85E-6	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	5.85E-6	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Carbon dioxide, biogenic	-	-	kg	9.78E-2	1	1.13	(1,4,2,2,1,3,BU:1.05); Emissions to air from tab. 2, Jauhiainen et al. 2005	1.21E-1	1	1.13	(1,4,2,2,1,3,BU:1.05); Emissions to air from tab. 2, Wälti & Keller, 2009
	Carbon monoxide, biogenic	-	-	kg	2.12E-3	1	5.02	(1,4,2,2,1,3,BU:5); Emissions to air from tab. 2, Jauhiainen et al. 2005	5.55E-4	1	5.02	(1,4,2,2,1,3,BU:5); Emissions to air from tab. 2, Wälti & Keller, 2009
	Chlorine	-	-	kg	1.80E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	1.80E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Chromium	-	-	kg	3.96E-9	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	3.96E-9	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Chromium VI	-	-	kg	4.00E-11	1	5.39	(1,4,4,5,4,5,BU:5); range of data	4.00E-11	1	5.39	(1,4,4,5,4,5,BU:5); range of data
	Copper	-	-	kg	2.20E-8	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	2.20E-8	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Dinitrogen monoxide	-	-	kg	7.00E-6	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	3.00E-6	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	-	kg	3.10E-14	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions	3.10E-14	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions
	Ethane	-	-	kg	1.02E-5	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Jauhiainen et al. 2005	0	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Wälti & Keller, 2009
	Ethene	-	-	kg	2.27E-4	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Jauhiainen et al. 2005	0	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Wälti & Keller, 2009
	Ethyne	-	-	kg	7.20E-5	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Jauhiainen et al. 2005	0	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Wälti & Keller, 2009
	Fluorine	-	-	kg	5.00E-8	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	5.00E-8	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Formaldehyde	-	-	kg	1.30E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	1.30E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Heat, waste	-	-	MJ	1.07E+0	1	1.65	(1,4,4,5,4,5,BU:1.05); standard for resources	1.08E+0	1	1.65	(1,4,4,5,4,5,BU:1.05); standard for resources
	Hexane	-	-	kg	4.92E-6	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Jauhiainen et al. 2005	0	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Wälti & Keller, 2009
	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg	9.10E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	9.10E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Hydrocarbons, aliphatic, unsaturated	-	-	kg	3.10E-6	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	3.10E-6	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Lead	-	-	kg	2.50E-8	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	2.50E-8	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Magnesium	-	-	kg	3.60E-7	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	3.60E-7	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Manganese	-	-	kg	1.70E-7	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	1.70E-7	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Mercury	-	-	kg	3.00E-10	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	3.00E-10	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Methane, biogenic	-	-	kg	2.66E-4	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Jauhiainen et al. 2005	4.00E-7	1	1.52	(1,4,2,2,1,3,BU:1.5); extrapolation, based on measuring data of other emissions
	m-Xylene	-	-	kg	1.20E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	1.20E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Naphthalene	-	-	kg	2.42E-5	1	3.02	(1,4,2,2,1,3,BU:3); Emissions to air from tab. 2, Jauhiainen et al. 2005	0	1	3.02	(1,4,2,2,1,3,BU:3); extrapolation, based on measuring data of other emissions
	Nickel	-	-	kg	6.00E-9	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	6.00E-9	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Nitrogen oxides	-	-	kg	1.60E-4	1	1.52	(1,4,2,2,1,3,BU:1.5); range of measuring data	3.33E-4	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Wälti & Keller, 2009
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	9.70E-6	1	1.52	(1,4,2,2,1,3,BU:1.5); range of measuring data	2.30E-6	1	1.52	(1,4,2,2,1,3,BU:1.5); range of measuring data
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	1.11E-8	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions	1.11E-8	1	3.34	(1,4,4,5,4,5,BU:3); extrapolation, based on measuring data of other emissions
	Particulates, < 2.5 um	-	-	kg	1.17E-4	1	3.34	(1,4,4,5,4,5,BU:3); taken from wood data set	5.70E-5	1	3.34	(1,4,4,5,4,5,BU:3); Emissions to air from tab. 2, Wälti & Keller, 2009
	Particulates, > 2.5 um, and < 10um	-	-	kg	0	1	2.35	(1,4,4,5,4,5,BU:2); taken from wood data set	3.17E-6	1	2.35	(1,4,4,5,4,5,BU:2); Emissions to air from tab. 2, Wälti & Keller, 2009
	Particulates, > 10 um	-	-	kg	0	1	1.90	(1,4,4,5,4,5,BU:1.5); taken from wood data set	3.17E-6	1	1.90	(1,4,4,5,4,5,BU:1.5); Emissions to air from tab. 2, Wälti & Keller, 2009
	Phenol, pentachloro-	-	-	kg	8.10E-12	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	8.10E-12	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Phosphorus	-	-	kg	3.00E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	3.00E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Potassium	-	-	kg	2.34E-5	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	2.34E-5	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Propene	-	-	kg	4.79E-6	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Jauhiainen et al. 2005	0	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions to air from tab. 2, Wälti & Keller, 2009
	Sodium	-	-	kg	1.30E-6	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	1.30E-6	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions
	Sulfur dioxide	-	-	kg	2.50E-6	1	1.65	(1,4,4,5,4,5,BU:1.05); extrapolation, based on measuring data of other emissions	2.50E-6	1	1.65	(1,4,4,5,4,5,BU:1.05); extrapolation, based on measuring data of other emissions
	Toluene	-	-	kg	3.00E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions	3.00E-7	1	1.90	(1,4,4,5,4,5,BU:1.5); extrapolation, based on measuring data of other emissions
	Zinc	-	-	kg	3.00E-7	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions	3.00E-7	1	5.39	(1,4,4,5,4,5,BU:5); extrapolation, based on measuring data of other emissions

Tab. 17: Unit process raw data for the combustion of poultry litter pellets and the fuel mixtures “horse dung and wood chips” and “slurry solids and bark chips”

	Name	Location	InfrastructureProcess	Unit	poultry litter pellets, burned in rotating grate furnace 250-350kW	UncertaintyType	StandardDeviation95%	GeneralComment	horse dung and waste wood chips, burned in grate furnace 500-600kW	UncertaintyType	StandardDeviation95%	GeneralComment	slurry solids and bark chips, burned in bark furnace 1MW	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH	Legende			CH	Legende			CH	Legende		
	InfrastructureProcess				0	🟩	taken from ecoinvent data sets for wood combustio		0	🟩	taken from ecoinvent data sets for wood combustion		0	🟩	taken from ecoinvent data sets for wood combustion	
	Unit				MJ	🟦	taken from literature		MJ	🟦	taken from literature		MJ	🟦	taken from literature	
product	poultry litter pellets, burned in rotating grate furnace 250-350kW	CH	0	MJ	1				0				0			
	horse dung and waste wood chips, burned in grate furnace 500-600kW	CH	0	MJ	0				1				0			
	slurry solids and bark chips, burned in bark furnace 1MW	CH	0	MJ	0				0				1			
technosphere	electricity, low voltage, at grid	CH	0	kWh	4.17E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); general assumption	4.17E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); general assumption	4.17E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); general assumption
	poultry litter pellets, at regional storehouse	CH	0	m3	1.47E-4	1	1.26	(1,4,2,1,3,4,BU:1.05); bulk density: 500 kg/m3, estimated; LHW 13.5 MJ/kg, APOLLO II, Salerno et al., 2001	0	1	1.26	(1,4,2,1,3,4,BU:1.05);	0	1	1.26	(1,4,2,1,3,4,BU:1.05);
	poultry litter pellets, on site	CH	0	m3	0	1	1.26	(1,4,2,1,3,4,BU:1.05); bulk density: 500 kg/m3, estimated; LHW 13.5 MJ/kg, APOLLO II, Salerno et al., 2001	0	1	1.26	(1,4,2,1,3,4,BU:1.05);	0	1	1.26	(1,4,2,1,3,4,BU:1.05);
	horse dung and waste wood chips, at farm	CH	0	m3	0	1	1.26	(1,4,1,1,3,4,BU:1.05);	3.64E-4	1	1.26	(1,4,1,1,3,4,BU:1.05); heating value: 8.61 MJ/kg; Tab.1 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	0	1	1.26	(1,4,1,1,3,4,BU:1.05);
	slurry solids and bark chips, at farm	CH	0	m3	0	1	1.26	(1,4,1,1,3,4,BU:1.05);	0	1	1.26	(1,4,1,1,3,4,BU:1.05);	6.13E-4	1	1.26	(1,4,1,1,3,4,BU:1.05); heating value pig slurry: 17.8 MJ/kg atro; Tab 7: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	disposal, ash poultry litter pellets, to landfarming	CH	0	kg	2.22E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	0	1	1.595	(1,4,3,1,4,5,BU:1.05);
	disposal, ash horse dung and waste wood chips, to landfarming	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	1.37E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	0	1	1.595	(1,4,3,1,4,5,BU:1.05);
	disposal, ash slurry solids and bark chips, to landfarming	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	1.87E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	disposal, ash poultry litter pellets, to municipal incineration	CH	0	kg	2.22E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	0	1	1.595	(1,4,3,1,4,5,BU:1.05);
	disposal, ash horse dung and wood chips, to municipal incineration	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	1.37E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	0	1	1.595	(1,4,3,1,4,5,BU:1.05);
	disposal, ash slurry solids and bark chips, to municipal incineration	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	1.87E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	disposal, ash poultry litter pellets, to sanitary landfill	CH	0	kg	4.44E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	0	1	1.595	(1,4,3,1,4,5,BU:1.05);
	disposal, ash horse dung and wood chips, to sanitary landfill	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	2.75E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	0	1	1.595	(1,4,3,1,4,5,BU:1.05);
	disposal, ash slurry solids and bark chips, to sanitary landfill	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	0	1	1.60	(1,4,3,1,4,5,BU:1.05);	3.73E-3	1	1.60	(1,4,3,1,4,5,BU:1.05); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	disposal, wood ash mixture, pure, 0% water, to municipal incineration	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05); homogeneous fuel	0	1	1.60	(1,4,3,1,4,5,BU:1.05); homogeneous fuel	0	1	1.60	(1,4,3,1,4,5,BU:1.05); homogeneous fuel
	disposal, wood ash mixture, pure, 0% water, to landfarming	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05); homogeneous fuel	0	1	1.60	(1,4,3,1,4,5,BU:1.05); homogeneous fuel	0	1	1.60	(1,4,3,1,4,5,BU:1.05); homogeneous fuel
	disposal, wood ash mixture, pure, 0% water, to sanitary landfill	CH	0	kg	0	1	1.60	(1,4,3,1,4,5,BU:1.05); homogeneous fuel	0	1	1.60	(1,4,3,1,4,5,BU:1.05); homogeneous fuel	0	1	1.60	(1,4,3,1,4,5,BU:1.05); homogeneous fuel
	transport, lorry 20-28t, fleet average	CH	0	tkm	2.52E-3	1	2.30	(1,4,3,1,4,5,BU:2); general assumption	3.77E-3	1	2.30	(1,4,3,1,4,5,BU:2); general assumption	3.77E-3	1	2.30	(1,4,3,1,4,5,BU:2); general assumption
	furnace, wood chips, mixed, 1000kW	CH	1	unit	0	1	3.30	(1,4,3,1,4,5,BU:3); uncertainty on lifetime	5.62E-9	1	3.30	(1,4,3,1,4,5,BU:3); uncertainty on lifetime	5.62E-9	1	3.30	(1,4,3,1,4,5,BU:3); uncertainty on lifetime
	furnace, wood chips, mixed, 300kW	CH	1	unit	1.81E-8	1	3.30	(1,4,3,1,4,5,BU:3); uncertainty on lifetime	0	1	3.30	(1,4,3,1,4,5,BU:3); uncertainty on lifetime	0	1	3.30	(1,4,3,1,4,5,BU:3); uncertainty on lifetime
emission air, high population density	Acetaldehyde	-	-	kg	6.10E-8	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	6.10E-8	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	6.10E-8	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Ammonia	-	-	kg	1.73E-6	1	1.24	(1,4,2,2,1,3,BU:1.2);	7.96E-6	1	1.24	(1,4,2,2,1,3,BU:1.2); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	1.73E-6	1	1.24	(1,4,2,2,1,3,BU:1.2);
	Arsenic	-	-	kg	1.00E-9	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	1.00E-9	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	1.00E-9	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Benzene	-	-	kg	9.10E-7	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	9.10E-7	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	9.10E-7	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions
	Benzene, ethyl-	-	-	kg	3.00E-8	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	3.00E-8	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	3.00E-8	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions
	Benzene, hexachloro-	-	-	kg	7.20E-15	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	7.20E-15	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	7.20E-15	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions
	Benzo(a)pyrene	-	-	kg	5.00E-10	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	5.00E-10	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	5.00E-10	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions
	Bromine	-	-	kg	6.00E-8	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	6.00E-8	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	6.00E-8	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Cadmium	-	-	kg	7.00E-10	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	7.00E-10	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	7.00E-10	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Calcium	-	-	kg	5.85E-6	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	5.85E-6	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	5.85E-6	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Carbon dioxide, biogenic	-	-	kg	1.08E-1	1	1.13	(1,4,2,2,1,3,BU:1.05); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	2.09E-1	1	1.13	(1,4,2,2,1,3,BU:1.05); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	3.14E-1	1	1.13	(1,4,2,2,1,3,BU:1.05); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	Carbon monoxide, biogenic	-	-	kg	5.16E-6	1	5.02	(1,4,2,2,1,3,BU:5); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	9.10E-5	1	5.02	(1,4,2,2,1,3,BU:5); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	1.41E-4	1	5.02	(1,4,2,2,1,3,BU:5); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	Chlorine	-	-	kg	1.80E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	1.80E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	1.80E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Chromium	-	-	kg	3.96E-9	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	3.96E-9	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	3.96E-9	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Chromium VI	-	-	kg	4.00E-11	1	5.28	(1,4,2,2,4,3,BU:5); range of data	4.00E-11	1	5.28	(1,4,2,2,4,3,BU:5); range of data	4.00E-11	1	5.28	(1,4,2,2,4,3,BU:5); range of data
	Copper	-	-	kg	2.20E-8	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	2.20E-8	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	2.20E-8	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Dinitrogen monoxide	-	-	kg	2.50E-6	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	2.30E-6	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	2.30E-6	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	-	kg	3.10E-14	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	3.10E-14	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	3.10E-14	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions
	Fluorine	-	-	kg	5.00E-8	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	5.00E-8	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	5.00E-8	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Formaldehyde	-	-	kg	1.30E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	1.30E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	1.30E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Heat, waste	-	-	MJ	1.08E+0	1	1.53	(1,4,2,2,4,3,BU:1.05); standard for resources	1.08E+0	1	1.53	(1,4,2,2,4,3,BU:1.05); standard for resources	1.08E+0	1	1.53	(1,4,2,2,4,3,BU:1.05); standard for resources
	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg	1.88E-6	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	1.71E-5	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	9.10E-7	1	1.52	(1,4,2,2,1,3,BU:1.5);
	Hydrocarbons, aliphatic, unsaturated	-	-	kg	3.10E-6	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	3.10E-6	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	3.10E-6	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Lead	-	-	kg	2.50E-8	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	2.50E-8	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	2.50E-8	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Magnesium	-	-	kg	3.60E-7	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	3.60E-7	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	3.60E-7	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Manganese	-	-	kg	1.70E-7	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	1.70E-7	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	1.70E-7	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Mercury	-	-	kg	3.00E-10	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	3.00E-10	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	3.00E-10	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Methane, biogenic	-	-	kg	4.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	4.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	4.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	m-Xylene	-	-	kg	1.20E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	1.20E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	1.20E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Nickel	-	-	kg	6.00E-9	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	6.00E-9	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	6.00E-9	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Nitrogen oxides	-	-	kg	1.35E-4	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	2.39E-4	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	6.67E-4	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	6.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); range of measuring data	6.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); range of measuring data	6.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); range of measuring data
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	1.11E-8	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	1.11E-8	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions	1.11E-8	1	3.24	(1,4,2,2,4,3,BU:3); extrapolation, based on measuring data of other emissions
	Particulates, < 2.5 um	-	-	kg	1.45E-4	1	3.02	(1,4,2,2,1,3,BU:3); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	2.05E-4	1	3.02	(1,4,2,2,1,3,BU:3); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	8.93E-4	1	3.02	(1,4,2,2,1,3,BU:3); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	Particulates, > 2.5 um, and < 10um	-	-	kg	8.07E-6	1	2.02	(1,4,2,2,1,3,BU:2); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	1.14E-5	1	2.02	(1,4,2,2,1,3,BU:2); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	4.96E-5	1	2.02	(1,4,2,2,1,3,BU:2); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	Particulates, > 10 um	-	-	kg	8.07E-6	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	1.14E-5	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	4.96E-5	1	1.52	(1,4,2,2,1,3,BU:1.5); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	Phenol, pentachloro-	-	-	kg	8.10E-12	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	8.10E-12	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	8.10E-12	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Phosphorus	-	-	kg	3.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	3.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	3.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Potassium	-	-	kg	2.34E-5	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	2.34E-5	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	2.34E-5	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Sodium	-	-	kg	1.30E-6	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	1.30E-6	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	1.30E-6	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions
	Sulfur dioxide	-	-	kg	4.17E-4	1	1.13	(1,4,2,2,1,3,BU:1.05); Emissions: Tab. 3.5.1.1: APOLLO II Schlussbericht, Salerno et al., 2001	1.71E-4	1	1.13	(1,4,2,2,1,3,BU:1.05); Emissions horse dung: Tab. 1+2 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2005	6.50E-5	1	1.13	(1,4,2,2,1,3,BU:1.05); Emissions pig slurry: Tab.7+8: Energetische Nutzung landwirtschaftlicher Biomasse, Hersener & Bühler, 1998
	Toluene	-	-	kg	3.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	3.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions	3.00E-7	1	1.79	(1,4,2,2,4,3,BU:1.5); extrapolation, based on measuring data of other emissions
	Zinc	-	-	kg	3.00E-7	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	3.00E-7	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions	3.00E-7	1	5.28	(1,4,2,2,4,3,BU:5); extrapolation, based on measuring data of other emissions

7.2.1. Disposal ash from combustion

There are three different ways considered to dispose the ash generated by the combustion process, namely the disposal in landfarming, the disposal to municipal incineration or the disposal to a sanitary landfill. Landfarming means that the ashes are spread as fertilizer on agricultural land. For the small furnaces below a threshold of 30 kW it is assumed that 50 % of the ash is disposed in landfarming and 50 % is disposed in municipal solid waste incineration. For bigger furnaces above 30 kW it is assumed that 50 % of the ash is disposed in a sanitary land fill, 25 % of the ash is disposed in landfarming and 25 % is disposed in municipal solid waste incineration. These fractions for the different disposal scenarios are the same as used for disposal of wood ash in the ecoinvent data set for wood combustion (Bauer 2007).

7.2.2. Particulate matter emissions

For the particulate emissions only data for the total suspended particulate matter (TSP) were available. The distribution of the size of the particles had to be estimated. It was assumed that the distribution of the size of the particles for biomass combustion corresponds to the distribution of the particles for wood combustion determined within the CEPMEIP project (Berdowski et al. 2001).

Tab. 18: Distribution of the total suspended particulate matter to the different classes of particulates for non-industrial combustion plants according to Berdowski et al. 2001

Emission factors Wood and wood waste	**Low**	**Fraction**	**Medium**	**Fraction**	**Medium-High**	**Fraction**	**High**	**Fraction**
Non-industrial combustion plants	Mg/PJ	%	Mg/PJ	%	Mg/PJ	%	Mg/PJ	%
TSP	150.0	100.0%	300.0	100.0%	300.0	100.0%	300.0	100.0%
Particulates, < 2.5 um	135.0	90.0%	270.0	90.0%	270.0	90.0%	270.0	90.0%
Particulates, > 2.5 um, and < 10um	8.0	5.3%	15.0	5.0%	15.0	5.0%	15.0	5.0%
Particulates, > 10 um	7.0	4.7%	15.0	5.0%	15.0	5.0%	15.0	5.0%

7.3. Heat generation

Tab. 19 shows the unit process raw data for the heat generation for olive pomace and coffee ground pellets. The efficiency factor of the furnace used for the combustion of the olive pomace and the efficiency factor of the furnace used for the combustion of coffee ground pellets are estimated to be equal to 0.85.

Tab. 19: Unit process raw data for the heat generation of olive pomace and coffee ground pellets

	Name	Location	Infrastructure-Process	Unit	heat, olive pomace, at boiler furnace, in oil mill	heat, coffee ground pellets, in wood furnace 25kW	Uncertainty-Type	Standard-Deviation-95%	GeneralComment
	Location				CY	CH			
	InfrastructureProcess				0	0			
	Unit				MJ	MJ			
product	heat, olive pomace, at boiler furnace, in oil mill	CY	0	MJ	1	0			
	heat, coffee ground pellets, in wood furnace 25kW	CH	0	MJ	0	1			
technosphere	olive pomace, burned in boiler furnace, at oil mill	CY	0	MJ	1.18E+0	0	1	2.34	(1,5,5,5,5,5,BU:1.05); Estimated efficiency factor 0.85
	coffee ground pellets, burned in wood furnace 25kW	CH	0	MJ	0	1.18E+0	1	2.34	(1,5,5,5,5,5,BU:1.05); Estimated efficiency factor 0.85

Tab. 20 shows the unit process raw data for the heat generations of the biomass substrates poultry litter pellets, horse dung and wood chips and slurry solids and bark chips. The efficiency factor of the grate furnace used for the combustion of poultry litter pellets is 0.94 (Salerno et al. 2001). The efficiency factors for grate furnace and the bark furnace used for the combustion of the other substrates no information was available and an efficiency factor of 0.85 was assumed.

Tab. 20: Unit process raw data for the heat generation of the mixtures “horse dung and wood chips” and “slurry solids and bark chips”

	Name	Location	InfrastructureProcess	Unit	heat, poultry litter pellets, in rotating grate furnace 250-350kW	heat, horse dung and waste wood chips, in grate furnace 500-600kW	heat, slurry solids and bark chips, in bark furnace 1MW	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH	CH	CH			
	InfrastructureProcess				0	0	0			
	Unit				MJ	MJ	MJ			
product	heat, poultry litter pellets, in rotating grate furnace 250-350kW	CH	0	MJ	1	0	0			
	heat, horse dung and waste wood chips, in grate furnace 500-600kW	CH	0	MJ	0	1	0			
	heat, slurry solids and bark chips, in bark furnace 1MW	CH	0	MJ	0	0	1			
technosphere	poultry litter pellets, burned in rotating grate furnace 250-350kW	CH	0	MJ	1.06E+0	0	0	1	1.20	(1,4,4,3,1,3,BU:1.05); Efficiency factor 0.94, APOLLO II, Salerno et al., 2001
	horse dung and waste wood chips, burned in grate furnace 500-600kW	CH	0	MJ	0	1.18E+0	0	1	1.50	(1,5,5,5,5,5,BU:1.05); Estimated efficiency factor 0.85
	slurry solids and bark chips, burned in bark furnace 1MW	CH	0	MJ	0	0	1.18E+0	1	1.50	(1,5,5,5,5,5,BU:1.05); Estimated efficiency factor 0.85

7.4. Disposal of the ashes

The elemental composition of the ash is taken from literature and the missing values are taken from the elemental composition of wood ash documented in the ecoinvent data set "disposal, wood ash mixture, pure, 0% water, to landfarming, CH, kg". Tab. 10 shows the elemental composition of the ash of the different biomass fuels.

The ash composition of the ash generated by the combustion of olive pomace is taken from Jauhiainen et al. (2005). The ash composition of the ash generated by the combustion of coffee ground pellets is taken from SGS-Institut-Fresenius (2008). The ash composition of the ash generated by the combustion of poultry litter pellets is taken from Salerno et al. (2001) and the composition of the ash generated by the combustion of horse dung is taken from Bühler et al. (2007). The ash composition of the ash generated by the combustion of slurry solids is taken from Hersener & Bühler (1998).

The natural concentration of heavy metals in wood and the natural concentration in the analysed biomass substrates are similar, but the ash formation when burning biomass substrates is ten times higher compared to the ash formation when burning wood. If 90% of the heavy metals are transferred to the residual ash, the concentration of the heavy metals in the wood ash is considerably higher than the concentration of the heavy metals in the ash generated by the combustion of the biomass substrates. To account for the higher ash formation the adopted values for the concentration of heavy metals taken from wood ash are reduced by a factor of 10 in the case of olive pomace, poultry litter and horse dung and by a factor of 3 in the case of coffee ground pellets. Without this correction the heavy metal content of the ash generated by biomass combustion is assumed to be overestimated.

Tab. 21: Elemental composition of the ash generated by the combustion process for the different biomass fuels

Fuel		ash olive pomace	ash coffee ground pellets	ash poultry litter pellets	ash horse dung and wood chips	ash slurry solids and bark chips
Water content	H2O	n.a.	n.a.	n.a.	n.a.	n.a.
Oxygen (without O from H2O)	O	0.38554	0.4012	0.2875	0.4909	0.4909
Hydrogen (without H from H2O)	H	n.a.	n.a.	n.a.	n.a.	n.a.
Carbon (enter share of biogenic C below)	C	0.14853	0.012	0.012	0.012	0.012
Sulfur	S	0.00987	0.0092	0.0092	0.0092	0.0092
Nitrogen	N	n.a.	n.a.	n.a.	n.a.	n.a.
Phosphor	P	0.01705	0.0098	0.112	0.00392	0.00392
Boron	B	n.a.	n.a.	n.a.	n.a.	n.a.
Chlorine	Cl	0.00305	0.0032	0.0032	0.000204	0.000204
Bromium	Br	n.a.	n.a.	n.a.	n.a.	n.a.
Fluorine	F	n.a.	n.a.	n.a.	n.a.	n.a.
Iodine	I	n.a.	n.a.	n.a.	n.a.	n.a.
Silver	Ag	n.a.	n.a.	n.a.	n.a.	n.a.
Arsenic	As	n.a.	0.0000067	0.0000067	0.0000067	0.0000067
Barium	Ba	n.a.	n.a.	n.a.	n.a.	n.a.
Cadmium	Cd	n.a.	1.03448E-05	0.00000022	0.000005	0.000005
Cobalt	Co	n.a.	3.44828E-05	0.0000018	0.0000018	0.0000018
Chromium	Cr	n.a.	3.44828E-05	0.0000195	0.0000195	0.0000195
Copper	Cu	n.a.	0.001034483	0.000426	0.000103	0.000103
Mercury	Hg	n.a.	0.000000033	0.00000001	0.00000001	0.00000001
Manganese	Mn	n.a.	0.002172414	0.02	0.02	0.02
Molybdenum	Mo	n.a.	0.0000037	0.0000037	0.0000037	0.0000037
Nickel	Ni	n.a.	6.89655E-05	0.000059	0.00000552	0.00000552
Lead	Pb	n.a.	0.000172414	0.0000065	0.000016	0.000016
Antimony	Sb	n.a.	0.000206897	n.a.	n.a.	n.a.
Selenium	Se	n.a.	n.a.	n.a.	n.a.	n.a.
Tin	Sn	n.a.	0.001172414	n.a.	n.a.	n.a.
Vanadium	V	n.a.	3.44828E-05	0.0000395	0.0000395	0.0000395
Zinc	Zn	n.a.	0.002965517	0.00091	0.00102	0.00102
Beryllium	Be	n.a.	n.a.	n.a.	n.a.	n.a.
Scandium	Sc	n.a.	n.a.	n.a.	n.a.	n.a.
Strontium	Sr	n.a.	n.a.		n.a.	n.a.
Titanium	Ti	0.00065	0.00138	0.00138	0.00138	0.00138
Thallium	Tl	n.a.	n.a.	n.a.	n.a.	n.a.
Tungsten	W	n.a.	n.a.	n.a.	n.a.	n.a.
Silicon	Si	0.06982	0.0826	0.0826	0.0826	0.0826
Iron (enter share of metallic iron below)	Fe	0.02528	0.0228	0.0228	0.0228	0.0228
Calcium	Ca	0.06675	0.284	0.284	0.284	0.284
Aluminium	Al	0.0241	0.079310345	0.0208	0.0208	0.0208
Potassium	K	0.21518	0.0545	0.099	0.01886	0.01886
Magnesium	Mg	0.03023	0.0321	0.044	0.0321	0.0321
Sodium	Na	0.00395	n.a.	n.a.	n.a.	n.a.
sum wet mass		**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

7.4.1. Landfarming

One possibility to dispose the ash generated by the combustion of the biomass substrates is the disposal in landfarming. Landfarming means the spreading of the ashes on arable land. The environmental impact of the spreading of the ashes is allocated to 100 % to the combustion of the biomass. The use of ashes as fertilisers is not considered although the high content of alkali metals and phosphorus in the ashes. The disposal of the ash in landfarming was modelled as a direct flux of the elements shown in Tab. 10 to agricultural soil. The sum of the elements listed in Tab. 22 and Tab. 23 is no equal to 1 kg. The missing mass corresponds to the oxygen in the ash as in Tab. 21.

Tab. 22 shows the unit process raw data of the disposal of the ash generated by the combustion of olive pomace and coffee ground pellets in landfarming. The elemental composition of the ash is taken from literature and the missing values are taken from the elemental composition of wood ash documented in the ecoinvent data set "disposal, wood ash mixture, pure, 0% water, to landfarming CH, kg". The completed values are highlighted with a dark green.

Tab. 22 Unit process raw data for the disposal of the ash of olive pomace and coffee ground pellets to landfarming

	Name	Location	Infrastructure-Process	Unit	disposal, ash olive pomace, to landfarming	UncertaintyType	StandardDeviation 95%	GeneralComment	disposal, ash coffee ground pellets, to landfarming	Uncertainty-Type	Standard-Deviation95%	GeneralComment
	Location				CY		Legende		CH		Legende	
	InfrastructureProcess				0		🟩	taken from ecoinvent data set for combusti	0		🟩	taken from ecoinvent data set for combustion
	Unit				kg		🟦	taken from literature	kg		🟦	taken from literature
product	disposal, ash olive pomace, to landfarming	CY	0	kg	1				0			
	disposal, ash coffee ground pellets, to landfarming	CH	0	kg	0				1			
	disposal, wood ash mixture, pure, 0% water, to landfarming	CH	0	kg	0				0			
technosphere	solid manure loading and spreading, by hydraulic loader and spreader	CH	0	kg	1.00E+0	1	1.62	(4,5,na,1,4,na,BU:1.05); Assumption for spreading	1.00E+0	1	1.62	(4,5,na,1,4,na,BU:1.05); Assumption for spreading
emission soil, agricultural	Aluminium	-	-	kg	2.41E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	7.93E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Antimony	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	2.07E-4	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Arsenic	-	-	kg	0	1	1.34	(1,4,2,3,3,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	6.70E-6	1	1.34	(1,4,2,3,3,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Cadmium	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	1.03E-5	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Calcium	-	-	kg	6.68E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	2.84E-1	1	1.26	(1,4,2,1,1,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Carbon	-	-	kg	1.49E-1	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition: Tab. 4, Jauhiainen et al. 2005	1.20E-2	1	1.58	(1,4,2,1,1,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Chloride	-	-	kg	3.05E-3	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition: Tab. 4, Jauhiainen et al. 2005	3.20E-3	1	1.58	(1,4,2,1,1,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Chromium	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	3.45E-5	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Cobalt	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	3.45E-5	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Copper	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	1.03E-3	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Iron	-	-	kg	2.53E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	2.28E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Lead	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	1.72E-4	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Magnesium	-	-	kg	3.02E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	3.21E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Manganese	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	2.17E-3	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Mercury	-	-	kg	0	1	1.34	(1,4,2,3,3,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	3.30E-8	1	1.34	(1,4,2,3,3,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Molybdenum	-	-	kg	0	1	1.34	(1,4,2,3,3,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	3.70E-6	1	1.34	(1,4,2,3,3,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Nickel	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	6.90E-5	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Phosphorus	-	-	kg	1.71E-2	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition: Tab. 4, Jauhiainen et al. 2005	9.80E-3	1	1.58	(1,4,2,1,1,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Potassium	-	-	kg	2.15E-1	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	5.45E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Silicon	-	-	kg	6.98E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	8.26E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Sodium	-	-	kg	3.95E-3	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition: Tab. 4, Jauhiainen et al. 2005	0	1	1.58	(1,4,2,1,1,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Sulfur	-	-	kg	9.87E-3	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition: Tab. 4, Jauhiainen et al. 2005	9.20E-3	1	1.58	(1,4,2,1,1,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Tin	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	1.17E-3	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Titanium	-	-	kg	6.50E-4	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	1.38E-3	1	1.26	(1,4,2,1,1,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Vanadium	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	3.45E-5	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;
	Zinc	-	-	kg	0	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Tab. 4, Jauhiainen et al. 2005	2.97E-3	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: Prüfbericht 544946, SGS Institut Fresenius, 2008;

Tab. 23 shows the unit process raw data of the disposal of the ash generated by the combustion of poultry litter pellets, horse dung and slurry solids in landfarming. The elemental composition of the ash is taken from literature and the missing values are taken from the elemental composition of wood ash documented in the ecoinvent data set "disposal, wood ash mixture, pure, 0% water, to landfarming CH, kg". The completed values are highlighted with a dark green.

Tab. 23: Unit process raw data for disposal of the ash of the mixtures “horse dung and wood chips” and “slurry solids and bark chips” to landfarming

	Name	Location	InfrastructureProcess	Unit	disposal, ash poultry litter pellets, to landfarming	UncertaintyType	StandardDeviation 95%	GeneralComment	disposal, ash horse dung and waste wood chips, to landfarming	UncertaintyType	StandardDeviation 95%	GeneralComment	disposal, ash slurry solids and bark chips, to landfarming	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH	Legende			CH	Legende			CH	Legende		
	InfrastructureProcess				0	🟩	taken from ecoinvent data sets for combustio		0	🟩	taken from ecoinvent data sets for combustion of wo		0	🟩	taken from ecoinvent data sets for combustion	
	Unit				kg	▢	taken from literature		kg	▢	taken from literature		kg	▢	taken from literature	
product	disposal, ash poultry litter pellets, to landfarming	CH	0	kg	1				0				0			
	disposal, ash horse dung and waste wood chips, to landfarming	CH	0	kg	0				1				0			
	disposal, ash slurry solids and bark chips, to landfarming	CH	0	kg	0				0				1			
technosphere	solid manure loading and spreading, by hydraulic loader and spreader	CH	0	kg	1.00E+0	1	1.24	(1,4,2,1,1,5,BU:1.05); approximate burden for spreading. (n.a.,n.a.,1,1,4,n.a.) & basic uncertainty of 1.05; solid manure spreadingfor landfarming of waste	1.00E+0	1	1.24	(1,4,2,1,1,5,BU:1.05); approximate burden for spreading. (n.a.,n.a.,1,1,4,n.a.) & basic uncertainty of 1.05; solid manure spreadingfor landfarming of waste	1.00E+0	1	1.24	(1,4,2,1,1,5,BU:1.05); approximate burden for spreading. (n.a.,n.a.,1,1,4,n.a.) & basic uncertainty of 1.05; solid manure spreadingfor landfarming of waste
emission soil, agricultural	Aluminium	-	-	kg	2.08E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	2.08E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	2.08E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Arsenic	-	-	kg	6.70E-6	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	6.70E-6	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	6.70E-6	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Cadmium	-	-	kg	2.20E-7	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3.6.1: APOLLO II Schlussbericht, Salerno et al., 2001	5.00E-6	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2007	8.68E-7	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: no information available, modelled equal to horse dung
	Calcium	-	-	kg	2.84E-1	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	2.84E-1	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	2.84E-3	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Carbon	-	-	kg	1.20E-2	1	1.85	(1,4,2,5,4,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.20E-2	1	1.85	(1,4,2,5,4,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.20E-2	1	1.85	(1,4,2,5,4,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Chloride	-	-	kg	3.20E-3	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition Tab. 3.6.1: APOLLO II Schlussbericht, Salerno et al., 2001	2.04E-4	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition Tab. 3 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2007	3.20E-3	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition: no information available, modelled equal to horse dung
	Chromium	-	-	kg	1.95E-5	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.95E-5	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.95E-4	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Cobalt	-	-	kg	1.80E-6	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.80E-6	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.80E-5	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Copper	-	-	kg	4.26E-4	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3.6.1: APOLLO II Schlussbericht, Salerno et al., 2001	1.03E-4	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2007	8.34E-4	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: no information available, modelled equal to horse dung
	Iron	-	-	kg	2.28E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	2.28E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	2.28E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Lead	-	-	kg	6.50E-6	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3.6.1: APOLLO II Schlussbericht, Salerno et al., 2001	1.60E-5	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2007	1.27E-5	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: no information available, modelled equal to horse dung
	Magnesium	-	-	kg	4.40E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3.6.1: APOLLO II Schlussbericht, Salerno et al., 2001	3.21E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2007	3.21E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: no information available, modelled equal to horse dung
	Manganese	-	-	kg	2.00E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	2.00E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	2.00E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Mercury	-	-	kg	1.00E-8	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.00E-8	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.00E-7	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Molybdenum	-	-	kg	3.70E-6	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	3.70E-6	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	3.70E-6	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Nickel	-	-	kg	5.90E-5	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3.6.1: APOLLO II Schlussbericht, Salerno et al., 2001	5.52E-6	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2007	5.52E-5	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: no information available, modelled equal to horse dung
	Phosphorus	-	-	kg	1.12E-1	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition Tab. 3.6.1: APOLLO II Schlussbericht, Salerno et al., 2001	3.92E-3	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition Tab. 3 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2007	8.37E-2	1	1.58	(1,4,2,1,1,5,BU:1.5); Ash composition: no information available, modelled equal to horse dung
	Potassium	-	-	kg	9.90E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3.6.1: APOLLO II Schlussbericht, Salerno et al., 2001	1.89E-2	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2007	1.47E-1	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: no information available, modelled equal to horse dung
	Silicon	-	-	kg	8.26E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	8.26E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	8.26E-2	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Sodium	-	-	kg	0	1	1.58	(1,4,2,1,1,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	0	1	1.58	(1,4,2,1,1,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	2.01E-1	1	1.58	(1,4,2,1,1,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Sulfur	-	-	kg	9.20E-3	1	1.85	(1,4,2,5,4,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	9.20E-3	1	1.85	(1,4,2,5,4,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	9.20E-3	1	1.85	(1,4,2,5,4,5,BU:1.5); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Tin	-	-	kg	0	1	1.59	(1,4,2,1,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	0	1	1.59	(1,4,2,1,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	0	1	1.59	(1,4,2,1,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Titanium	-	-	kg	1.38E-3	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.38E-3	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	1.38E-3	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Vanadium	-	-	kg	3.95E-5	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	3.95E-5	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.	3.95E-5	1	1.61	(1,4,2,5,4,5,BU:1.1); direct emission from landfarming process. Uncertainty from uncertainty in waste composition.
	Zinc	-	-	kg	9.10E-4	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3.6.1: APOLLO II Schlussbericht, Salerno et al., 2001	1.02E-3	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition Tab. 3 Thermische Nutzung von anspruchsvollen Biomassebrennstoffen, Bühler et al. 2007	2.92E-3	1	1.26	(1,4,2,1,1,5,BU:1.1); Ash composition: no information available, modelled equal to horse dung

7.4.2. Municipal incineration

A second possibility to dispose the ashes is the disposal in municipal incineration. The disposal of the ash to municipal incineration was modelled according to Doka (2007). The same elemental composition of the ash, which is shown in Tab. 10, was used for the calculations. This includes the combustion of the ash in municipal incineration and the landfilling of the residual waste.

7.4.3. Sanitary landfill

The third possibility to dispose the ashes is the disposal of the ashes to a sanitary landfill. The disposal of the ashes to a sanitary landfill was modelled according to Doka (2007). The same elemental composition of the ash, which is shown in Tab. 10, was used for the calculations. This includes the construction of the sanitary landfill and the treatment of the sewage sludge from the wastewater treatment.

7.5. Coffee grounds in municipal incineration

For the coffee ground a second way of energy recovery was modelled, namely the combustion of the wet coffee grounds in municipal incineration instead of the drying and pelletising of the coffee grounds. The heat and electricity generation was modelled according to Doka (2007). The same elemental composition for the moist fuel as shown in Tab. 3 was used for the calculations.

For the analysis the net benefit of the combustion of coffee grounds in municipal incineration is calculated. The net benefit is calculated as the difference between the avoided environmental impact of energy generation and the environmental impact of the combustion of one kilogram of coffee grounds in municipal. The combustion of 1 kg of coffee grounds in municipal incineration generates 0.53 kWh electricity and 3.92 MJ of useful heat according to Doka (2007).

For the substitution of the energy generation two possibilities for electricity generation and heat production are analysed resulting in a minimal net benefit and a maximal net benefit. This minimum maximum analysis is performed to cover the range of the different technologies for energy generation.

As substitution processes for electricity generation the process „electricity, natural gas, at combined cycle plant, best technology, RER“ is chosen for the minimal net benefit and for the maximal net benefit the electricity import mix shown in Tab. 11.

Tab. 24: Unit process raw data of the electricity import mix used for the calculation of the maximal net benefit of the electricity generation

	Name	Location	InfrastructureProces	Unit	electricity mix, import FR/DE/IT	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				kWh			
product	electricity mix, import FR/DE/IT	CH	0	kWh	1			
technosphere	electricity mix	FR	0	kWh	9.17E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); Leuenberger M. and Frischknecht R. (2010) Life Cycle Assessment of Swiss Electricity Mixes. implemented in ecoinvent data v2.2
	electricity mix	IT	0	kWh	1.92E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); Leuenberger M. and Frischknecht R. (2010) Life Cycle Assessment of Swiss Electricity Mixes. implemented in ecoinvent data v2.2
	electricity mix	DE	0	kWh	6.41E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); Leuenberger M. and Frischknecht R. (2010) Life Cycle Assessment of Swiss Electricity Mixes. implemented in ecoinvent data v2.2

As substitution process for heat generation the process “heat, light fuel oil, at industrial furnace 1MW, CH” is chosen for the maximal net benefit and the process “heat, natural gas, at industrial furnace >100kW, RER” for the minimal net benefit.

7.6. Meta information to the unit process raw data

Tab. 25, Tab. 26 , Tab. 27 and Tab. 28 show the meta information to all the unit process raw data for biomass combustion presented in this report.

Tab. 25: Meta information to the unit process raw data of the biomass substrates coffee grounds and olive pomace

ReferenceFunction	Name	coffee ground pellets, at regional storehouse	poultry litter pellets, at regional storehouse	olive pomace, burned in boiler furnace, at oil mill	coffee ground pellets, burned in wood furnace 25kW	heat, olive pomace, at boiler furnace, in oil mill	heat, coffee ground pellets, in wood furnace 25kW	disposal, ash olive pomace, to landfarming	disposal, ash coffee ground pellets, to landfarming	olive pomace, dried, at oil mill	coffee ground pellets, on site	poultry litter pellets, on site	coffee ground pellets, burned in furnace, produced on site	heat, coffee ground pellets, burned in furnace, produced on site
Geography	Location	CH	CH	CY	CH	CY	CH	CY	CH	CY	CH	CH	CH	CH
ReferenceFunction	InfrastructureProcess	0	0	0	0	0	0	0	0	0	0	0	0	0
ReferenceFunction	Unit	m3	m3	MJ	MJ	MJ	MJ	kg	kg	kg	m3	m3	MJ	MJ
	IncludedProcesses	This data set includes the production of the pellets and the transport to the regional storage centre	This data set includes the production of the pellets and the transport to the regional storage centre	This data set describes the emission into air caused by the combustion, infrastructure, fuel input and transport are included	This data set describes the emission into air caused by the combustion, infrastructure, fuel input and transport are included	This data set describes the efficiency of the combustion	This data set describes the efficiency of the combustion	This data set describes the disposal of the ash, only spreading of the ash is included (no transport)	This data set describes the disposal of the ash, only spreading of the ash is included (no transport)	This data set includes the drying process of the olive pomace on site (without transport)	This data set includes the production of the pellets on site (without transport)	This data set includes the production of the pellets on site (without transport)	This data set describes the emission into air caused by the combustion, infrastructure, fuel input and transport are included	This data set describes the efficiency of the combustion
	LocalName	Kaffeesatzpellets, ab Regionallager	Hühnermistpellets, ab Regionallager	Oliventrester, in Kesselfeuerung, in Ölmühle	Kaffeesatzpellets, in Holzkessel 25kW	Nutzwärme, Oliventrester, ab Kesselfeuerung, in Ölmühle	Nutzwärme, Kaffeesatzpellets, in Holzkessel 25kW	Entsorgung, Asche Oliventrester, in Landfarming	Entsorgung, Asche Kaffeesatzpellets, in Landfarming	Oliventrester, getrocknet, in Ölmühle	Kaffeesatzpellets, am Standort	Hühnermistpellets, am Standort	Kaffeesatzpellets, in Feuerung, produziert am Standort	Nutzwärme, Kaffeesatzpellets, in Feuerung, produziert am Standort
	Synonyms	0	0	0	0	0	0	0	0	0	0	0	0	0
	GeneralComment	Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"; own calculations: 3.78 MJ required for drying one kg water; bulk density coffee pellets 650 kg/m3; 0.7 kg water/kg fuel removed from coffee ground	Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"; own calculations: 3.78 MJ required for drying one kg water; bulk density poultry litter pellets 500 kg/m3; 0.57 kg water/kg fuel removed from poultry litter	Air emission from combustion data completed with ecoinvent inventory of "logs, mixed, burned in wood heater 6kW"; LHW 14.82 MJ/kg; Disposal ash: 50% landfarming, 50% municipal incineration	Air emission coffee ground data completed with ecoinvent inventory of "pellets, mixed, burned in furnace 15kW"; LHW: 17.4 MJ/kg; bulk density 650 kg/m3; Disposal ash: 50% landfarming, 50% municipal incineration	Provision of heat with efficiency factor 0.85 (estimated)	Provision of heat with efficiency factor 0.85 (estimated)	Ash composition data completed with the ecoinvent inventory of "disposal, wood ash mixture, pure, 0% water, to landfarming"	Ash composition data completed with the ecoinvent inventory of "disposal, wood ash mixture, pure, 0% water, to landfarming"	Own calculations: 3.78 MJ required for drying one kg water; 0.72 kg water/kg fuel removed from olive pomace	Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"; own calculations: 3.78 MJ required for drying one kg water; bulk density coffee pellets 650 kg/m3; 0.7 kg water/kg fuel removed from coffee ground	Based on ecoinvent dataset "wood pellets, u=10%, at storehouse, RER, [m3]"; own calculations: 3.78 MJ required for drying one kg water; bulk density poultry litter pellets 500 kg/m3; 0.57 kg water/kg fuel removed from poultry litter	Air emission coffee ground data completed with ecoinvent inventory of "pellets, mixed, burned in furnace 15kW"; LHW: 17.4 MJ/kg; bulk density 650 kg/m3; Disposal ash: 50% landfarming, 50% municipal incineration	Provision of heat with efficiency factor 0.85 (estimated); Disposal ash: 50% landfarming, 50% municipal incineration
	InfrastructureIncluded	1	1	1	1	1	1	1	1	1	1	1	1	1
	Category	biomass	biomass	biomass	biomass	biomass	biomass	waste management	waste management	biomass	biomass	biomass	biomass	biomass
	SubCategory	fuels	fuels	heating systems	heating systems	heating systems	heating systems	landfarming	landfarming	fuels	fuels	fuels	heating systems	heating systems
	LocalCategory	Biomasse	Biomasse	Biomasse	Biomasse	Biomasse	Biomasse	Entsorgungssysteme	Entsorgungssysteme	Biomasse	Biomasse	Biomasse	Biomasse	Biomasse
	LocalSubCategory	Brenn- und Treibstoffe	Brenn- und Treibstoffe	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme	Landfarming	Landfarming	Brenn- und Treibstoffe	Brenn- und Treibstoffe	Brenn- und Treibstoffe	Heizungssysteme	Heizungssysteme
	Formula													
	StatisticalClassification													
	CASNumber													
TimePeriod	StartDate	2008	2001	2006	2009	2006	2009	2006	2008	2006	2008	2001	2009	2009
	EndDate	2008	2001	2006	2009	2006	2009	2006	2008	2006	2008	2001	2009	2009
	DataValidForEntirePerio	1	1	1	1	1	1	1	1	1	1	1	1	1
	OtherPeriodText	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.
Geography	Text	The inventory is modelled for pellet production in Switzerland	The inventory is modelled for pellet production in Switzerland	The inventory is modelled for a typical production area for olives in the Lythrodontas region in Cyprus.	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a typical production area for olives in the Lythrodontas region in Cyprus.	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a typical production area for olives in the Lythrodontas region in Cyprus.	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a typical production area for olives in the Lythrodontas region in Cyprus.	The inventory is modelled for pellet production in Switzerland	The inventory is modelled for pellet production in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland
Technology	Text	none	none	Boiler Furnace	Furnace 25kW	Boiler Furnace	Furnace 25kW	none	none	none	none	none	Furnace 25kW	Furnace 25kW
Representativeness	Percent	0	0	0	0	0	0	0	0	0	0	0	0	0
	ProductionVolume	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown
	SamplingProcedure	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature
	Extrapolations	Drying and pellet manufacturing process estimated with data for wood drying and wood pellet production	Drying and pellet manufacturing process estimated with data for wood drying and wood pellet production	Several air emissions estimated with data for wood combustion.	Several air emissions estimated with data for wood combustion.	none	none	ash composition estimated with data for wood ash	ash composition estimated with data for wood ash	none	Drying and pellet manufacturing process estimated with data for wood drying and wood pellet production	Drying and pellet manufacturing process estimated with data for wood drying and wood pellet production	Several air emissions estimated with data for wood combustion.	none
	UncertaintyAdjustments	none	none	none	none	none	none	none	none	none	none	none	none	none
	Details	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011
	OtherDetails	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_6-30kW-v1.0.xlsx]X-Process

Tab. 26: Meta information to the unit process raw data of the mixtures “horse dung and wood chips”, “slurry solids and bark chips”

ReferenceFunction	Name	horse dung and waste wood chips, at farm	slurry solids and bark chips, at farm	poultry litter pellets, burned in rotating grate furnace 250-350kW	horse dung and waste wood chips, burned in grate furnace 500-600kW	slurry solids and bark chips, burned in bark furnace 1MW	heat, poultry litter pellets, in rotating grate furnace 250-350kW	heat, horse dung and waste wood chips, in grate furnace 500-600kW	heat, slurry solids and bark chips, in bark furnace 1MW	disposal, ash poultry litter pellets, to landfarming	disposal, ash horse dung and waste wood chips, to landfarming	disposal, ash slurry solids and bark chips, to landfarming	poultry litter pellets, burned in furnace, produced on site	heat, poultry litter pellets, burned in furnace, produced on site
Geography	Location	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH
ReferenceFunction	InfrastructureProcess	0	0	0	0	0	0	0	0	0	0	0	0	0
ReferenceFunction	Unit	m3	m3	MJ	MJ	MJ	MJ	MJ	MJ	kg	kg	kg	MJ	MJ
	IncludedProcesses	This data set includes the wood chips. Horse dung as a waste is assumed to be used with zero burden from its production.	This data set includes the bark chips. Slurry as a waste is assumed to be used with zero burden from its production.	This data set includes fuel, infrastructure, ash disposal and air emissions.	This data set includes fuel, infrastructure, ash disposal and air emissions.	This data set includes fuel, infrastructure, ash disposal and air emissions.	This data set includes the efficiency of the combustion	This data set includes the efficiency of the combustion	This data set includes the efficiency of the combustion	This data set includes emissions to agricultural soil due to the land farming of ash	This data set includes emissions to agricultural soil due to the land farming of ash	This data set includes the wood chips. Horse dung as a waste is assumed to be used with zero burden from its production.	This data set includes fuel, infrastructure, ash disposal and air emissions.	This data set includes the efficiency of the combustion
	LocalName	Pferdemist und Abfallholzschnitzel, ab Bauernhof	Güllefeststoffe und Rindenschnitzel, ab Bauernhof	Hühnermistpellets, in rotierender Rostfeuerung 250-350kW	Pferdemist und Abfallholzschnitzel, in Rostfeuerung 500-600kW	Güllefeststoffe und Rindenschnitzel, in Feuerung 1MW	Nutzwärme, Hühnermistpellets, in rotierender Rostfeuerung 250-350kW	Nutzwärme, Pferdemist und Abfallholzschnitzel, in Rostfeuerung 500-600kW	Nutzwärme, Güllefeststoffe und Rindenschnitzel, in Rindenfeuerung 1MW	Entsorgung, Asche Hühnermistpellets, in Landfarming	Entsorgung, Asche Pferdemist und Abfallholzschnitzel, Landfarming	Entsorgung, Asche Güllefeststoffe und Rindenschnitzel, in Landfarming	Hühnermistpellets, in Feuerung, produziert am Standort	Nutzwärme, Hühnermistpellets, in Feuerung, produziert am Standort
	Synonyms	0	0	0	0	0	0	0	0	0	0	0	0	0
	GeneralComment	Mixture horse dung (67%) and waste wood (33%); lower heating value: 8.4 MJ/kg; bulk density 315 kg/m3	Mixture slurry solids (15.5%) and bark chips (84.5%); lower heating value: 5.4 MJ/kg; bulk density: 300 kg/m3	Air emission data completed with the inventory of wood chips, from forest, mixed, burned in furnace 300kW; lower heating value 13.5 MJ/kg; bulk density: 500kg/m3; Disposal Ash: 25% landfarming, 25% MSWI, 50% sanitary landfill	Air emission data completed with the inventory of wood chips, from forest, mixed, burned in furnace 1000kW; lower heating value: 8.4 MJ/kg; bulk density 315 kg/m3; Disposal Ash: 25% landfarming, 25% MSWI, 50% sanitary landfill	Air emission data completed with the inventory of wood chips, from forest, mixed, burned in furnace 1000kW; lower heating value: 5.4 MJ/kg; bulk density: 300 kg/m3; Disposal Ash: 25% landfarming, 25% MSWI, 50% sanitary landfill	Provision of heat with efficiency factor 0.94	Provision of heat with efficiency factor 0.85 (estimated)	Provision of heat with efficiency factor 0.85 (estimated)	Ash composition data completed with the inventory of disposal, wood ash mixture, pure, 0% water, to landfarming	Ash composition data completed with the inventory of disposal, wood ash mixture, pure, 0% water, to landfarming	Ash composition pig slurry: no information available, modelled equal to horse dung; data completed with the inventory of disposal, wood ash mixture, pure, 0% water, to landfarming;	Air emission data completed with the inventory of wood chips, from forest, mixed, burned in furnace 300kW; lower heating value 13.5 MJ/kg; bulk density: 500kg/m3; Disposal Ash: 25% landfarming, 25% MSWI, 50% sanitary landfill	Provision of heat with efficiency factor 0.94
	InfrastructureIncluded	1	1	1	1	1	1	1	1	1	1	1	1	1
	Category	biomass	biomass	biomass	biomass	biomass	biomass	biomass	biomass	waste management	waste management	waste management	biomass	biomass
	SubCategory	fuels	fuels	heating systems	heating systems	heating systems	heating systems	heating systems	heating systems	landfarming	landfarming	landfarming	heating systems	heating systems
	LocalCategory	Biomasse	Biomasse	Biomasse	Biomasse	Biomasse	Biomasse	Biomasse	Biomasse	Entsorgungssysteme	Entsorgungssysteme	Entsorgungssysteme	Biomasse	Biomasse
	LocalSubCategory	Brenn- und Treibstoffe	Brenn- und Treibstoffe	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme	Landfarming	Landfarming	Landfarming	Heizungssysteme	Heizungssysteme
	Formula													
	StatisticalClassification													
	CASNumber													
TimePeriod	StartDate	2005	1998	2001	2005	1998	2001	2005	1998	2001	2005	1998	2001	2001
	EndDate	2005	1998	2001	2005	1998	2001	2005	1998	2001	2005	1998	2001	2001
	DataValidForEntirePeriod	1	1	1	1	1	1	1	1	1	1	1	1	1
	OtherPeriodText	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.	Collection of data and publication.
Geography	Text	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland	The inventory is modelled for a pilot plant in Switzerland
Technology	Text	Preparation of fuel for grate firing 500-600 kW	bark furnace 1MW	grate furnace 300kW	grate firing 500-600 kW	bark furnace 1MW	grate furnace 300kW	grate firing 500-600 kW	bark furnace 1MW	grate furnace 300kW	grate firing 500-600 kW	bark furnace 1MW	grate furnace 300kW	grate furnace 300kW
Representativeness	Percent	0	0	0	0	0	0	0	0	0	0	0	0	0
	ProductionVolume	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown
	SamplingProcedure	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature	Literature
	Extrapolations	none	none	Several air emissions estimated with data for wood combustion.	Several air emissions estimated with data for wood combustion.	Several air emissions estimated with data for wood combustion.	none	none	none	none	none	none	Several air emissions estimated with data for wood combustion.	none
	UncertaintyAdjustments	none	none	none	none	none	none	none	none	none	none	none	none	none
	Details	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011	29.04.2011
	OtherDetails	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process	Z:\ESU-Docs\Projekte laufend\321 FP Biomasse Verbrennung Feste Substrate\EcoSpold\[321_Biomasse_300-1000kW-1.0.xlsx]X-Process

Tab. 27: Meta information to the unit process raw data of disposal of the ash to municipal incineration

ReferenceFunction	Name	disposal, ash olive pomace, to municipal incineration	disposal, ash coffee ground pellets, to municipal incineration	disposal, ash poultry litter pellets, to municipal incineration	disposal, ash horse dung and waste wood chips, to municipal incineration	disposal, ash slurry solids and bark chips, to municipal incineration
Geography	Location	CH	CH	CH	CH	CH
ReferenceFunction	InfrastructureProcess	0	0	0	0	0
ReferenceFunction	Unit	kg	kg	kg	kg	kg
ReferenceFunction	IncludedProcesses	waste-specific air and water emisions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emisisons to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber slugde). Process energy demands for MSWI.	waste-specific air and water emisions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emisisons to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber slugde). Process energy demands for MSWI.	waste-specific air and water emisions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emisisons to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber slugde). Process energy demands for MSWI.	waste-specific air and water emisions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emisisons to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber slugde). Process energy demands for MSWI.	waste-specific air and water emisions from incineration, auxiliary material consumption for flue gas cleaning. Short-term emissions to river water and long-term emisisons to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber slugde). Process energy demands for MSWI.
ReferenceFunction	LocalName	Entsorgung, Asche Oliventrester, in Kehrichtverbrennung	Entsorgung, Asche Kaffeesatzpellets, in Kehrichtverbrennung	Entsorgung, Asche Hühnermistpellets, in Kehrichtverbrennung	Entsorgung, Asche Pferdemist und Holzschnitzel, in Kehrichtverbrennung	Entsorgung, Asche Güllefeststoffe und Rindenschnitzel, in Kehrichtverbrennung
ReferenceFunction	Synonyms					
ReferenceFunction	GeneralComment	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 385540; H n.a.; C 148530; S 9870; N n.a.; P 17050; B n.a.; Cl 3050; Br n.a.; F n.a.; I n.a.; Ag n.a.; As n.a.; Ba n.a.; Cd n.a.; Co n.a.; Cr n.a.; Cu n.a.; Hg n.a.; Mn n.a.; Mo n.a.; Ni n.a.; Pb n.a.; Sb n.a.; Se n.a.; Sn n.a.; V n.a.; Zn n.a.; Be n.a.; Sc n.a.; Sr n.a.; Ti 650; Tl n.a.; W n.a.; Si 69820; Fe 25280; Ca 66750; Al 24100; K 215180; Mg 30230; Na 3950; Share of carbon in waste that is biogenic 100%.Share of iron in waste that is metallic/recyclable 0%. Net energy produced in MSWI: 0MJ/kg waste electric energy and 0MJ/kg waste thermal energyAllocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI.One kg of this waste produces 0.5558 kg of slag and 0.1405 kg of residues, which are landfilled. Additional solidification with 0.0562 kg of cement.	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 401500; H n.a.; C 12000; S 9200; N n.a.; P 9800; B n.a.; Cl 3200; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 6.7; Ba n.a.; Cd 9.9055; Co 34.483; Cr 31.997; Cu 1020.7; Hg n.a.; Mn 2172.4; Mo 3.7; Ni 65.2; Pb 156.72; Sb 206.9; Se n.a.; Sn 1172.4; V 34.483; Zn 2777.2; Be n.a.; Sc n.a.; Sr n.a.; Ti 1380; Tl n.a.; W n.a.; Si 82600; Fe 22800; Ca 284000; Al 79310; K 54500; Mg 32100; Na n.a.; Share of carbon in waste that is biogenic 100%.Share of iron in waste that is metallic/recyclable 0%. Net energy produced in MSWI: 0MJ/kg waste electric energy and 0MJ/kg waste thermal energyAllocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI.One kg of this waste produces 0.7736 kg of slag and 0.1359 kg of residues, which are landfilled. Additional solidification with 0.05436 kg of cement.	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 287500; H n.a.; C 12000; S 9200; N n.a.; P 112000; B n.a.; Cl 3200; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 6.7; Ba n.a.; Cd 0.22; Co 1.8; Cr 19.5; Cu 426; Hg 0.01; Mn 20000; Mo 3.7; Ni 59; Pb 6.5; Sb n.a.; Se n.a.; Sn n.a.; V 39.5; Zn 910; Be n.a.; Sc n.a.; Sr n.a.; Ti 1380; Tl n.a.; W n.a.; Si 82600; Fe 22800; Ca 284000; Al 20800; K 99000; Mg 44000; Na n.a.; Share of carbon in waste that is biogenic 100%.Share of iron in waste that is metallic/recyclable 0%. Net energy produced in MSWI: 0MJ/kg waste electric energy and 0MJ/kg waste thermal energyAllocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI.One kg of this waste produces 0.9728 kg of slag and 0.1665 kg of residues, which are landfilled. Additional solidification with 0.0666 kg of cement.	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 490900; H n.a.; C 12000; S 9200; N n.a.; P 3920; B n.a.; Cl 204; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 6.7; Ba n.a.; Cd 5; Co 1.8; Cr 19.5; Cu 103; Hg 0.01; Mn 20000; Mo 3.7; Ni 5.52; Pb 16; Sb n.a.; Se n.a.; Sn n.a.; V 39.5; Zn 1020; Be n.a.; Sc n.a.; Sr n.a.; Ti 1380; Tl n.a.; W n.a.; Si 82600; Fe 22800; Ca 284000; Al 20800; K 18860; Mg 32100; Na n.a.; Share of carbon in waste that is biogenic 100%.Share of iron in waste that is metallic/recyclable 0%. Net energy produced in MSWI: 0MJ/kg waste electric energy and 0MJ/kg waste thermal energyAllocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI.One kg of this waste produces 0.6717 kg of slag and 0.1037 kg of residues, which are landfilled. Additional solidification with 0.04149 kg of cement.	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 363500; H n.a.; C 12000; S 9200; N n.a.; P 83654; B n.a.; Cl n.a.; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 6.7; Ba n.a.; Cd 0.86775; Co 1.8; Cr 18.969; Cu 833.59; Hg -0.030194; Mn 20000; Mo 3.7; Ni 4.7161; Pb 12.651; Sb n.a.; Se n.a.; Sn n.a.; V 39.5; Zn 2921.3; Be n.a.; Sc n.a.; Sr n.a.; Ti 1380; Tl n.a.; W n.a.; Si 82600; Fe 22800; Ca n.a.; Al 20800; K 147120; Mg 32100; Na 200960; Share of carbon in waste that is biogenic 100%.Share of iron in waste that is metallic/recyclable 0%. Net energy produced in MSWI: 0MJ/kg waste electric energy and 0MJ/kg waste thermal energyAllocation of energy production: no substitution or expansion. Total burden allocated to waste disposal function of MSWI.One kg of this waste produces 0.7604 kg of slag and 0.2264 kg of residues, which are landfilled. Additional solidification with 0.09055 kg of cement.
ReferenceFunction	InfrastructureIncluded					
ReferenceFunction	Category	waste management	waste management	waste management	waste management	waste management
ReferenceFunction	SubCategory	municipal incineration	municipal incineration	municipal incineration	municipal incineration	municipal incineration
ReferenceFunction	LocalCategory	Entsorgungssysteme	Entsorgungssysteme	Entsorgungssysteme	Entsorgungssysteme	Entsorgungssysteme
ReferenceFunction	LocalSubCategory	Kehrichtverbrennung	Kehrichtverbrennung	Kehrichtverbrennung	Kehrichtverbrennung	Kehrichtverbrennung
ReferenceFunction	Formula					
ReferenceFunction	StatisticalClassification					
ReferenceFunction	CASNumber					
TimePeriod	StartDate	1994	1994	1994	1994	1994
TimePeriod	EndDate	2000	2000	2000	2000	2000
TimePeriod	DataValidForEntirePeriod	1	1	1	1	1
TimePeriod	OtherPeriodText	Waste composition as given in literature reference, theoretical data or other source. Transfer coefficients for modern Swiss MSWI. Emission speciation based on early 90ies data.	Waste composition as given in literature reference, theoretical data or other source. Transfer coefficients for modern Swiss MSWI. Emission speciation based on early 90ies data.	Waste composition as given in literature reference, theoretical data or other source. Transfer coefficients for modern Swiss MSWI. Emission speciation based on early 90ies data.	Waste composition as given in literature reference, theoretical data or other source. Transfer coefficients for modern Swiss MSWI. Emission speciation based on early 90ies data.	Waste composition as given in literature reference, theoretical data or other source. Transfer coefficients for modern Swiss MSWI. Emission speciation based on early 90ies data.
Geography	Text	Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan.	Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan.	Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan.	Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan.	Specific to the technology mix encountered in Switzerland in 2000. Well applicable to modern incineration practices in Europe, North America or Japan.
Technology	Text	average Swiss MSWI plants in 2000 (grate incinerators) with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 29.4% SNCR , 32.2% SCR-high dust , 24.6% SCR-low dust -DeNOx facilities and 13.8% without Denox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag : 50%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%	average Swiss MSWI plants in 2000 (grate incinerators) with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 29.4% SNCR , 32.2% SCR-high dust , 24.6% SCR-low dust -DeNOx facilities and 13.8% without Denox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag : 50%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%	average Swiss MSWI plants in 2000 (grate incinerators) with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 29.4% SNCR , 32.2% SCR-high dust , 24.6% SCR-low dust -DeNOx facilities and 13.8% without Denox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag : 50%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%	average Swiss MSWI plants in 2000 (grate incinerators) with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 29.4% SNCR , 32.2% SCR-high dust , 24.6% SCR-low dust -DeNOx facilities and 13.8% without Denox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag : 50%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%	average Swiss MSWI plants in 2000 (grate incinerators) with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 29.4% SNCR , 32.2% SCR-high dust , 24.6% SCR-low dust -DeNOx facilities and 13.8% without Denox (by burnt waste, according to Swiss average). Share of waste incinerated in plants with magnetic scrap separation from slag : 50%. Gross electric efficiency technology mix 12.997% and Gross thermal efficiency technology mix 25.57%
Representativenes	Percent					
Representativenes	ProductionVolume					
Representativenes	SamplingProcedure	waste-specific calculation based on literature data	waste-specific calculation based on literature data	waste-specific calculation based on literature data	waste-specific calculation based on literature data	waste-specific calculation based on literature data
Representativenes	Extrapolations	Typical elemental transfer coefficients from current studies for modern MSWI, completed with data from coal power plants and estimates, adapted for inert/burnable waste.	Typical elemental transfer coefficients from current studies for modern MSWI, completed with data from coal power plants and estimates, adapted for inert/burnable waste.	Typical elemental transfer coefficients from current studies for modern MSWI, completed with data from coal power plants and estimates, adapted for inert/burnable waste.	Typical elemental transfer coefficients from current studies for modern MSWI, completed with data from coal power plants and estimates, adapted for inert/burnable waste.	Typical elemental transfer coefficients from current studies for modern MSWI, completed with data from coal power plants and estimates, adapted for inert/burnable waste.
Representativenes	UncertaintyAdjustments	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1
	Details	automatic validation	automatic validation	automatic validation	automatic validation	automatic validation
	OtherDetails	none	none	none	none	none

Tab. 28: Meta information to the unit process raw data of disposal of the ash to sanitary landfill

Type	Field name, IndexNumber	for MSW landfill	for MSW landfill	for MSW landfill	for MSW landfill	for MSW landfill
ReferenceFunction	**Name**	disposal, ash olive pomace, to sanitary landfill	disposal, ash coffee ground pellets, to sanitary landfill	disposal, ash poultry litter pellets, to sanitary landfill	disposal, ash horse dung and waste wood chips, to sanitary lan	disposal, ash slurry solids and bark chips, to sanitary landfill
Geography	**Location**	CH	CH	CH	CH	CH
ReferenceFunction	**InfrastructureProcess**	0	0	0	0	0
ReferenceFunction	**Unit**	kg	kg	kg	kg	kg
ReferenceFunction	IncludedProcesses	Waste-specific short-term emissions to air via landfill gas incineration and landfill leachate. Burdens from treatment of short-term leachate (0-100a) in wastewater treatment plant (including WWTP sludge disposal in municipal incinerator). Long-term emissions from landfill to groundwater (after base lining failure).	Waste-specific short-term emissions to air via landfill gas incineration and landfill leachate. Burdens from treatment of short-term leachate (0-100a) in wastewater treatment plant (including WWTP sludge disposal in municipal incinerator). Long-term emissions from landfill to groundwater (after base lining failure).	Waste-specific short-term emissions to air via landfill gas incineration and landfill leachate. Burdens from treatment of short-term leachate (0-100a) in wastewater treatment plant (including WWTP sludge disposal in municipal incinerator). Long-term emissions from landfill to groundwater (after base lining failure).	Waste-specific short-term emissions to air via landfill gas incineration and landfill leachate. Burdens from treatment of short-term leachate (0-100a) in wastewater treatment plant (including WWTP sludge disposal in municipal incinerator). Long-term emissions from landfill to groundwater (after base lining failure).	Waste-specific short-term emissions to air via landfill gas incineration and landfill leachate. Burdens from treatment of short-term leachate (0-100a) in wastewater treatment plant (including WWTP sludge disposal in municipal incinerator). Long-term emissions from landfill to groundwater (after base lining failure).
ReferenceFunction	**LocalName**	Entsorgung, Asche Oliventrester, in Reaktordeponie	Entsorgung, Asche Kaffeesatzpellets, in Reaktordeponie	Entsorgung, Asche Hühnermistpellets, in Reaktordeponie	Entsorgung, Asche Pferdemist und Holzschnitzel, in Reaktordep	Entsorgung, Asche Güllefeststoffe und Rindenschnitzel, in Reaktordeponie
ReferenceFunction	Synonyms					
ReferenceFunction	GeneralComment	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 385540; H n.a.; C 148530; S 9870; N n.a.; P 17050; B n.a.; Cl 3050; Br n.a.; F n.a.; I n.a.; Ag n.a.; As n.a.; Ba n.a.; Cd n.a.; Co n.a.; Cr n.a.; Cu n.a.; Hg n.a.; Mn n.a.; Mo n.a.; Ni n.a.; Pb n.a.; Sb n.a.; Se n.a.; Sn n.a.; V n.a.; Zn n.a.; Be n.a.; Sc n.a.; Sr n.a.; Ti 650; Tl n.a.; W n.a.; Si 69820; Fe 25280; Ca 66750; Al 24100; K 215180; Mg 30230; Na 3950; Share of carbon in waste that is biogenic 100%.Overall degradability of waste during 100 years: 5%.	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 401500; H n.a.; C 12000; S 9200; N n.a.; P 9800; B n.a.; Cl 3200; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 6.7; Ba n.a.; Cd 9.9055; Co 34.483; Cr 31.997; Cu 1020.7; Hg n.a.; Mn 2172.4; Mo 3.7; Ni 65.2; Pb 156.72; Sb 206.9; Se n.a.; Sn 1172.4; V 34.483; Zn 2777.2; Be n.a.; Sc n.a.; Sr n.a.; Ti 1380; Tl n.a.; W n.a.; Si 82600; Fe 22800; Ca 284000; Al 79310; K 54500; Mg 32100; Na n.a.; Share of carbon in waste that is biogenic 100%.Overall degradability of waste during 100 years: 5%.	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 287500; H n.a.; C 12000; S 9200; N n.a.; P 112000; B n.a.; Cl 3200; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 6.7; Ba n.a.; Cd 0.22; Co 1.8; Cr 19.5; Cu 426; Hg 0.01; Mn 20000; Mo 3.7; Ni 59; Pb 6.5; Sb n.a.; Se n.a.; Sn n.a.; V 39.5; Zn 910; Be n.a.; Sc n.a.; Sr n.a.; Ti 1380; Tl n.a.; W n.a.; Si 82600; Fe 22800; Ca 284000; Al 20800; K 99000; Mg 44000; Na n.a.; Share of carbon in waste that is biogenic 100%.Overall degradability of waste during 100 years: 5%.	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 490900; H n.a.; C 12000; S 9200; N n.a.; P 3920; B n.a.; Cl 204; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 6.7; Ba n.a.; Cd 5; Co 1.8; Cr 19.5; Cu 103; Hg 0.01; Mn 20000; Mo 3.7; Ni 5.52; Pb 16; Sb n.a.; Se n.a.; Sn n.a.; V 39.5; Zn 1020; Be n.a.; Sc n.a.; Sr n.a.; Ti 1380; Tl n.a.; W n.a.; Si 82600; Fe 22800; Ca 284000; Al 20800; K 18860; Mg 32100; Na n.a.; Share of carbon in waste that is biogenic 100%.Overall degradability of waste during 100 years: 5%.	Inventoried waste contains .waste composition (wet, in ppm): H2O n.a.; O 363500; H n.a.; C 12000; S 9200; N n.a.; P 83654; B n.a.; Cl n.a.; Br n.a.; F n.a.; I n.a.; Ag n.a.; As 6.7; Ba n.a.; Cd 0.86775; Co 1.8; Cr 18.969; Cu 833.59; Hg -0.030194; Mn 20000; Mo 3.7; Ni 4.7161; Pb 12.651; Sb n.a.; Se n.a.; Sn n.a.; V 39.5; Zn 2921.3; Be n.a.; Sc n.a.; Sr n.a.; Ti 1380; Tl n.a.; W n.a.; Si 82600; Fe 22800; Ca n.a.; Al 20800; K 147120; Mg 32100; Na 200960; Share of carbon in waste that is biogenic 100%.Overall degradability of waste during 100 years: 5%.
ReferenceFunction	**InfrastructureIncluded**					
ReferenceFunction	**Category**	waste management	waste management	waste management	waste management	waste management
ReferenceFunction	**SubCategory**	**sanitary landfill**	**sanitary landfill**	**sanitary landfill**	**sanitary landfill**	**sanitary landfill**
ReferenceFunction	**LocalCategory**	Entsorgungssysteme	Entsorgungssysteme	Entsorgungssysteme	Entsorgungssysteme	Entsorgungssysteme
ReferenceFunction	**LocalSubCategory**	**Reaktordeponie**	**Reaktordeponie**	**Reaktordeponie**	**Reaktordeponie**	**Reaktordeponie**
ReferenceFunction	Formula					
ReferenceFunction	StatisticalClassification					
ReferenceFunction	CASNumber					
TimePeriod	**StartDate**	1994	1994	1994	1994	1994
TimePeriod	**EndDate**	2000	2000	2000	2000	2000
TimePeriod	**DataValidForEntirePeriod**	1	1	1	1	1
TimePeriod	OtherPeriodText					
Geography	Text	Technology encountered in Switzerland in 2000. Landfill includes base seal, leachate collection system, treatment of leachate in municipal wastewater treatment plant.	Technology encountered in Switzerland in 2000. Landfill includes base seal, leachate collection system, treatment of leachate in municipal wastewater treatment plant.	Technology encountered in Switzerland in 2000. Landfill includes base seal, leachate collection system, treatment of leachate in municipal wastewater treatment plant.	Technology encountered in Switzerland in 2000. Landfill includes base seal, leachate collection system, treatment of leachate in municipal wastewater treatment plant.	Technology encountered in Switzerland in 2000. Landfill includes base seal, leachate collection system, treatment of leachate in municipal wastewater treatment plant.
Technology	**Text**	Swiss municipal sanitary landfill for biogenic or untreated municipal waste ('reactive organic landfill'). Landfill gas and leachate collection system. Recultivation and monitoring for 150 years after closure.	Swiss municipal sanitary landfill for biogenic or untreated municipal waste ('reactive organic landfill'). Landfill gas and leachate collection system. Recultivation and monitoring for 150 years after closure.	Swiss municipal sanitary landfill for biogenic or untreated municipal waste ('reactive organic landfill'). Landfill gas and leachate collection system. Recultivation and monitoring for 150 years after closure.	Swiss municipal sanitary landfill for biogenic or untreated municipal waste ('reactive organic landfill'). Landfill gas and leachate collection system. Recultivation and monitoring for 150 years after closure.	Swiss municipal sanitary landfill for biogenic or untreated municipal waste ('reactive organic landfill'). Landfill gas and leachate collection system. Recultivation and monitoring for 150 years after closure.
Representativeness	Percent					
Representativeness	ProductionVolume					
Representativeness	SamplingProcedure	Landfill model based on observed leachate concentrations in literature. Extrapolated to 60'000 years heeding chemical characteristics. Initial waste composition from various literature sources.	Landfill model based on observed leachate concentrations in literature. Extrapolated to 60'000 years heeding chemical characteristics. Initial waste composition from various literature sources.	Landfill model based on observed leachate concentrations in literature. Extrapolated to 60'000 years heeding chemical characteristics. Initial waste composition from various literature sources.	Landfill model based on observed leachate concentrations in literature. Extrapolated to 60'000 years heeding chemical characteristics. Initial waste composition from various literature sources.	Landfill model based on observed leachate concentrations in literature. Extrapolated to 60'000 years heeding chemical characteristics. Initial waste composition from various literature sources.
Representativeness	Extrapolations					
Representativeness	UncertaintyAdjustments	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1. Mean long-term emissions are the emissions until the next glacial period occurs (in 60'000a) and the landfill is eroded. Maximal long-term emissions are the complete emissions of all landfilled material (except Cr). Minimal long-term emissions are derived implicitly from the mean and maximal values assuming a lognormal distribution.	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1. Mean long-term emissions are the emissions until the next glacial period occurs (in 60'000a) and the landfill is eroded. Maximal long-term emissions are the complete emissions of all landfilled material (except Cr). Minimal long-term emissions are derived implicitly from the mean and maximal values assuming a lognormal distribution.	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1. Mean long-term emissions are the emissions until the next glacial period occurs (in 60'000a) and the landfill is eroded. Maximal long-term emissions are the complete emissions of all landfilled material (except Cr). Minimal long-term emissions are derived implicitly from the mean and maximal values assuming a lognormal distribution.	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1. Mean long-term emissions are the emissions until the next glacial period occurs (in 60'000a) and the landfill is eroded. Maximal long-term emissions are the complete emissions of all landfilled material (except Cr). Minimal long-term emissions are derived implicitly from the mean and maximal values assuming a lognormal distribution.	uncertainty of waste input composition data derived from generic formula GSD(c) = N*ln(c)+1. Mean long-term emissions are the emissions until the next glacial period occurs (in 60'000a) and the landfill is eroded. Maximal long-term emissions are the complete emissions of all landfilled material (except Cr). Minimal long-term emissions are derived implicitly from the mean and maximal values assuming a lognormal distribution.

7.7. Data quality

All the measurements were performed in pilot plants. Therefore the measurements are not comparable to a continuous operation of the plants. No adjustments have been made to the emission factors in order to account for the measurements in pilot plants.

For all substrates only the total amount of suspended particulate matter (TSP) in the flue gas was measured. The particle distribution had to be extrapolated from other measurements (Berdowski et al. 2001). This resulted in a fraction of 90% of the TSP belonging to the smallest category of the particulate matter (PM) smaller than 2.5 um. Because the combustion process of the biomass is worse compared to the combustion of wood, it is expected that the amount of small particles is smaller for the biomass fuels than for the wooden fuels, but there was no data available to prove this assumption. Therefore the same particle distribution as for the combustion of wooden fuels was used. This might lead to a higher environmental impact because the environmental impact of smaller particles is higher than the environmental impact of bigger particles.

Because of the availability, the up-to-dateness and the quality of the data an inclusion in the ecoinvent data base is only recommended for the data sets for coffee ground pellets, poultry litter pellets and horse dung mixed with wood chips.

7.7.1. Olive pomace

Data quality for olives pomace is debatable. The ash composition and the air emissions during the combustion are documented in Jauhiainen et al. (2005), but in the measurements of Jauhiainen et al. (2005) no heavy metals emissions, no nitrogen oxide emissions and no particle emissions into air are reported, as well as there are no heavy metals detected in the ash after combustion. Because the heavy metal emissions and the heavy metal content of the ash have a high impact on the result of the ecological scarcity method 2006 it is recommended to consider this fact when comparing the olive pomace with the other substrates, especially in case of the disposal of the ash.

7.7.2. Coffee grounds

For coffee grounds there are measurements for the nitrogen oxides, carbon monoxides and particle emissions from the combustion in Waelti & Keller (2009) as well as the metal content of the fuel (SGS-Institut-Fresenius 2008). This covers the factors with the highest impact on the result of the ecological scarcity method 2006. Because of the recent measurements and the emissions measured, the air emission data quality for coffee grounds is sound.

For the ash composition of the coffee grounds there was no information available, but there was detailed information on the composition of the fuel regarding metals and heavy metals in SGS-Institut-Fresenius (2008). In order to estimate the transfer of the heavy metals to the ash, the heavy metal balance of the combustion process was calculated, assuming that all heavy metals which are not emitted into air during the combustion are transferred to the ash. This calculation provides a reliable estimate for the heavy metal content in the ash.

7.7.3. Poultry litter

The data quality for poultry litter is considered as sound. The measurements took place in 2001 (Salerno et al. 2001) and as for coffee grounds the key emissions into, namely nitrogen oxides, sulphur oxides, particulate matter and carbon monoxide are measured. The other emissions are again taken from the data sets for wood combustion.

For the ash composition there is information on the potassium, phosphorus, magnesium, cadmium, copper, nickel and zinc content of the ash in Salerno et al. (2001). This selection covers the most important metals except of lead in case of the heavy metals.

7.7.4. Horse dung

The most important air emissions generated by the combustion of horse dung regarding environmental impact are measured in Bühler et al. (2005). This includes the emissions of nitrogen oxides, sulphur oxides and particulate matter. The basis of the data regarding air emissions is considered as sound.

For the ash composition there is information on the content of phosphorus, potassium, lead, zinc, copper and cadmium in Bühler et al (2007). This covers most of the elements with a high environmental impact

7.7.5. Pig slurry solids

For pig slurry there was only information available on the air emissions in Hersener & Bühler (1998). Again the most important air emissions are measured. For the ash composition there was no data available , but there was information on the composition of the fuel regarding metals and heavy metals in Hersener & Bühler (1998). In order to estimate the transfer of the heavy metals to the ash, the heavy metal balance of the combustion process was calculated, assuming that all heavy metals which are not emitted into air during the combustion are transferred to the ash.

Because the measurements for pig slurry took place in 1998 and because of the missing data regarding ash composition the data quality for pig slurry solids is considered as the lowest among these five biomass substrates. Further the fuel mixture for slurry solids mainly consists of wood (about 85%, cf. Tab. 14) and rather represents the co-combustion of a small fraction of slurry solids with wood.

8. References

Allica et al. 2001	Allica J. H., Mitre A. J., Bustamante J. A. G., Itoiz C., Blanco F., Alkorta I. and Garbisu C. (2001) Straw quality for its combustion in a straw-fired power plant. In: Biomass and Bioenergy(21), pp. 249-258.
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