

VII Climate Change

1 Introduction

Climate change has been considered a fact since a decade, after the proof of rising CO₂ levels, rising earth's temperatures, smelting of glaciers, etc. The consequences can be observed in daily life, by events such as strong floods of rivers, stronger storms and snowfall, cloudbursts, but also drought, and desertification. The reasons of the climate change - natural or anthropogenic? - have been under discussion for a longer term.

But there is no doubt, that mankind contributes to climate change by all activities which are connected with climate gas emissions: use of fossil resources as fuels with high emissions of carbon dioxide and other climate gases, especially in transportation and traffic; industrial production and application of substances, which are climate gases of extreme high warming potentials; agricultural activities such as animal farming and rice cultivation, with the deliberation of methane or nitrous oxides; methane emissions from landfills caused by ineffective waste management, etc.

To control the situation, reduction measures or climate gases and other relevant actions, are urgently necessary on all levels. This is understood by the public and by policy makers. Climate related activities thus are high ranking on the political agenda. They are implemented into the political programs on UN level, in state groups and states, but also on communal levels as in climate initiatives of cities, or NGOs. Examples are the programs launched in the last 10 years such as the so-called Kyoto protocol, to reduce climate gas emissions, and bans of persistent chemical components; the shift of energy sources from fossil to renewable; or the program of CO₂-emission trading. It is but obvious, that the efforts must be strengthened, to reduce the risks of a climate collapse.

The lecture is intended to give a more detailed insight into the problem and the efforts to tackle it, so that the reader is able to follow up best climate strategies in practical cases. In the first part, fundamentals of climate and climate change are discussed, including facts on the climate system and its modeling, as well as the climate effects on sustainable development, and international policy approaches. In the second part, evaluation of climate and related effects of technology are discussed, and an overview of climate effects of industrial and agricultural processes are given, including technological, infrastructural, economic, and socially oriented activities to reduce climate gas emissions.

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7.1 The technological evaluation problem

The reduction of negative climate effects of every human activity - in private life as well as in business - is urgently needed. There are a lot of measures possible as a result of technological, social, infrastructural, economic, etc. oriented systems analysis, which is a precondition for the improvement of the given situation.

But having such options defined, another problem arises. We have to choose one of the options and only one, for we need a definite solution. What option is to be selected? This is not a simple question, and the solution is a complex task.

Let us look for some types of situation: Some of the solutions proposed by the systems analysis efforts may be of such a character, that they direct into the right direction, especially if they have extra positive side effects other than climate relevant. Such an example is the reduction of individual traffic in a city by use of public traffic - if it is available. This would result in reduced emissions of carbon dioxide and other greenhouse as well as toxic gases from the combustion of fuel. Traffic burdens such as noise are reduced, lower risks of traffic accidents and health troubles are envisaged. Lower use of fossil fuels reduces its overall consumption.

This example is but not typical for the decision situation of reducing greenhouse gas burdens: In most cases, a certain measure will result in different effects, which include both positive and negative consequences.

Some examples of problems related with climate effect related measures are given in table 1.

Tab 1 Interdependences of climate related problem solutions

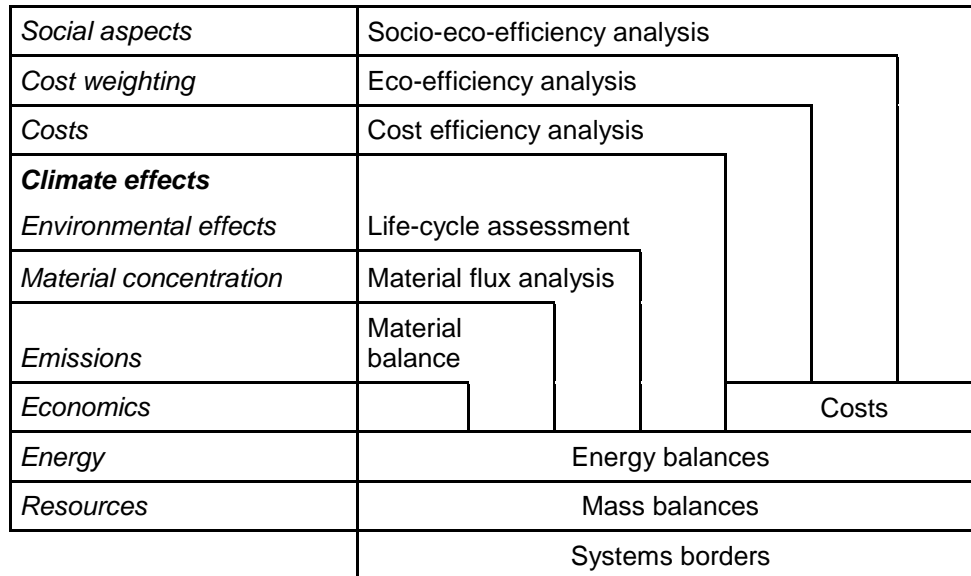
Problem	Possible effects
Is it environmental effective to reduce greenhouse gas emissions by use of end of pipe technologies?	<p>End of pipe technologies, as washers, biofilters, or gas incineration is able to reduce direct CO₂ emissions</p> <p>But this causes extra facilities, and may be accompanied by higher energy input for the process, which cause indirect climate effects as well as other environmental burdens. Sometimes, environmental effects are transferred from one media such as atmosphere to another (e.g. water)</p>
Are the reduction of emissions of Nitrous oxide (N ₂ O) from a chemical process more climate effective than emissions of CO ₂ ?	<p>Both substances are climate factors. Their effects are in a clear relationship: 310 tons CO₂ are equal to 1 ton of N₂O reduced. These effects can be clearly calculated.</p> <p>But the efforts to reduce both items are different and must be taken into consideration.</p>
How can financial resources be invested most efficient for climate improving measures?	Nearly every measure for improved climate efficiency costs money. The more a technical solution costs, the better normally the effect is. But the money spent for that may be also used for other kinds of improvements, which may result in a better total climate effect. Best solution is given, if the cost/efficiency relation is best.
Is the reduction of climate gas emissions more important than the reduction of emissions of cancer causing substances?	Climate gas reduction is influential on a global scale. Cancer causing substances are important factors in human health. Both cannot be compared directly. A decision on the effects on human beings on site is necessary.
Under which conditions is the substitution of fossil fuel by bio-fuels efficient with respect to climate?	<p>Fuels can be produced from fossil or from renewable feed-stocks. Renewable feed-stocks generally are to be preferred.</p> <p>But they are produced in agricultural processes, thus they are in competition with human food. Land need may foster deforestation. Production needs input of fertilizers and pesticides, which may negatively influence soil and air emissions. The production of fertilizers also depends on fossil fuel. Environmental effects of alcohol production are also to be considered.</p>
Should waste be deposited with or without pre-treatment?	<p>Waste pre-treatment may reduce the organic matter and separates recyclable materials. Thus, methane production in the landfill is minimized. Virgin matter as well as production efforts for production of materials can be reduced, thus reducing climate gas emissions. Long term effects of leachates and emissions are reduced.</p> <p>But low methane emissions from landfill also means that no possibility exists of collecting gas in a gas recovery system and using it as an alternative energy source instead of fossil fuels.</p>
Is it useful to use a washer and scrubber for waste gas cleaning instead of incineration?	<p>A scrubber normally is a more simple technology than an incinerator.</p> <p>But it may transfer the waste substance from one media (gas) to another (water). The effects have to be compared.</p>

Obviously, a clear decision for a certain option under discussion is only possible, if decision criteria are available, which focus on climate effects, but at the same time consider also other environmental as well as economic and social aspects.

This problem is not new, and it is not only true for problems of climate respect. Therefore a variety of evaluation procedures (or assessment tools) was established, which can be used for such decision tasks. They normally focus on special items or groups of it. A general decision procedure which fully covers

simultaneously all aspects of sustainability does not yet exist. Climate effects play an important role in most of the procedures. A graphic representation of some assessment tools is given in figure 1.

Abb. 1 Hierarchy of assessment tools (16)



Obviously, all methods are based on balances of matter and energy in certain systems boundaries which are to be defined during the evaluation process (see later). Economic evaluation is clearly based on costs only. Environmental effects solely are considered in the life cycle assessment. Combinations of economic as well as ecologic facts may be estimated after methods such as eco-efficiency (26) or cost-efficiency analysis. The triple of economy, environment, and social aspects is studied and evaluated by the socio-eco-efficiency analysis (27). This method as well as others of this kind are relatively close to the needs of a sustainability oriented evaluation criteria, but focus on selected aspects of the item under consideration.

A more detailed description of assessment tools is given in table 2.

Tab 2 Selected environmental assessment tools (6)

Assessment tool	Purpose of application	Example
Environmental audit	Actual ecological performance is analysed, targets are set for future environmental performance on company level	Auditing of a production plant, including situation report and targets definition
Environmental Impact assessment (EIA)	Analysis of the environmental impact potentials on a location of a planned facility or other activities	Choosing a production site for a chemical plant or a landfill site
Life-Cycle Assessment (LCA)	Comparison of the environmental effects of the whole life cycle of products, processes, services, or other activities with the same function, identification of improvement and optimisation potentials	Comparison of beverage bottles systems Identification of key process steps in climate control Comparison of effects of different substances on climate potential Weighting climate and health impacts
Risk Assessment	Estimation impacts of an event and its probability	Assessment of the risks of landfill gas emissions after destroying of a landfill cover
Substance and material flow management (38, 39)	Balancing of the material flows in an observation unit (e.g. company, regional, national level) Identification of problem flows and causes of environmental problem in a region Control of flows after given criteria	Analysis of wood balance in a region to find the best use of this renewable resource
Sustainable Process Index Assessment (37)	Definition of the impacts of a certain process in terms of the area needed per process unit	Comparison of ethanol production on base of renewable or fossil feed-stocks
Eco-efficiency assessment	Combined assessment of the impacts of a process, technology, or service on ecological (LCA) as well as economic criteria	Definition of the best waste management technology for a unit of waste, including deposition, pre-treatment, and waste combustion for a region

The most important method actually used for the estimation of climate effects of processes and services is Life Cycle Assessment (LCA). It is therefore explained in more detail in the following chapter.

7.2 Life Cycle Assessment for climate control - overview

7.2.1 Background issues

Life-Cycle Assessment (LCA) is applied for research in environmental aspects and potential impacts throughout a product's life, including raw material acquisition, production, use of the item, and disposal. This life cycle assessment thus is often termed as "from cradle to grave".

It serves

- to compare environmental effects of different products
- to identify environmental key issues, as climate effects
- to improve and to optimize products and the production thereof.

The term “product” refers not only to a product from a process, but includes also material products and services.

The definition as well as the whole procedure are standardised by ISO 14040 norm group (16). This norm provides a framework and defines the key methodological needs, to make LCA’s comparable with each other, independent on the institutions, or country, where the LCA analysis was performed.

There are several activities world wide to improve the methodology and support its application:

- On United Nations Environmental programme (UNEP) level, a Life Cycle Initiative was established as a response to the call from governments for a life cycle economy in the Malmö Declaration (in 2000). It contributes to the 10-year framework of programmes to promote sustainability consumption and production patterns, as requested at the World Summit on Sustainable Development (WSSD) in Johannesburg (in 2002). This initiative develops and disseminates practical tools for evaluating the opportunities, risks, and trade-offs, associated with products and services over their whole life cycle (19).
- EU commission launched a simplified method which condenses the basic methodology of ISO 14040 into an EXCEL calculation spreadsheet, which already contains basic dates for environmental impacts. The aim is to enhance the application of LCA activities also in small enterprises for the environmental and climate related improvement of their products, or services (17, 18).
- The Society of Environmental Toxicology and Chemistry (SETAC) provides an international infrastructure to support Life-Cycle Assessment groups in advancing the science, practice, and application of LCA and related approaches worldwide. The organization serves as a focal point of a broad-based forum for the identification, resolution, and communication of issues regarding LCAs, and facilitates, coordinates, and provides guidance for the development and implementation of LCAs in close cooperation with each other. Core tasks include planning and organizing LCA sessions and conferences (such as the Annual Meetings in Europe and North America and the LCA Case Studies Symposium), coordination of topical working groups, preparation and global integration of LCA publications, and promotion of the UNEP/SETAC Life-Cycle Initiative (25).
- Several countries, such as Denmark and the Netherlands also have more detailed guidelines prepared for internal use on that base, including databases for LCA activities. In Germany, several calculation programmes are available for a free of charge in LCA procedures (e.g. 40)

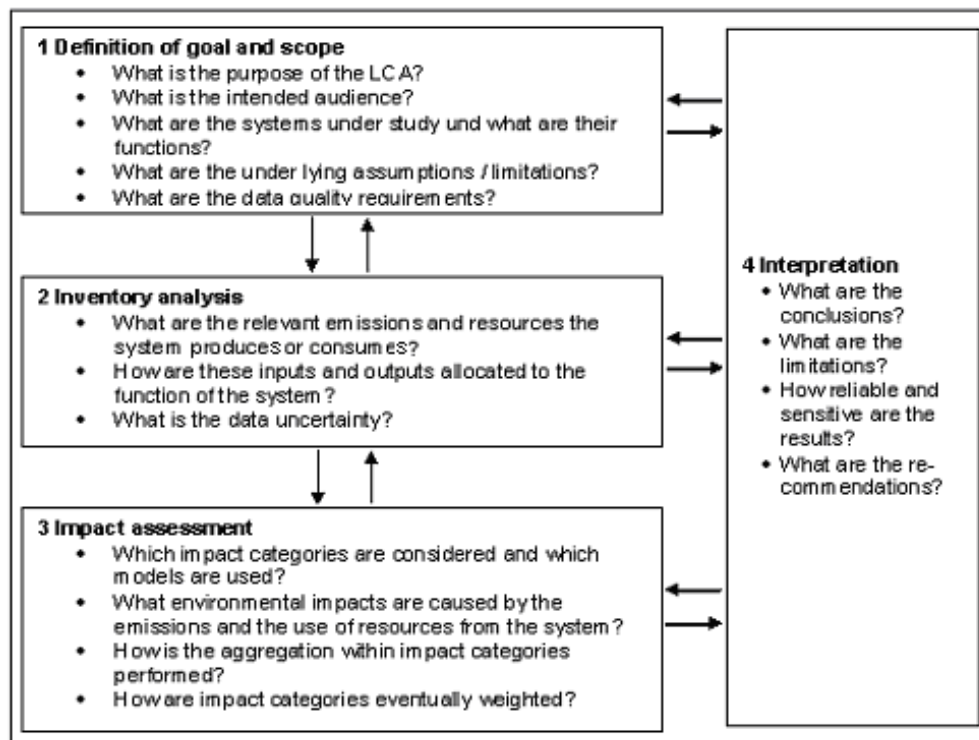
7.2.2 LCA Methodology

LCA after the general ISO framework consists of four phases, which are of iterative character (16):

- In the *Goal and Scope Definition* the purpose of the study and the boundary conditions are defined.
- In the *Life-Cycle Inventory* phase (also called LCI) emission and resource data of the process under study are gathered.
- In the *Life-Cycle Impact assessment* phase (also called LCIA) potential environmental impacts of the emissions as well as resource consumption facts gathered in the LCI phase are analysed and quantified.
- In the *Interpretation* phase, the results are interpreted by a group consisting of LCA team, client, as well as of independent people interested in the topic, and conclusions are drawn.

A more detailed description of the items to be worked out in the four phases and the questions to be answered is given in figure 2.

Abb. 2 Schematic representation of the LCA framework (16)



7.2.2.1 Step 1: Definition of goal and scope

In this first LCA phase, the purpose and the boundary conditions of the study are defined (see tab.3). Amongst the issues to be described, the definition of the “functional unit” which captures the functions of the study is most important, since it provides the reference to which input and output are normalized. Some example of functional units for climate related studies are given in table 3.

Tab 3 **Examples of functional units for climate related studies**

Example	Typical functional unit
Comparison of transportation systems	Transport of one ton of raw material over a distance of one kilometre
Comparison of product containers for chemical substances	One container carrying one ton of material (i.e. not the ton of material of the container itself is used as a functional unit, since the materials are different in weight, which is irrelevant for the transportation task)
Comparison of waste treatment practices	Treatment of a certain amount of waste, e.g. one ton of municipal solid waste

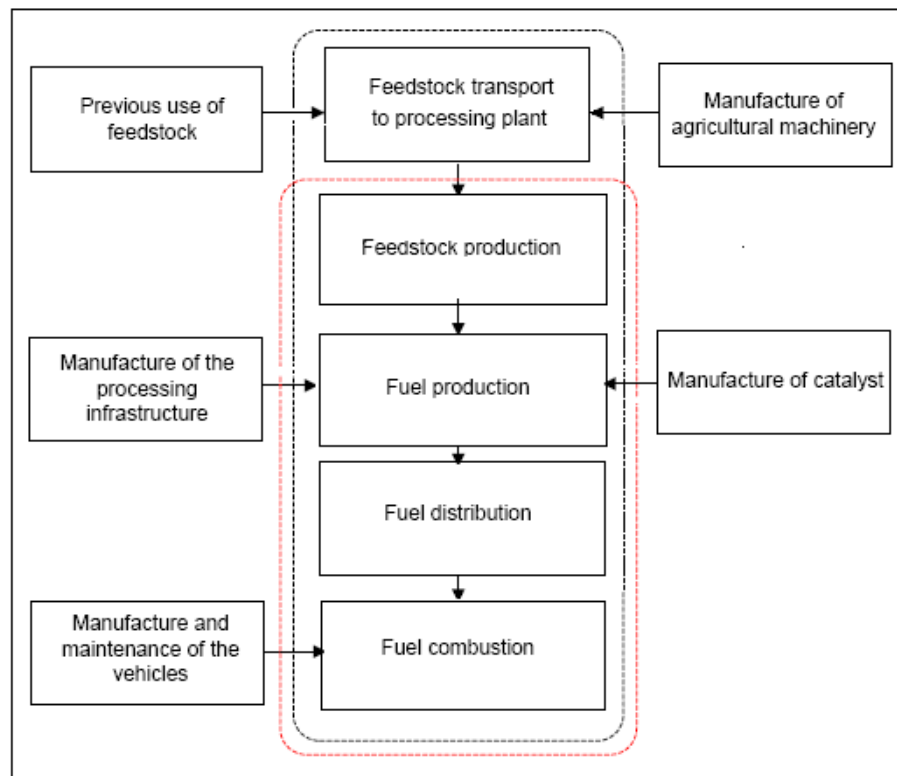
In principal, all processes from cradle to grave have to be included into such a study. But in practise, all such processes can be eliminated from the scope of study, which are identical and do not influence the result.

Following example of boundary for life cycle assessment demonstrates a possible approach for bio-fuels - see table 4 and figure 3. All technological measures dealing with manufacturing of machinery and infrastructure are excluded, since these items are the same for all processes. But there is a choice whether or not to include the production of the feedstock of the bio-fuel process, like agricultural inputs or raw material for processing. This is a question of the aim of the analysis.

Tab 4 **Items to be considered in the boundary of the bio-fuel production process (43)**

To be included	To be excluded
Origination of the raw material, as production, mining, or extraction Manufacture or processing of the raw materials into finished product Manufacture of material inputs consumed in origination, manufacturing, or processing Transportation of raw materials and finished products to points of use or sale Product use, including combustion, if applicable Disposal of waste products from manufacture and use	Manufacture of machines and physical infrastructure used in product or raw material origination, manufacturing, distribution, use, and disposal Manufacture of machines used to manufacture materials consumed in the origination, manufacturing, distribution, use, and disposal processes Operation of ancillary offices and activities such as business travel, not directly associated with the origination, manufacturing, distribution, use, and disposal of the product

Abb. 3 Boundary for LCA of bio-fuel production (43)



7.2.2.2 Step 2: Life-cycle inventory analysis (LCI)

The inventory analysis involves data gathering and calculation procedures to quantify inputs and outputs, i.e. resources and emissions. This is based on setting up flowcharts of the system under study, which contain all details of the processes and the interconnections of process steps. A definition may be necessary at this stage of the work, which mass and energy fluxes are important and which eventually can be eliminated to reduce the complexity of the LCA. Indeed, a pre-condition for such a definition is knowledge about the process effects. These may be a result of previous steps in a trial and error procedure, which is typical for LCA measures.

Data gathering can be a time-consuming task. Potential data sources may be primary data from process studies, or from literature, or expert judgement. Also public databases, such as GEMIS database (40), which offer inventory data for a large number of processes, can be used, if - as is often the case - primary data cannot be extracted.

The data have to be normalised to the functional unit.

7.2.2.3 Step 3: Life Cycle impact assessment (LCIA)

This step of the Life Cycle Assessment aims to evaluate the magnitude and the significance of the potential environmental impacts of the system under study. It involves three mandatory elements: Most important is the selection of i) impact categories, ii) indicators for these categories, and iii) models to quantify the contribution of resources and emissions to it. This also may comprise a ranking of the indicators. In the classification step,

the inventory data have to be assigned to the impact categories. Afterwards, in the characterization procedure, the contribution of the inventory data has to be quantified to the chosen impacts.

In life cycle assessment practice, following impact categories with specific indicators were established (see table 5). Table 5 also indicates some examples of substances, which primarily influence these impact categories.

Besides impact categories after table 5, which are used in the LCA after ISO 14040, also other criteria are used for environmental analysis, e.g. energy and material needs per unit of product, etc., which may also have an indirect effect on climate (see chapter 9 to 12 for examples of industrial and other processes).

Tab 5 LCA impacts categories and indicators

Impact category	Indicator	Description and climate relevance	
Global warming potential, GWP	CO ₂	Contribution to global warming by its heat absorption capacity. Value depends on the time horizon considered. Typically, 100 years time horizon is used. High climate relevance.	CO ₂ , CH ₄ , N ₂ O, SF ₆ , HFCs, PFCs
Ozone depletion potential, ODP	HCFC 11	Contribution to the depletion of the stratospheric ozone layer by persistent chlorine and bromine hydrocarbons. Global effects on biosphere by UV radiation, effects on human health. Climate neutral.	HCFCs
Photochemical ozone formation potential, PCOP (Summer smog potential)	Ethylene	Contribution to the formation of oxidizing substances, e.g. ozone, mostly by reactions between NO _x and NMVOCs under the influence of UV-radiation in the troposphere. Effects of human health and ecosystem (e.g. damage of forests). No direct climate effects.	NMVOCs, CH ₄
Acidification potential, AP	SO ₂	Contribution to the acidification of an environment. Regional effects. No climate relevance.	SO ₂ , NO _x , NH ₄ , HF, HCl
Nutrition potential, NP	PO ₄ ³⁻	Contribution to the production of biomass. Regional effects. No climate relevance.	NO _x , NH ₃ , NH ₄ ⁻
Cancer potential (short term and long term)	Unit risk values	Contribution to cancer disease risks of certain substances after a deposition with the same substances. Short and long term effects. No environmental effect, no climate effect.	Cd, Hg, Cr IV

To define how much a process contributes to the impact categories, the effects of all material and energy fluxes of the relevant process steps and their individual impact have to be considered. The total of the impact category is given as the sum of the effects of all substances “k” in all process steps.

In the case of the Global Warming Potential of a process, this is given in the following equation:

Formel (1)
$$GWP_{total} = \sum (\beta_k * GWP_{100; k})$$

GWP_{total} : total global warming potential

$GWP_{100, k}$: individual GWP of the substance k in the time horizon of 100 years

β_k : mass of emission of substance k

An example for the calculation of the greenhouse gas potentials for two variants of a simple fictitious process is given in table 6 using individual Global Warming Potentials GWP_k of the substances k (for GWP_k see table 8 in chapter 9).

Tab 6 Greenhouse potential of two processes (fictitious numbers)

Substance k	GWP _k	Emission β_k (g/t)		GWP _k * β_k (gCO ₂ -eq./t)	
		Variant 1	Variant 2	Variant 1	Variant 2
N ₂ O	310	12	10	3720	3100
Methane	21	15	12	315	252
Chlormethane	9	0,8	1	7,2	9
Tetrachlormethane	1400	0,045	0,060	63	84
CO ₂	1	100	200	100	200
Sum				4205,2	3645

The process is characterised by emissions of five substances (see columns 3 and 4 for the two variants of the process considered) with different individual GWPs (see column 2). The resulting value for each substance is given in columns 5 and 6 for the variants 1 and 2, respectively. The total GWPs result if the values in columns 5 and 6 are summed up. In the case given, variant 2 has a lower GWP compared to variant 1. Thus, this variant 2 would be chosen, if the decision is made only on the base of GWP.

It should be mentioned, that this result is not a simple one: If only emissions were considered, there would have been also preferences for variant 1, since there are lower emission fluxes for chlormethane, tetrachlormethane, and CO₂. Only the combined approach comes down with the real information

7.2.2.4 Step 4: Interpretation

To reach conclusions and recommendations consistent with goal and scope of the LCA, an interpretation phase is necessary, where the results of the inventory analysis and the impact assessment are combined. This phase comprises i) the identification of the significant issues, ii) the evaluation of completeness of data, sensitivity, and consistency, as well as iii) conclusions and recommendations.

7.2.3 LCA case study: Integrated waste management systems

Examples for LCAs are given in the next chapters for certain defined industrial, agricultural, energetic, etc. processes. They focus on the climate effects of the process, mainly on the greenhouse gas potential, given as “mass unit CO₂ equivalents per mass unit of product”, as was given in chapter 8.2.2.3. As was explained, the LCA methodology comprises also other environmental burdens, which have to be kept in mind for a comprehensive decision. Therefore, the following example is given to elucidate the methodology of a full LCA (all data after 49).

The example refers to waste management technologies, which are described in detail in chapter 10.

7.2.3.1 Definition of goal and scope

The goal of the study is to find out the best solution for the treatment of municipal solid waste of a region with respect to the impact categories. This implies

- Comparison of the impacts of different waste management options
- Identification of key factors and critical paths
- Assessment of the importance of political, economical and technical background conditions
- Assessment of the ecological benefits through material flow specific waste management
- Identification of most effective improvement strategies and measures
- Systematic analysis of uncertainties
- Determination of best values in (technical) compromise situations

The systems boundaries include the pre-treatment plants and the landfill. Waste collection is not considered. Credits are given for recovered materials and energy resources. The consumption of materials and energy for the operation of the pre-treatment plants and the landfills are taken into account.

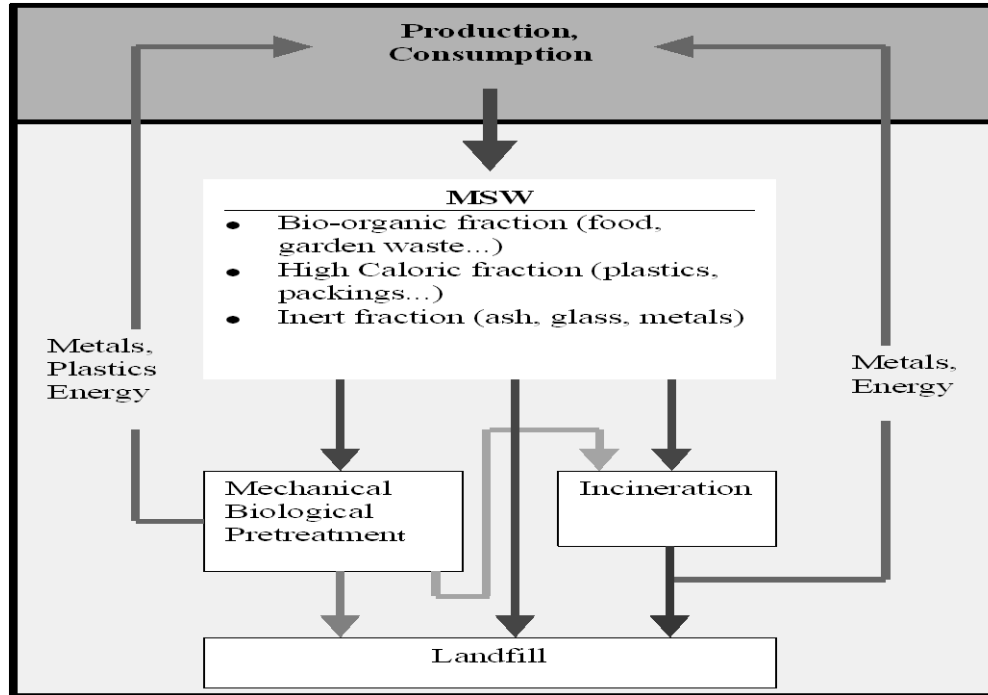
Since the technologies can be set up anywhere in the world, the analysis in principle is independent from a certain country. But for a concrete solution, German conditions are used.

Reference point of the calculation is the specific contribution to the total effects of waste management in Germany, i.e. to which percentage the waste management system would contribute to the total national impacts of every category if the total amount of residual waste was treated by the considered system.

7.2.3.2 Technology description and functional unit

For waste treatment, several technologies can be applied. Under EU conditions, a so-called pre-treatment is necessary. In principle, all technologies after figure 4 can be applied.

Abb. 4 Waste management pre-treatment technology options



In the study, following special waste management processes after table 7 are included.

Tab 7 Technologies included in the LCA

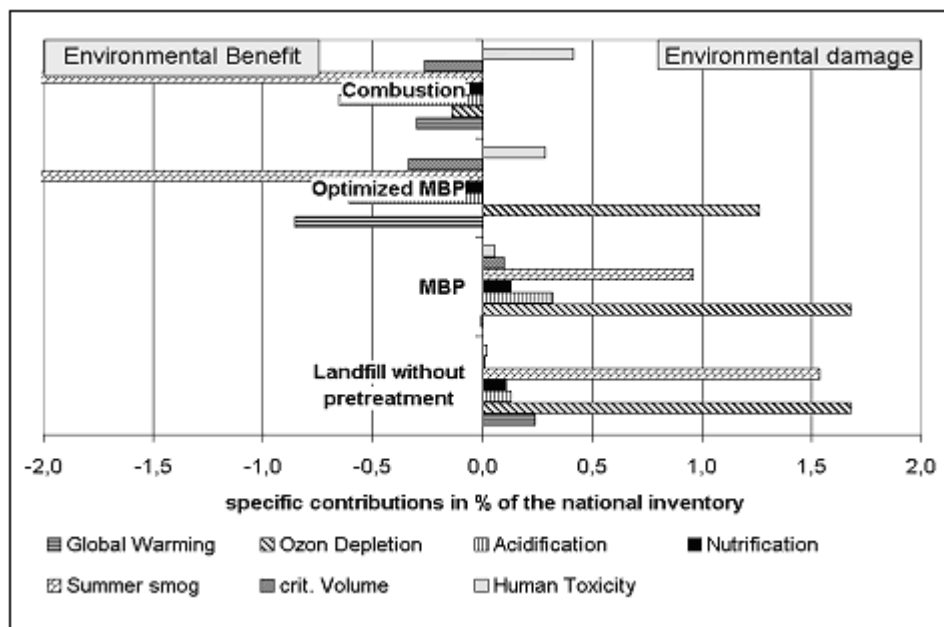
Technology	Assumptions and specialities
Landfill without pre-treatment	No decomposition of organic matter before the landfill. Capping of landfill emission and energy production from landfill gas recovery.
Mechanical biological pre-treatment	High decomposition of organic matter by intensive rotting (8 weeks with forced aeration) and subsequent extensive rotting, Recovery of the metal fraction. Collecting and cleaning of waste gas of the pre-treatment by a bio-filter system.
Optimised mechanical biological pre-treatment	Like b), additionally biogas production by anaerobic digestion of a part of the organic fraction. Energetic use of a RDF-fraction in a cement kiln. Material recovery of Fe-, non-ferrous metals and of plastics. No waste gas incineration.
Combustion	Conventional combustion plant with grate firing.

The principal function of all technologies is the treatment of waste. Therefore, as the functional unit, the treatment of 1 ton of waste material is defined.

7.2.3.3 Impact assessment results

Impact assessment is performed using the impact categories after table 5. Figure 5 represents the results of the assessment.

Abb. 5 National relevance and specific contributions



7.2.3.4 Interpretation and conclusions

Figure 5 indicates in terms of the impact categories the environmental benefits and disadvantages of the waste management options. If a decision is to be made only on the base of one category, that in case of summer smog potential as well as for climate impacts, a clear decision would be possible: combustion and optimized MBP are preferable options. For climate impacts alone, the optimized MBP would be the best solution.

But it is also to be seen, that no one of the waste treatment options is best in every criteria considered. Direct deposition results only in environmental burdens in every impact categories considered. The other options also result in environmental benefits in the total results. The specific contributions mostly do not exceed the one percent level.

The Global warming potential (GWP) is mainly caused by CO₂ and CH₄. The burdens result from the energy consumption and the landfill emissions. However, these burdens can be equalised by credits through recovery of waste fractions for recycling or power production, so that the optimised MBP and the combustion end up with an climate benefit.

The ozone depletion (ODP) and the summer smog potentials (POCP) of the landfill and the MBP are caused mainly by CFC (CFC-11, CFC-12) and by highly volatile chlorinated hydrocarbons, which are emitted during pre-treatment and in the landfill. The specific contributions of the burdens exceed one percent. During combustion, these substances are almost completely destroyed, so that no burdens result from them. On the other hand, in the combustion facility, energy is recovered, which results in benefits. For the optimised MBP-Option the benefits from material and energetic recovery prevail.

The acidification potential (AP) is caused by SO₂, NO_x, and ammonia emissions, the nitrification potential (NP) by ammonia and NO_x emissions. Both burdens are comparatively low and are balanced through credits for material and energetic recovery.

The Human Toxicity Potential is predominated by the air emissions of heavy metals such as chrome, cadmium, and nickel. These metals are mobilised to higher a degree when the waste or waste fraction is combusted, this option as well as the optimised MBP option (which includes the recovery of a RDF-fraction) end up with higher burdens. In the landfill a certain percentage of the metals can be considered to be stored over a very long period (several thousand years), depending on the buffer capacity and humification within in the landfill. Therefore the landfill option has the lowest Human Toxicity Potential.

More examples of greenhouse gas effect evaluations for processes of various kinds are given in he following chapters.

8 Climate effects of industrial processes

8.1 Background

Every industrial process results not only in the products wanted, but also in by-products, wastes and emissions. Amongst the emissions, normally also greenhouse gases occur. Hence, every industrial process is climate relevant, for greenhouse gases are emitted as a result of the technological processes taking place.

Which substance is emitted and in which amount it is emitted depends on the specific process and the conditions of its application. Thus, the choice of the technology, the apparatus, the cleaning devise, etc. may influence the climate effects of the production process. An optimisation of the process with reference to a decision criteria reflecting the climate effects is thus a necessary precondition for the choice of the best technologies (see chapter 8.1).

Some examples of industrial processes are given in the next chapter. The data used for description of the processes are either derived from assumptions of chemical reactions or upon published empirical data (1).

The emissions considered here are by-products of the industrial process itself. Typically, in such processes, raw materials are transformed from one state to another in the end product. This transformation is accompanied by the release of emissions, such as carbon dioxide (CO₂), methane (CH₄), or nitrous oxide (N₂O). They are the reason of the greenhouse effect of the process.

It is to be stressed that these emissions are not directly a result of the energy consumption of the process, as for heating or cooling for best process conditions, or electrical energy for melting processes (as in the case of aluminum production), or stirrer power for stirring of the process fluids (as in the case of liquid-liquid reactions or solvents), etc. The energy related emissions are considered independent of the process.

Typical emissions in industrial processes and their Global Warming Potential (GWP, 100 years period) as well as their atmospheric life time are given in table 8. The table also indicates, that there are changes in the numbers due to improved knowledge base, but obviously, the chances are not thus dramatic. Partly they are because of the changes in the global warming potential of the reference substance CO₂, which is set lower than in previous studies.

Tab 8 GWP and atmospheric lifetime of important industrial emissions (27)

Substance	Global warming potential (CO ₂ -equivalents)	Atmospheric life time (years)
CO ₂	1	50-200
CH ₄	23	12 ± 3
HFC-152a	120	1,5
N ₂ O	296	120
HFC-32	550	5,6
HFC-134a	1300	14,6
HFC-4310mee	1500	17,1
HFC-125	3400	32,6
HFC-227ea	3500	36,5
HFC-143a	4300	48,3
HFC-236fa	9400	209
CF ₄	5700	50000
C ₄ F ₁₀	8600	2600
C ₆ F ₁₄	9000	3200
C ₂ F ₆	11900	10000
HFC-23	12000	264
SF ₆	22200	3200

Amongst the emissions, CO₂, CH₄, and N₂O, are most important, due to their total mass. But also the other gases influence the overall climate effects of industrial processes, especially the anthropogenic (man-made) chlorinated and fluorinated carbons, as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and the sulphur hexafluoride (SF₆). HFCs, PFCs and SF₆ are used as substitutes for a group of so called ozone depleting substances (ODSs), which are being phased-out under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. Moreover, they are employed and emitted by important industrial processes, as aluminum and HCFC-22 production, semiconductor manufacture, and magnesium metal production and processing. In addition, they are generated at electric power transmission and distribution.

Many of these substances are characterised by very high global warming potentials. E.g., SF₆ is one of the most potent greenhouse gases with a GWP of 23.900 (see Table 1). Nevertheless, at present, their contribution to the overall global greenhouse gas effect is small due to the relative small amount employed, but in relation to the effect in industrial processes of classical greenhouse gases as CO₂, CH₄, and SF₆ they contribute to more than 40percent already: In U.S. industry, in 2004, 152,6 Teragrams (Tg) CO₂ equivalents were emitted as CO₂ itself, 2,7 Mio ton caused by Methane, and 22,4 Mio ton caused by N₂O, compared to 143 Mio ton emitted as HFCs, PFCs and SF₆ (4, 7).

Their usage is growing very rapidly to substitute the ODSs. Moreover, they have an extremely long lifetime under atmospheric conditions, e.g. CF₄ has a lifetime of 50.000 years, compared with methane, which has only 12±3years (see table 8). Thus, many of the HFCs, PFCs and SF₆ will accumulate in the atmosphere as long as

such substances are emitted. Accumulation may cause extremely negative climate effects of these substances in future times.

In addition to the greenhouse gases, which directly influence climate factors, many industrial processes generate so called indirect greenhouse gases. Such indirect effects of gases occur, when chemical transformations involving the chemical substance produce greenhouse gases. Another indirect effect occurs, when the gas considered influences other climate important processes such as atmospheric lifetime of greenhouse gases. Most important indirect greenhouse gases are NO_x, carbon monoxide (CO) and non methane volatile organic carbon compounds (NMVOCs). They are produced in chemical and allied product manufacturing, metals processing, during storage and transport, as well as health services, cooling tower operation, fugitive dusts, various uncompleted combustion processes, and accidental or catastrophic releases.

To get a clearer impression of the importance of industrial processes in the climate change, the emission date given should be compared with the total greenhouse gas emissions in an economy: In the case of the United States, industrial processes in 2004 generated emissions of 320,7 Mio ton of CO₂ equivalents. This is equal to only 5 percent of total U.S. greenhouse gas emissions, measured as CO₂ equivalents. Calculated in real figures of the substances themselves, CO₂ contributed to about 3 percent of the national CO₂ emissions, methane to less than 1 percent of the national methane emissions, N₂O to about 6 percent of the national N₂O emissions.

In the last 15 years the industrial emissions increased by 6,5 percent, though emissions from several industrial processes decreased, e.g. for the iron and steel, as well as from aluminum production. In the iron and steel branch, there was a reduction from 85 to 51,3 Mio ton CO₂ Eq. between 1990 and 2004. The total increase was driven partly by an increase in the emissions originating from cement manufacture, but mostly by the emissions from the use of substitutes for the ozone depleting substances ODSs.

By the emissions discussed, industry actively influences the climate change. On the other side, industry itself is influenced passively by climate effects. One main factor could be the situation of infrastructure, which may be influenced or even destroyed by weather events, as snow, floods, or low water levels in rivers, which make river transportation untenable, or low water supplies that make process cooling and environmental activities more difficult.

Moreover, industrial activities would be affected through the impact of government policies pertaining to climate change, such as carbon taxes, which increase the material and energy costs. They could also be affected through a changed consumer behavior. An example is clothing, the choice of which depends on the temperature, and more warm-weather clothing might be ordered under cold climates, and visa versa. Climatic impacts on natural resources may influence manufacture that depends on such resources, as food processing which depends on the agricultural yields, which strongly depend on climate factors (IPCC, 2006). This aspect of climate influence on industrial processes is not yet clarified fully.

The actual situation of climate gas emissions by the most important six substances (*Kyoto gases*) as well as their contribution to the economic sectors of the European Union and USA is given in table 9. The value totals to about 4,13 and 7,07 Million t CO₂ Equivalents, respectively (7, 28)

Tab 9 Emission of Greenhouse gases in industrial and related sectors (EU and USA)

Contribution of Kyoto gases	Percent of total GHG emissions	
	EU (in 2002) (28)	USA (in 2004) (7)
CO ₂	82,0	84,6
CH ₄	8,5	7,9
N ₂ O	7,9	5,5
HFCs	1,2	2,0
PFCs	0,1	
SF ₆	0,2	
Contribution of economic sectors		
Energy	84,5	
Industrial production	6,2	
Solvents	0,2	
Agriculture and Forestry	6,5	
Waste	2,5	

The total emissions of industrial processes in the US American industry are given in table 10 for the main greenhouse gases. They sum up to about 320 million tons of CO₂ equivalents annually.

Tab 10 Total emissions from selected industrial processes in U.S. industry, 2004, (Mio ton CO₂ Equivalents) (7)

Process	CO ₂	CH ₄	N ₂ O	HFCs, PFCs, SF ₆	All
Sum	152,6	2,7	22,6	143,0	320,9
Substitution of Ozone Depleting Substances				103,3	103,3
Iron and Steel production	51,3	1,0			52,4
Cement manufacture	45,6				45,6
Ammonia manufacture and Urea application	16,9				16,9
Nitric Acid Production			16,6		16,6
HCFC-22 Production				15,6	15,6
Electrical Transmission and Distribution				13,8	13,8
Lime Manufacture	13,7				13,7
Aluminum Production	4,3			2,8	7,1
Limestone and Dolomite Use	6,7				6,7
Adipic Acid Production			5,7		5,7
Semiconductor Manufacture				4,7	4,7
Petrochemical Production	2,9	1,6			4,5
Soda Ash Manufacture and Consumption	4,2				4,2
Magnesium production and Processing				2,7	2,7
Titanium Dioxide Production	2,3				2,3

8.2 Climate contributions of industrial processes (7)

8.2.1 Production of Iron and Steel

Worldwide steel production is about 757 million tons (1995) (1), markets are very fast growing, especially in the developing countries, as China and India. In China the annual production was about 150 million of tons in 2005, with an increase of 10 percent per year. In Germany 6,3 million tons of steel were consumed in 2002.

Iron and steel production is of climatic relevance by two reasons: first it is an energy intensive process, and thus uses large amounts of fossil energy sources, which result in CO₂ emissions. In additions to that during the different process steps, non energetic production related emissions of direct climate gases such as CO₂ and CH₄, but also other pollutants with direct greenhouse gas effects (see table 11).

Tab 11 Emission of selected pollutants in sinter production (4)

Pollutant	Amount (g/t liquid steel)
PAH	200
VOC	90
CO	14900
NO _x	1000
SO ₂	930

Iron is produced by reducing iron oxide from iron ore using metallurgical coke in a blast furnace. Iron is introduced in the form of raw iron ore, pellets, briquettes, or sinter material. The result of this first production step is an impure pig iron. It is the raw material for steel production by specialised steel making furnaces, and for the production of iron products in foundries. During pig iron production CO₂ and CH₄ are emitted.

Metallurgical coke, which is needed as a reducing agent, is produced by heating coking coal in a coke oven in a low oxygen environment. This process is considered to be a non-energetic process. The emissions from it are considered in the greenhouse balance. During the process, the volatile compounds of the coking coal are driven off as a coke oven gas. When applied in the blast furnace, the metallurgical coke is oxidized. The result is reduced iron and CO₂.

When volatile compounds resulting from metallurgical coke production condensate, tar products are generated. Coal tar is the raw material for the production of anodes for electrolytic processes, such as primary aluminum production, and for several other coal tar products. During the processes, CO₂ and CH₄ are emitted.

The majority of the CO₂ emissions in the iron and steel production comes from the production of pig iron (using metallurgical coke). Smaller amounts originate from the removal of carbon during the steel production. Carbon is also stored in the products, i.e. iron (about 4 percent carbon) and steel (about 0,4 percent carbon). The emissions totalled to about 52,4 Mio ton CO₂-equivalents, where 51,3 stem from CO₂, and 1 Mio ton from CH₄.

Methane, which is produced during the processes for coal coke, sinter, and pig iron, is mostly emitted via leaks in the production, only partly through the emission stacks of the plants. Thus, a treatment of methane, which has a much higher greenhouse potential as carbon dioxide, is difficult. The emission factors are 0,5 g CH₄/kg produced coal coke, 0,9 for pig iron, and 0,5 for sinter.

8.2.2 Cement and lime manufacture

8.2.2.1 Cement manufacture

Cement is a finely ground grey powder of inorganic non-metallic nature. After mixing with water it forms a paste, which sets and hardens due to the formation of silicate hydrates from cement constituents. Cement is a critical element of the construction industry. World wide cement production amounts to nearly 1,8 billion tons annual (2). It is produced in nearly 40 states all over the world. The production rises heavily in dependence of the global economic situation.

The manufacture is energy and raw material intensive and results in greenhouse gas emissions. An amount of 60 to 130 kg fuel oil is used as well as 110 kWh electrical power pr ton of cement. As in the case of steel

production, climate relevant emissions originate from direct energy consumed in making cement, as well as from the chemical processes during the reaction. Greenhouse gas emissions are 50 percent due to the chemical process, 40 percent for burning fuels. The remainder splits into transport and electricity needs.

By these specific numbers cement industry massively contributes to the global CO₂ balances with an amount of 5 percent of the total CO₂ emissions. In the USA, cement is one of the largest sources of industrial CO₂ emissions (see table 2). There with a cement production of 88 million tons of clinker and 5,3 million tons of masonry, a total of 45,6 million tons of CO₂ equivalents is emitted.

The reduction of CO₂ emissions is a first priority in the cement industry, which in a cement sustainability initiative prepared a standard after which the balancing of the cement process is ruled and measures are defined (3).

To produce cement, in the first process the raw material limestone (calcium carbonate) is heated at a temperature of about 1300°C in a cement kiln. This “calcinating” results in lime (calcium oxide) and CO₂. The amount of CO₂ released is directly proportional to the lime content. In the next step as an intermediate product the so called clinker is produced through the combination of lime with silica-containing material. An average of 0,525 tons CO₂ is emitted per ton of clinker produced. The clinker is cooled and then mixed with small amounts of gypsum, which results in Portland cement. Masonry cement for construction needs is produced by addition of more lime. This results in additional CO₂ emissions.

Typical methane emissions are in the range of 0,01 percent of CO₂ emissions in CO₂ equivalents.

Measures to reduce the climate gas emissions are realised by substitution of traditional fossil fuels by industrial wastes, as used plastics insulation, shredded plastics and paper fractions, and municipal solid waste as well as refused derived fuels (RDF; see chapter...). In German cement industry, about 2,8 million tons of secondary fuels are applied. In the case of RDF the application benefits from a reduced CO₂ emission per energy unit due to the organic carbon content of about 60 percent.

8.2.2.2 Lime manufacture

Lime is not only used in the cement production, but is also a manufactured product, which has many industrial, chemical and environmental applications, mainly in steel making, as a purifier in metallurgical furnaces, in cleaning (desulfurisation) of flue gas (FGD) at coal-fired electric power plants, in construction, and in water purification or as raw material in glass manufacturing and magnesium production (dolomite). Lime production in U.S. amounts to about 20 Mio tons (without cement production); it ranks high under the most important chemicals (historically fifth in total production of all chemicals in the US).

The term lime refers to a broad variety of chemical substances, including high-calcium quicklime (calcium oxide, CaO), hydrated lime (calcium hydroxide, Ca(OH)₂), dolomite quicklime (CaO*MgO) and dolomite hydrate (e.g. Ca(OH)₂*Mg(OH)₂).

The main technological step - in analogy to the cement production - is the calcination, where the CaO is produced. CO₂ is liberated, which is normally emitted to the atmosphere. The total of greenhouse gas emissions equals to 13,7 Mio ton CO₂ equivalents in the US industry.

In some facilities carbon dioxide is recovered for use in sugar refining and for the production of precipitated calcium carbonate (PCC), which is applied as a speciality filler in premium-quality coated and uncoated papers. In 2004, in the US, 1,125 Gg CO₂ were recovered, which means about 7 percent of the total CO₂-production in the lime industry (and 90 percent of the CO₂ involved in sugar refining and PCC production). Recovering activities in future will be applied in a wider range to reduce greenhouse effects on a reduced level of raw material needs, which would be a contribution to a sustainable production.

8.2.3 Ammonia manufacture and Urea application

Ammonia and Urea are nitrogen fertilizers for application in agriculture to improve agricultural yields. The annual world production is about ... million tons.

Temporarily, feedstocks of ammonia production are natural gas, but also petroleum coke. In the case of production from natural gas, there are five main process steps, including a primary and a secondary reforming and a shift reforming process, by which CO₂ is removed from the process. During the following ammonia synthesis, from H₂ and N₂ by a catalytic process NH₃ is formed.

The CO₂ together with process impurities is a constituent of the waste gas. It is washed out by a scrubber, from which the CO₂ is released into the atmosphere during regeneration of the scrubber solution. A part of the CO₂ is used as a raw material in the production of urea (CO(NH₂)₂) together with ammonia. The carbon in the urea is released into the environment after application of the urea fertilizer in agriculture. This means that the whole amount of CO₂ produced in the ammonia synthesis is finally emitted into the atmosphere. For greenhouse gas balancing these CO₂ emissions are allocated to ammonia or urea production according to the amount of both fertilizers.

The emission factor is 1,2 ton CO₂ eq. per ton of NH₃ in the case of natural gas feedstock. For each ton of urea, 0,73 tons of CO₂ eq. are emitted.

8.2.4 Aluminum production

Aluminum is a light weight metal with high corrosion resistance and a high heat and electric conductivity. Its annual global production is about 18 million tons (1990) and the second in the range of the most important metals. In USA, 2,5 mio tons were produced in 2004. It is used in a variety of manufactured products. This includes aircraft, automobiles, bicycles, and utensils for daily life, as kitchen ware and packaging material. By the so called eloxation, a thin surface cover is produced, which improves the corrosion resistance and makes aluminum better applicable in the construction sector.

In nature, aluminum occurs as a low soluble oxide and silicate. The production of primary aluminum from the ores (especially bauxite ores) is very power consuming (via electrolytical processes) and results - despite this energy aspect - in process related emissions of CO₂ and PFCs, especially perfluormethane (CF₄) and perfluoroethane (C₂F₆), both characterised by high global warming potentials (see table 1).

The emission of CO₂ occurs during the aluminum smelting process, when aluminum oxide from the ores is reduced (Hall-Heroult reduction process) through electrolysis in reduction cells. The cells contain a molten bath of cryolite (Na₃AlF₆), which is of natural or synthetic origin. As the cathode in the electrolytic process, a carbon lining is used. As the anode, also carbon containing material is applied. Carbon is oxidised during the reduction, and emitted as CO₂, which is released into the atmosphere. The amount of CO₂ released is approximately 1,5 t/t aluminum produced. In another technology (so called Soderberg cell), 1,8 t/t are released.

Aluminum production industry, in addition to CO₂, is a source of PFC emissions. The reason are so called anode effects, by which the voltage in the electrolysis bath rapidly increases due to reduced levels of the melting bath. Than reactions of carbon and fluorine of the molten cryolite bath occur. As a result, fugitive emissions of CF₄ and C₂F₆ occur. Their magnitude depends on the process conditions (measured as anode effect minutes per Cell-Day), and can be massively reduced if anode effects are minimised by better control technologies. In the US aluminum industry, PFC emissions declined by a factor of 6,6 in the last 15 years. The relation of CO₂ emissions to PFC emissions actually is about 1:0,7 compared with 1:2,6 in 1990.

8.2.5 Petrochemical production

Petrochemicals are substances produced from petroleum or natural gas via different processes. The production is accompanied by the release of small amounts of CH₄ and CO₂. Products considered in this chapter are carbon black, ethylene, ethylene dichloride, styrene, and methanol. CH₄ emissions occur at the production of all these substances, CO₂ emissions only from carbon black production.

Carbon black is generated by the incomplete combustion of petroleum or coal. It is intensely black in colour. Its main use is in the rubber industry, where it gives strength and abrasion resistance, especially for tyres. Ethylene is a raw material for plastics processing, e.g. for polymers as polyethylene varieties (high, low, and linear low polyethylene, HDPE, LDPE, LLDPE resp.), polyvinyl chloride (PVC), as well as other ethylene derivatives (ethylene dichloride, ethylene oxide, and ethylbenzene). Amongst them, ethylene dichloride is an important intermediate in the chlorinated hydrocarbons synthesis, an industrial solvent and a fuel additive. From styrene, plastics, rubber, and resins are produced. It is also a constituent of products in the construction industry, as insulation foam, vinyl flooring, and adhesives. Methanol is used as an alternative fuel and the source of many chemical products, as paints, solvents, refrigerants, and disinfectants. It is the precursor of acetic acid, which is used to make PET plastics and polyester fibres.

Specific CH₄ emission factors from various productions are given in table 12.

Tab 12 CH₄ emission factors from petrochemical production

product	Specific CH ₄ production	
	kg/t product	CO ₂ eq.
Carbon black	11	253
Ethylene	1	23
Ethylene dichloride	0,4	9,2
Styrene	4	92
Methanol	2	46

8.2.6 Carbon Dioxide Consumption

CO₂ is used for food processing, chemical production, beverage production, refrigeration, as a greenhouse fertiliser, or in the petroleum industry for enhanced oil recovery (EOR). In the case of EOR, CO₂ is injected into the underground to rise the reservoir pressure, so that additional oil is produced.

CO₂ is a by product of many industrial processes (e.g., ammonia production, fossil fuel combustion, ethanol production, lime processing), but also from production of crude oil and natural gas, of which it is a naturally occurring constituent. Other feed-stocks of CO₂ are natural CO₂ reservoirs.

The methodology for the accounting CO₂ is not yet fully available. There are following assumptions made: In the case of enhanced oil recovery, the CO₂ applied is assumed to remain sequestered in the underground and is not balanced as greenhouse driving. For all other CO₂ uses, the CO₂ is assumed to be released into the atmosphere during or after the process. Energetic CO₂ balances are not considered in this chapter.

Under these conditions, an amount of 1,2 Mio ton CO₂ equivalents are emitted under the U.S. conditions, which number is only less than 1percent of the total greenhouse gas production.

8.2.7 Semiconductor manufacture

Semiconductors are produced using multiple long-lived fluorinated gases in plasma etching (patterning) and in plasma enhanced chemical vapour deposition (PECVD). About 100 process steps, using fluorinated gases are used to produce the semiconductor products, as devices or chips from silicon wafers.

Plasma etching is applied to provide pathways for conducting substances which connect the circuit components of the semiconductors. Plasma-generated fluorine atoms are used. These atoms chemically react with exposed dielectric films. By this means, certain portions of the film are removed selectively. Some residual undissociated fluorinated gases remain. They - together with the material removed - partly are emitted as waste gas, partly are treated in emission abatement systems.

PECVD chambers are periodically cleaned by using fluorinated gases, which in plasma are converted to fluorine atoms. By this atoms, the residual material from chamber walls, electrodes and hardware are moved away. Residues and reaction products, as CF_4 , are emitted.

For these purposes, dependent of the specificity of the products, mainly the following gases are used: Trifluoromethane (HFC-23 , CHF_3), perfluoromethane (CF_4), perfluoroethane (C_2F_6), nitrogen trifluoride (NF_3), and sulphur hexafluoride (SF_6), moreover perfluoropropane (C_3F_8) and perfluorocyclobutane ($\text{c-C}_4\text{F}_8$).

These substances were applied in the US semiconductor industry by about 500 tons per year (in 2004). This seems to be a relative low amount. But these gases are high potent greenhouse gases (see table 1), and thus end up with about 4,7 Mio ton CO_2 Eq. emitted (in 2004). The numbers were growing all over the last 15 years, due to the growth of the industry and the higher complexity of the semiconductors, which use more PFCs. But there is a tendency in the growth rate of PFCs to decline in the last years, due to process optimisation and abatement technologies. The decline in growth was about one third in the last 5 years.

8.2.8 Adipic acid production

Adipic acid is a white, crystalline solid. Chemically it is also called hexanedioic acid, which is a C6 straight-chain dicarboxylic acid. It is slightly soluble in water and soluble in alcohol and acetone.

The annual world production is about 3 million ton. One third is produced in the U.S. industry in only 4 companies. Its commercial use to approximately 90 percent is linked to nylon production, which is further processed into fibers for applications in carpeting, automobile tire cord, and clothing. Furthermore, adipic acid is used for plasticizers and lubricants components, and making polyester polyols for polyurethane systems. Food grade adipic acid is used as gelling aid, acidulant, leavening and buffering agent. Its derivatives are used in making flavoring agents, internal plasticizers, pesticides, dyes, textile treatment agents, fungicides, and pharmaceuticals.

Commercial adipic acid is mostly produced from cyclohexane through a two-stage oxidation process. The first involves the catalytic reaction of cyclohexane with oxygen to produce cyclohexanol and cyclohexanone. Afterwards, adipic acid is formed by another catalytic reaction of the mixture with nitric acid and air.

Due to the use of nitric acid in this process, N_2O is generated at a rate of 0,3 tons per ton of adipic acid. It is emitted by the waste gas stream. In modern plants, the waste gas is treated by an abatement system, which destroys pollutant by catalytic or by thermal reactions, with an efficiency of 95 and 98 percent, respectively. Due to the installation of these technologies in most plants, the N_2O emissions from adipic acid production have been reduced by two thirds since 1990. The actual total in US industry is about 5,7 Mio ton CO_2 Equivalents.

9 Climate effects of agricultural processes

Agriculture as the producer of all renewable crops will be the most important factor in future reducing of greenhouse as emissions, especially by substituting energy sources from fossil fuels. Nevertheless, agricultural activities also contribute to greenhouse gas emissions in an amount comparable with industrial activities, in the case of the US, the emissions sum up to 440 Mio ton CO₂ Equivalents, equal to 7 percent of the greenhouse gas emissions, compared with 5,1 percent emitted by industry (without energy sector).

Primary greenhouse gases from agriculture are methane (CH₄) and nitrous oxide (N₂O), with an average emission relation of 1:1,7.

Methane is emitted from enteric fermentation of domestic animals, especially beef and dairy cattle, which are the largest emitters of CH₄ due to their ruminant digestion system. The amount of methane emitted by the domestic animals is about 20 percent of total CH₄ emissions from anthropogenic activities! Another 7 percent originate from the management of manure from livestock breeding - this totals to more than one quarter caused by this agricultural activities. Rice cultivation is of minor importance with respect to methane greenhouse gas emissions (7,6 Mio ton CO₂ Eq in USA, 2004), but represents also a magnitude comparable with industrial activities.

N₂O is predominantly released by agricultural soil management activities, which count for more than two thirds of the total national N₂O emissions (in US, 2004). Other sources of N₂O are manure management in animal breeding and agricultural residue burning. It is to be mentioned, that in the case of residual burning, CO₂ emissions are not balanced as climate relevant, since the assumption is made, that carbon released into the environment as CO₂ will be reabsorbed in the following season. Only methane, N₂O, CO and NO_x are considered in the balance, which are the result of the combustion.

An overview about the contribution on agricultural greenhouse gas emissions of agricultural activities is given in table 20.

Tab 20 Greenhouse gas emissions from agriculture (relative numbers, total: 440 Mio ton CO₂ Equivalents, US agriculture, 2004)

	Methane (percent)	Nitrous oxide (percent)
Enteric fermentation of livestock	25,6	0
Manure management	9	4
Rice Cultivation	1,7	0
Agricultural Residues burning	0,2	0,1
Agricultural soil Management	0	59,4

The following information on agricultural processes gives details on emissions and possible ways to reduce it.

9.1 Greenhouse gas emissions by livestock enteric fermentation

Livestock methane emissions are the largest methane source globally. 75 mio tons of methane are emitted annually (27), which equals to 1725 mio tons of CO₂ eq. Total CH₄ emissions of total US livestock in 2004 were 112,6 mio tons CO₂ (7), which is more than the total of the emissions from iron and steel as well as

cement industry. Beef cattle contribute by 71 percent, dairy cattle by 24 percent. The residual small portion comes from other animals.

The background of GHG production by livestock is as follows: Nutrients from the food consumed by the animals are digested in its digestion system. During this complex process also microbes take part, which metabolize the nutritional components. As the process partly takes place under anaerobic conditions, i.e. in an oxygen free atmosphere, anaerobic bacteria predominate.

In a metabolic process, including the production of intermediates as acetic acid and hydrogen, microbes produce methane as an end-product. This is exhaled or eructated by the animal. The amount of methane produced depends primarily on the type of the digestive system of the animal. Other factors are the amount and composition of the feed consumed. Energy rich feed results in more methane.

As methane producers ruminant animals as cattle, sheep, goats, and camels dominate. In their rumen, which is a type of a fore-stomach, bacteria break down the feed, so that it can be absorbed and afterwards metabolized by the following indestinal organs. Ruminant animals are thus able to digest coarse plant material, as grass, and other high cellulose containing green crops. For more details of the bioprocess see chapter 11.4.

An estimation of the amount of methane produced by the animals can be made using information on population, energy requirements (GE), digestible gross energy intake, and a so called methane conversion rate (Y_m), which describes the fraction of gross energy converted to methane. This value is estimated after feeding experiments by 3,5 to 4,5 percent and 5,5 to 6,5 for feedlot cattle and for all other cattle, respectively.

The relationship for daily emitted methane Day_{Emit} is given than by the following equation 2 (7):

Formel (2) $Day_{Emit} = (GE \times Y_m) / (55,65 \text{ MJ/kg CH}_4)$

where

- Day_{Emit} = Emission factor (kg CH₄/head/day)
- GE = gross energy intake (MJ/head/day)
- Y_m = Methane conversion rate (percent)

Cattle typically produce and emit an amount of 150 to 250 liter methane per day. Other livestock have considerable lower individual emission factors, as given in table 21.

Tab 21 Emission factors of livestock other than cattle

Animal	Emission factor (kg methane per head per year)
Horses	18
Sheep	8
Goats	5
Swine	1,5

9.2 Manure management and biogas production

Manure from animal livestock contains high concentrations of residual carbon, as well as nitrogen and other substances. Its composition depends on the concrete situation of the manure management, such as liquid or solid handling, the type of animal, feed composition, etc. By microbial attack similar to the processes in the

rumen of cattle, methane is produced from the manure in an amount which depends on the concentration of organic residues in the manure.

A portion of the total nitrogen excreted as a consequence of protein digestion into the manure is converted to N₂O by bacterial processes of nitrification and denitrification (for details see chapter 10.4). Both CH₄ and N₂O contribute to the effects of agriculture. In the US agriculture, this amounts to a total of about 39,4 and 17,7 Mio ton CO₂ Equivalents for CH₄ and N₂O, respectively (7).

The microbial processes which take place by metabolizing of manure components can be used in a technical process, which aims to prevent such negative climate effects by a controlled decay of the manure. The reasonability of such a process becomes clear considering that the quality of the manure and its applicability as a fertilizer are improved, for in the digested manure, the easily degradable odor producing as well as aggressive organic substances no longer exist. Thus, air pollution is reduced, and the effect on soil of manure used as a fertilizer is improved. Moreover, as a main benefit, the production of electrical power and heat from biogas is possible. Biogas is a renewable energy source which can be used instead of fossil fuels. Hence, it causes climate benefits by avoidance of fossil fuel burning GHG emissions. Positive effects are possible also with regard to other items - see table 22.

Tab 22 Agricultural and climatic effects of biogas production from manure (after 27)

Biogas production in agriculture	Measurable effects
Reduced climate burdens by CO ₂ - neutral energy supply	1 kW _{el inst.} avoids 7.000 kg CO ₂ /a
Reduced deliberation of CH ₄	1.500 kg CO ₂ Eq. per cattle unit per year
De-central energy supply	4 cattle units supply 1 household
Regional economy improved by use of internal resources	
Reduced odor emissions	
Improved sanitary and environmental situation at higher supply security	
Empowerment of low developed regions	
Reduced use of mineral fertilizers	Improved value of the manure as fertilizer + equiv. of 20 kg N per cattle unit per year

Some characters may illustrate the energetic and thus climate effects of such a biogas process. Per head of cattle, an amount of 1-1,5 m³ biogas can be expected from digestion of the manure per day in the biogas plant. The gas consists of 40-70 percent of methane and 30 to 60 percent of carbon dioxide, including small traces of pollutant gasses, as sulfur components. The average heating value of the gas is about 6 kWh per cubic meter, and an amount of electricity of about 1,8-2 kWh per cubic meter of biogas can be generated.

Table 23 presents some of the energetic characters of the biogas process.

Tab 23 Energetic characters of biogas processes from manure

Character	Value
Heating value	6 kWh/m ³
Mineral oil equivalents	0,62 l/m ³ biogas
Performance (cattle manure)	1-1,5 m ³ / head / day
Electricity performance	1,8-2 kWh _{el} /m ³ biogas
Biogas substrate	Biogas yield (m³ biogas/t)
Cattle manure (8 percent dry mass)	22
Swine manure (22 percent dry mass)	25
Chicken manure (22 percent dry mass)	76
Grass silage (40 percent dry mass)	200
Straw (86 percent dry mass)	300

If we assume a biogas yield of 1 m³ per animal and day and a methane concentration in the biogas of 50 percent, than from the application of the biogas process a saving of a global warming potential of 7 kg CO₂ equivalent per animal and day results. An even greater effect can be calculated considering the substitution of fossil fuel by biogas (see chapter 8.2).

9.3 Rice cultivation

Rice is the most important cereal in world's nutrition. It is mostly cultivated for the own consumption and is consumed mostly in the countries where it is produced. Only 5 percent of the world's rice production is on the world market. Most important exporters of rice are the USA, Thailand and some European countries as Italy, Spain, and France.

According to the situation in the production region, rice can be grown in dry or wet systems. Dry cultivation is marginal; the wet system in flooded fields dominates. A precondition for this method is a warm and humid climate. For the cultivation, seedlings are positioned in flooded fields, for a first crop. In many countries, a second crop, so called ratoon, is possible, after the first crop is harvested. This crop is produced from the regrowth of the stubble.

In the flooded system, organic material is decomposed by microbial activities in the soil and in the floodwater. After the oxygen being exhausted, an oxygen free environment exists. This causes anaerobic degradation which results in the production of methane. The more organic matter available to decompose, the more methane can be produced.

The methane produced is decomposed by different mechanisms. The largest portion, about 60 to 90 percent, is oxidized by aerobic methanotrophic bacteria existing in the soil, and thus is metabolized to CO₂. Minor amounts are transported to the surface of the cultivation area by different mechanisms, where they act as climate gas. Some parts bubble through the floodwater or are transported by diffusion to the surface. Some methane is dissolved in the water and leaves the cultivation area by flushing when water is exchanged. The remaining methane is transported through the rice plants by diffuse transportation processes and thus is emitted from the soil into the atmosphere.

The resulting emissions of methane from the rice cultivation field depend on the water management system applied. Most is emitted by shallow systems. Deep water rice with water depth of more than one meter is characterized by a much lower emission, due to the fact, that the lower stems and roots of the plants are dead, so that the transport of the methane through the plant is inhibited. If the field is drained periodically and the soil is dried sufficiently, methane is no longer produced and thus not emitted.

Fertilizer practices also influence the methane production, especially application organic fertilizers which enhance the amount of organics decomposable. Some fertilizers, as nitrate and sulfate fertilizers, also inhibit the methane production.

Emission factors of methane were estimated defined by yield experiments. They came down with different emission factors for primary and secondary crops. These averaged over a broad variety of results were 210 and 780 kg CH₄/hectare and season, respectively.

With respect to the cultivation method the secondary crop results in an about threefold emission compared with primary crops.

9.4 Agricultural soil management

Agricultural soil management is the primary source of N₂O emissions, which heavily contributes to the greenhouse effect. In the U.S. agriculture, its contribution amounts to about 60 percent of the overall greenhouse gas emissions (see table 20). The total is about 260 Mio ton CO₂ Eq. per year in 2004. This equals to more than 80 percent of the total greenhouse gas emissions of all industrial processes.

N₂O production is a naturally occurring process in every soil. Its magnitude depends on agricultural activities. The processes behind are microbial nitrification and denitrification. Nitrification is defined as the aerobic microbial oxidation of ammonium (NH₄) to nitrate (NO₃). Denitrification takes place under anaerobic conditions. Microorganisms then reduce nitrate to free nitrogen gas (N₂). N₂O in this process is an intermediate during both nitrification and denitrification, where the contribution of denitrification is well understood and predominates.

The amount of N₂O produced during these processes depends on the amount of nitrogen available in the soil. The predominant factor in enhancing the nitrogen level is fertilizer application, as mineral nitrogen, or organic fertilizers from livestock manure (see chapter 10.1), compost, or the direct application of sewage sludge. Also nitrogen fixing crops, as leguminoses, contribute to the N-level.

10 Climate effects of Waste management processes

10.1 Background

Municipal solid waste is the end product of the life cycle of all material consumed by the people. Its management is an important environmental challenge facing all states. Besides effects on material use and exhaustion of natural resources, need of landfill space and health problems, the impacts of waste and waste management on climate are of considerable importance.

Greenhouse gas effects can be addressed to every step of the life cycle of waste. This comprises the extraction and processing of the raw materials, the production of goods and services, the transportation of the raw materials and of the products to the markets and to the consumers, as well as the waste management after a product or a material becomes a waste. Waste management decisions can influence every of these steps.

Different strategies were established, which after their potential in reduction of climate impacts may be ranked in the following schema:

- 1 Source reduction and Waste avoidance
- 2 Reuse and Recycling of waste material, including composting
- 3 Waste pre-treatment before deposition, including waste stabilisation by mechanical and biological methods, as well as waste incineration
- 4 Ecologically sound waste disposal in landfills.

With respect to the net emissions of climate relevant gases, following sources and sinks of various management strategies may be defined (see table 24).

Tab 24 Climate effects of waste management strategies (relative to a base line system) (7)

Waste management Strategy	Sources and sinks of greenhouse gas		
	Transportation and processing	Forest carbon Sequestration	Waste management GHGs
Waste avoidance and source reduction	Decrease of GHG emissions	Increased forest carbon sequestration	No emissions
Recycling	Decrease of GHG (lower energy needs, avoided material and energy for production)	Increased forest carbon sequestration	Process and transportation (counted in the production stage) emissions
Composting	No manufacturing emissions	Increased sequestration in soil carbon storage	Emissions by compost production and marketing, biogenic N ₂ O emissions
Combustion	Baseline emissions from process and transportation due to the current mix of virgin and recycled inputs	No effect	Non biogenic CO ₂ , N ₂ O emissions, avoided utility emissions and transportation emissions
Deposition	Baseline emissions from process and transportation due to the current mix of virgin and recycled inputs	No change	CH ₄ emission, long term carbon storage, avoided utility emissions and transport

All waste management activities mentioned provide opportunities for reducing GHG emissions. Waste avoidance and source reduction as well as recycling are often the most advantageous practices in waste

management. Which reduction is achieved, depends on the individual circumstances, amongst which the composition of waste material plays a dominant role. Moreover, the specific technology applied influences the calculation. Therefore, a material-specific comparison of all options available would define where the benefits are biggest.

In the following chapter, typical climate effects of some waste management activities are considered. They may help for decisions what should be planned and realised in a concrete situation.

Some examples may give a first rough indication on the effects possible (7). For a more detailed estimation see chapter 11.7.

- Firm level: The recycling of 50 tons of paper and 4 tons of aluminum per year instead of deposition this may reduce the GHG emissions by about 350 tons CO₂ equivalents.
- A re-use of carbon dioxide from composting of 1000 tons of green waste substitutes 150 tons of technically produced CO₂ used as a fertilizer in a greenhouse.
- Community level: An increase of the recycling rate from 30 percent to 40 percent at an average waste generation of 1 kg per person per day in a community of 30.000 and disposed at a landfill without a gas collection system results in a reduction of GHG emissions by 10.000 tons CO₂ equivalents. In a town of 50.000 and a waste mass of 30.000 tons per year, the installation of a landfill gas recovery system is reduced by 22.000 tons CO₂ equivalents.
- City level (1 million inhabitants): Waste management in a mass burn combustor unit instead of deposition on a landfill without gas collection, reduces GHG emissions by about 450.000 CO₂ equivalents.
- On the national level of the USA, an increase of the average recycling rate from 30 percent to 35 percent results in a reduction of GHG effects by about 10 million tons CO₂ equivalents annually.

10.2 Source reduction and waste recycling

10.2.1 Background and preconditions

Besides waste avoidance, source reduction and waste recycling are two other options to improve the waste management situation.

In the case of source reduction, less material is used to produce a product. It is achieved by practices such as “green design” or “ecological design”. Such activities also are targets of the new EU strategy for an improved resource management (47). It is also possible to source reduce one type of material by a substitute, which consists of another type of material with lower GHG emissions.

In the case of recycling the material is used in place of a virgin input in the manufacturing process, instead of being disposed of and managed as waste. The material after its first use is recovered and prepared for a second use in the same field of application. Examples are the paper recycling or the use of remould tyres. In a “closed loop” recycling the material is used to produce new material of the same kind, e.g. newspapers, which are recycled into new newspapers. Most of the materials are but recycled into a broader variety of manufactured products. This type of recycling is named as “open loop”.

Benefits of recycling due to GHG emissions are calculated as the difference between GHG emissions from manufacturing of a material only from recycled and only from virgin input.

Also new fields of application of waste components may be opened for recycling, if a suitable physical, chemical, or biological treatment of the original waste is applied. An example is the granulation of used tyres or of plastic waste for a second use as a filling material in construction. A third kind of recycling is oriented towards processing of wastes into basic chemicals and their use in the production processes. Examples are the gasification of plastics components for the production of methanol or the use of scrap metals from old cars in steel manufacture.

For basic information on these waste management activities and their influence on climate, first a typical waste composition should be considered, which comprises the waste components most likely to have the greatest impact in GHGs.

Following 16 materials (see table 25) can be considered as most important under the aspects of

- quantity generated,
- potential contribution to methane production if deposited in a landfill
- different energy and material use for manufacturing a certain product from virgin or from recycled material.

They represent about two thirds of the US waste.

Tab 25 Municipal solid waste components comprising two thirds of total waste (in USA, 2004), (7)

Material	Mass percent
Corrugated Cardboard	13,0
Yard trimmings	12,0
Food discards	11,2
Newspaper	6,5
Glass	5,5
Dimensional Lumber	3,4
Magazines/Third class Mail	3,3
Office Paper	3,2
HDPE	1,6
LDPE	1,3
Steel Cans	1,1
PET	0,8
Aluminum Cans	0,7
Textbooks	0,5
Phonebooks	0,3

10.2.2 GHG effects of source reduction and recycling

By means of source reduction or recycling, GHG emissions caused by making the material and managing the post-consumer waste are avoided. Manufacturing from recycled material requires less energy, so that lower GHG emissions occur compared with manufacturing from virgin inputs. With reference to GHG emissions,

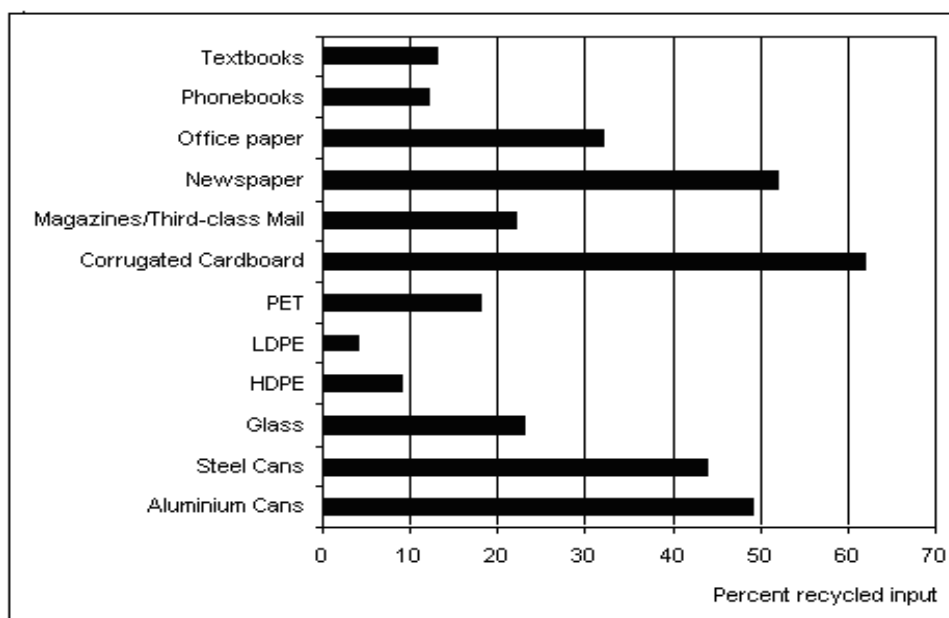
source reduction is the most favourable waste management option; for most materials it results in lowest GHG values emissions.

10.2.2.1 Source reduction effects

Greenhouse gas effects by source reduction are given in figure 6 for selected materials. There two versions were compared: In the first case (“source reduction - mix”) the current mix of virgin material and recycled is displaced. In the other case (“source reduction- virgin”) the case is displayed, were the material was prepared only of virgin material.

The current mix of virgin and recycled inputs in the manufacture of selected materials is given in figure 6.

Abb. 6 Use of recycled inputs in the current mix of selected material (7)



As figure 26 indicates, in the case of aluminum or steel cans, about half of the raw material used is recycled. For corrugated cardboard, approximately two thirds consist of recycled material. The portion of recycled paper in new paper products is in the wide range between 10 and 50 percent. Obviously, it strongly depends on the quality needs of the target product. Thus, the choice of the paper quality for a certain application also strongly influences GHG effects. The portion of recycled material in plastics is relative low.

10.2.2.2 Waste recycling effects

With reference to waste recycling, it is to be noted, that a 100 percent recycling is not possible. Besides losses of material during the recovering process, a portion of the material is not suitable as input. Less than one mass unit of new material is made from one mass unit of the recovered material. Table 26 indicates estimated loss rates for recovered material.

Tab 26 Loss rates for recovered material (7)

Material	Recovered material retained in the recovery stage (percent)	Product made per ton of recycled inputs in the manufacturing stage	Loss rate (t product made per t recovered materials)
Steel cans	100	0,98	0,98
Aluminum cans	100	0,93	0,93
Corrugated Cardboard	100	0,93	0,93
Newspaper	95	0,94	0,90
Glass	90	0,98	0,88
Dimensional Lumber	88	0,91	0,80
Medium-density fiberboard	88	0,91	0,80
HDPE	90	0,86	0,78
LDPE	90	0,86	0,78
PET	90	0,86	0,78
Phonebooks	95	0,71	0,68
Magazines/Third Class Mail	95	0,71	0,67
Textbooks	95	0,69	0,66
Office paper	91	0,66	0,60

Calculation results of climate effects based on these assumptions are shown in figure 6 in terms of greenhouse gas emission reduction. The numbers given as a per-ton basis characterize the improvement of emissions due to a waste generation reference point, which is defined by the situation, that the material has already undergone the acquisition of the raw material and the manufacturing phase.

For more GHG reduction dates from selected materials see chapter 11.8.

Abb. 7 Effects of source reduction and recycling on GHG emissions (7)

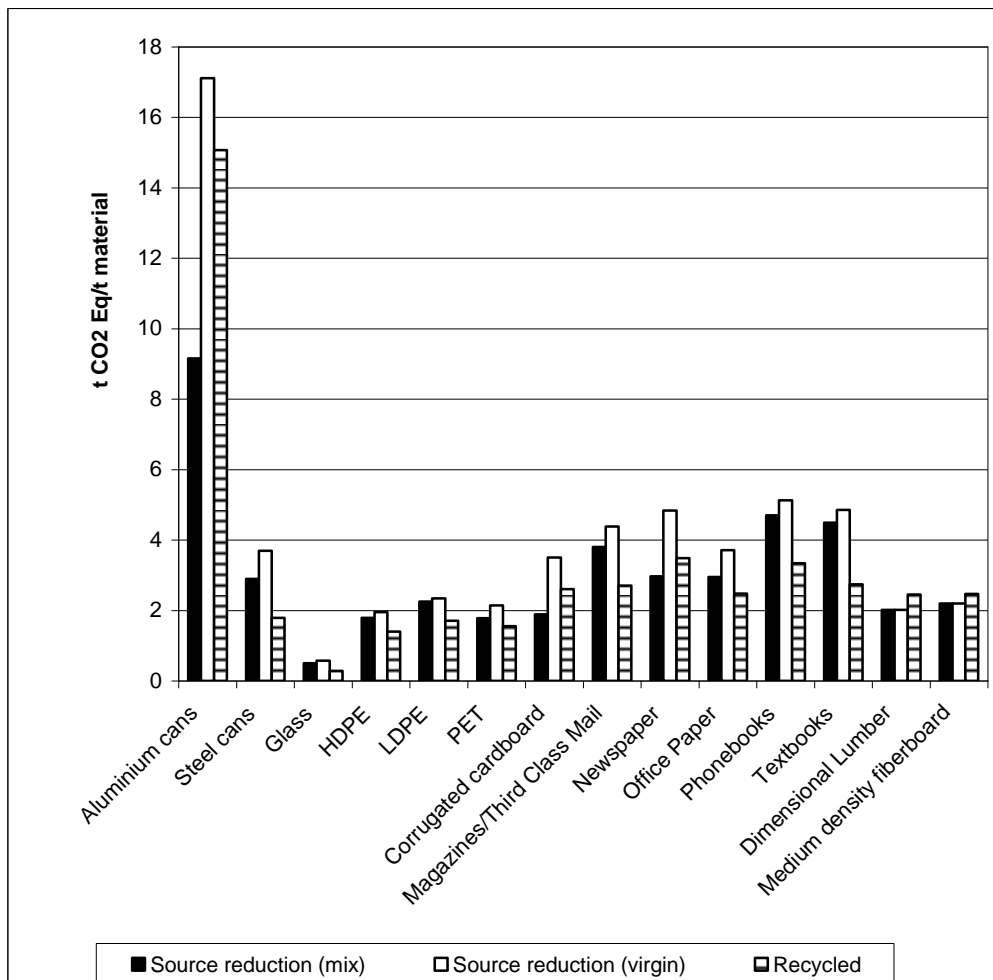
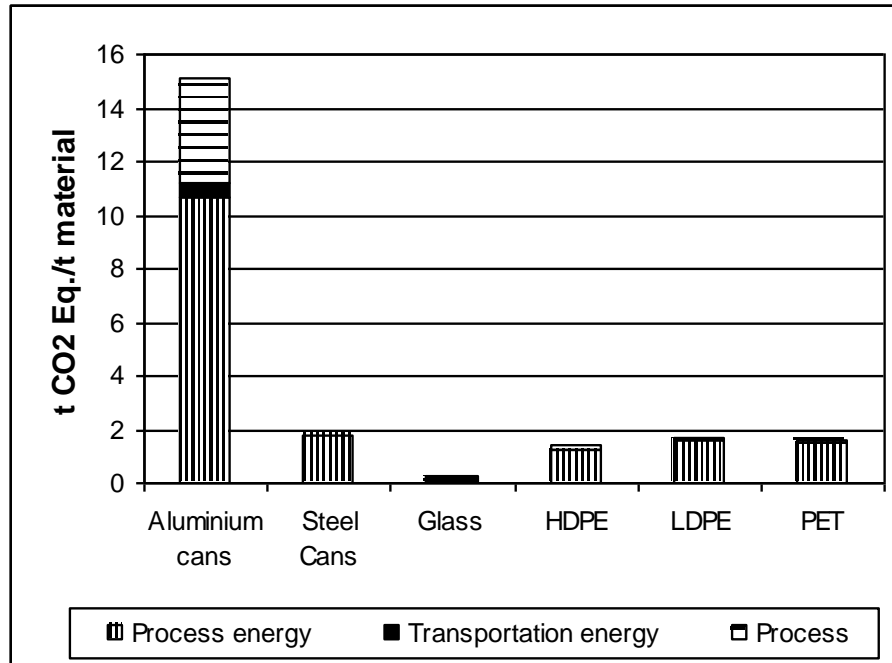


Figure 7 indicates, that for all the materials considered, a reduction of greenhouse gas emissions occurs, if a source reduction or a recycling takes place.

Greatest potentials for emission reduction result for aluminum cans, copper, and for several paper grades. Thus, if such measures are intended, they should start at these most effective materials, depending on the situation on site.

Emission reductions caused by recycling activities are due to several factors, which contribute to the total GHG reductions, namely the process energy, transportation energy as well as process emissions which are not energy related. Figure 8 represents recycled input credits for selected materials. In most cases process energy related emissions dominate. In the case of aluminum also process emissions are a relevant factor. In the case of paper and products made from it, positive recycling effects are also due to forest carbon sequestration, which amounts to 2,69 t CO₂ eq./t paper raw material.

Abb. 8 Emission reduction contribution by process steps of recycling (7)



10.2.3 Case study: German packaging material recycling system DSD

In Germany, a private organisation was founded by the business community to recycle light weight packaging, named DSD (Dual System Deutschland GmbH). Under this system, manufacturers apply for DSD and pay for the corporation a fee to place their symbol of DSD, the Green Dot, on their packages. DSD collect and recycle the packages, instead of the producer of the packaging material, which are responsible after the law. The Green Dot signalizes to the consumer, that the package can be put into separate bins or sacks, which exist in every household for collection purposes. The material collected is treated in sorting plants, of which temporarily about 250 exist in Germany.

The treatment implies several steps, such as dry mechanical pre-sorting, wet mechanical preparation, and plastic processing. The result consists of about 80 percent of secondary raw material and a residue consisting of wood, textiles, and stones. The material balance is given in table 27.

Tab 27 Material balance of secondary material and residues (15)

Component	Percentage
Tinplate	23,5
Beverage cartons	5,0
Paper fibres	8,0
Aluminum	4,0
Polyethylene granulate	13,0
Polystyrene granulate	3,5
PET	1,5
Poly-olefine agglomerates	23,0
Residues (wood, textiles, minerals)	18,5
Total	100

The climate effects of this system may be calculated as a difference of following both characters:

- Expense in energy and material for the establishment of the system, the collection and the treatment of packaging material
- Benefits from avoided process and energy needs for the materials collected (see chapter...)

The balancing of these items comes down with the following results (14):

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10.3 Composting

10.3.1 Composting process characters

Composting is a technology for the treatment of organic residues using aerobic bioprocesses. During the process, the organic material after its composition (sugar, starch, cellulose, hemi-cellulose, and lignin like fractions) is fully or partly decomposed by different kinds of micro-organisms which act in a complicated metabolic schema. The result of the composting process is compost, which mainly consists of those organic waste components, which are not or only partly destroyed by the microbial attack.

The compost is used as a fertilizer in agriculture. Benefits arise from the nutrient content of the compost, as Potassium, Phosphorus, and Nitrate. But it is even more important, that the organic matter in the compost, as humus like substances, improve the structure of the soil and the fertility over long periods.

Sources of composing processes are wastes from agricultural activities as crop residues, wastes from gardening, yard trimmings, as well as source separated kitchen waste. In Germany, a capacity of about 4 million tons of bio-waste is treated and processed into compost.

The technology of composting comprises different methods, as open windrow systems and closed reactors with high process intensity and a good aeration capacity which is also a pre-condition for high compost quality. Besides technical composting in centralised facilities, also home composting of garden residues takes place, mostly in open heaps (see figure 9).

10.3.2 GHG sources in composting

Composting may result in emissions from different sources

- biogenic processes during the composting,
- the steps of gas cleaning and process control,
- collection and transportation of the raw material and the compost,
- application of compost in agriculture.

Main gas components to be considered are CO₂, CH₄, N₂O, and NH₃. A qualitative review on the emissions comes down with the following consideration:

- Emissions from the process itself mainly consist of carbon dioxide, as the result of the aerobic decomposition. Depending in the type of the raw material, the duration of the composting process, as well as other bioprocess characters, different amounts of CO₂ are emitted per ton of composted raw material. But because this CO₂ is biogenic in its origin, this emission is not counted in greenhouse gas inventories (see chapter 12.2). Nevertheless, capturing emitted CO₂ and its use instead of carbon dioxide from fossil sources might contribute to a better greenhouse gas balance.
- In a well-managed composting process, CO₂ is the only process gas. But if aeration in the compost heap is poor, or the material is too wet, an anaerobic situation may occur, which is accompanied by methane production and the liberation of smelling substances.
- As another substance, ammonia has to be taken into account. This is not a climate gas, but may be a precursor of the formation of N₂O. Such production may take place in the bio-filtration step, where odour substances are eliminated. Thus, bio-filters applied in the treatment of organic gas components, may act as climate gas sources (see table 28). This can be prevented, if ammonia is eliminated from the waste gas stream by use of an acid washer and scrubber.

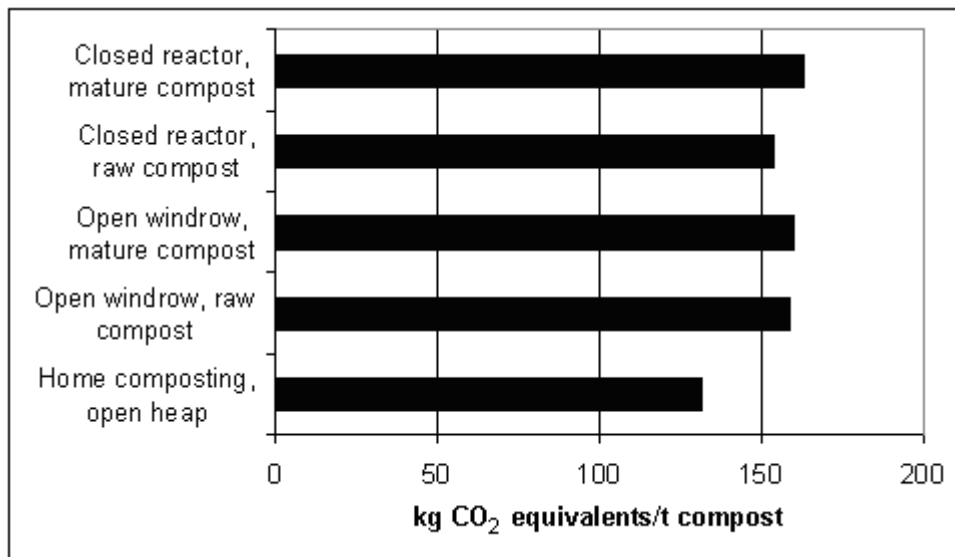
Tab 28 Bio-filter as a source of climate gases (g/t waste)

Substance	Raw gas	Clean gas after biofilter
N ₂ O	19	130
NO	1	190
NH ₃	500	200
N(org)	100	100
Percolation	0	1-10

- During collection of bio-waste and its transportation to the composting facility, as well as during turning of compost and aeration, CO₂ and methane emissions may take place.
- Application of compost in agriculture results in the deliberation of carbon dioxide from biological processes of aerobic decomposition of organic substances (but is also to be considered as a carbon sequestration factor).

The overall greenhouse gas emissions sums up to about 150 kg CO₂ eq. per ton of waste treated (see figure 9), depending on the technology and the type of compost produced.

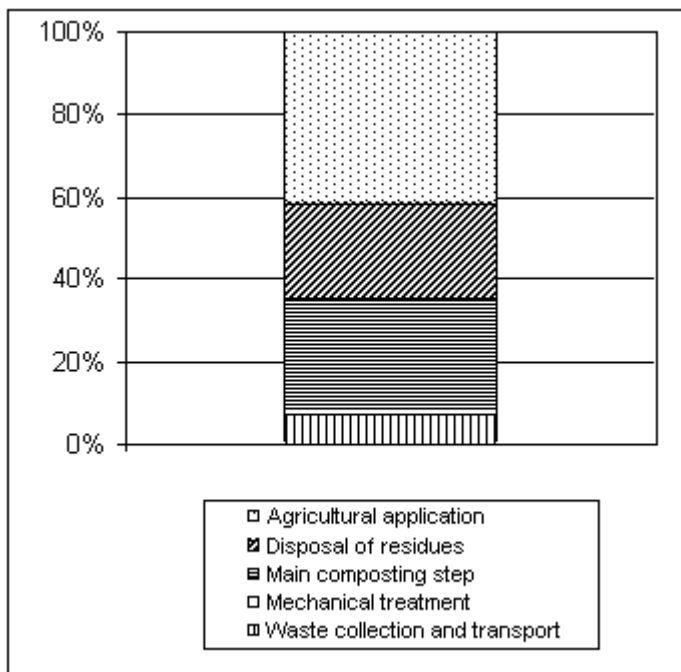
Abb. 9 Greenhouse gas emissions by different composting technologies (after 29)



Obviously, the emission values are quite similar for different technologies, with highest values for mature compost, the production of which normally comprises an extra step. Home composting represents the lowest value, for no energy consumption in transportation etc. takes place. Thus, home composting under climate aspect is a favourable composting option.

A more comprehensive specification of the contribution of the steps of processing and application is given in figure 10.

Abb. 10 Specification of climate contributions of composting steps for production of raw compost (after 29)



Waste collection and mechanical treatment as a step of the composting process contribute to only 10 percent, the main process phase to not more than a quarter. Largest effect is by agricultural application. If matured compost is produced, this value is cut in half. But in this case, the production effort is higher, so that the benefits are equalized and the total GHG effect is for the most part unchanged.

10.3.3 Carbon sequestration by compost application in soils

Compost is applied in agriculture to improve soil fertility by means of supply of mineral fertilizers, as Potassium, Phosphorus, and Nitrogen. Moreover, the input of compost influences the soil carbon storage, which is also an important factor of soil fertility. This is due to the fact, that composting partly results in increased formation of stable carbon compounds, especially humus like substances and aggregates. These are made of complex compounds that render them resistant to microbial attack.

The input of organic matter is especially important, where an intensive cultivation of soils results in its depleting, because decomposition rates and removals of carbon in the crops are not well balanced by raised inputs. By adding compost an input of new organic matter takes place, so that the soil carbon level is restored. Enhanced crop residues, which serve as another organic matter input, may also contribute to increased soil carbon. In the case of compost, its Nitrogen content stimulates productivity which results in the higher volume of crop residues. By multiplier effects caused by compost components, an increased carbon storage is possible, by which a carbon mass accumulation results that is even higher than the direct carbon dioxide input by the organic compost mass.

The type of organic matter which is produced by composting can be stored in soil over periods of more than 50 years. Thus, this amount of carbon dioxide is sequestered. Field application of compost therefore is a temporary sink in carbon dioxide and results in a real net improvement of the overall greenhouse gas balance. The storage effect of soil carbon sequestration is estimated to about 0,24 ton of CO₂ Equivalents per ton of

compost applied (7). Taking into account a total CO₂ emission of about 0,15 t, there a benefit for the total greenhouse balance of about 0,1 ton CO₂ equivalents per ton of compost produced results.

10.3.4 Use of composting CO₂ as greenhouse fertilizer

If compost born CO₂ instead of fossil derived carbon dioxide could be applied in production processes, a net reduction of the GHG balance would be possible. As was mentioned, a total of about 150 kg CO₂ (see figure 8) is emitted per ton of compost raw material. Thus, in a facility with a capacity of 100.000 ton annual, about 15.000 tons of carbon dioxide is produced. In Germany, CO₂ from composting totals to about one million tons carbon dioxide, which could be used instead of fossil derived CO₂.

A sensible solution is the application in greenhouses, where crops are fertilized by CO₂ to improve the yields by about 30-40 percent with a CO₂ input of 100 tons per hectare annually. Actually, the CO₂ is from gas burners or is industrially produced. If compost CO₂ is used, by a medium sized composting facility an area of about 150 hectares could be fully fertilized by self produced CO₂. As another advantage, the residues from the greenhouse crop can be applied as raw material in the composting process. Moreover, renewable heat energy, produced by the composting process can be used for heating the greenhouse, hence avoiding climate gas missions from fossil fuel for greenhouse heating (5).

10.4 Climate effects of waste deposition in landfills

Waste deposition in landfills is the final step in the waste management hierarchy.

The climatic effects from landfills mainly result from

- landfill gas emissions, especially methane emissions, as a result of microbial decaying processes of organic matter in the waste deposited in the landfill,
- waste transportation on the landfill site,
- carbon sequestration in the landfill body by forming stable carbon structures.

10.4.1 Climatic effects by landfill gas emissions

Landfill gas contributes to the global methane emissions to about 13 percent with a total amount of 842 Million tons of CO₂ eq. per year (in 2000, 8). Nearly half of the total emissions stem from four countries: USA, China, Russia, and Mexico (see table 29).

Tab 29 Annual landfill Methane emissions by 10 most relevant countries (in 2000 and estimations for 2020, in Mio t CO₂ eq. (8)

Country	2000	2020
USA	199,3	145,2
Russian Federation	51,1	45,3
China	44,6	49,7
Mexico	31,0	39,2
Ukraine	25,2	37,4
Canada	22,8	33,5
Poland	17,0	17,0
Brazil	15,6	19,0
Australia	14,8	22,0
Germany	14,4	4,4

In the U.S., where 1800 operational landfills exist, annual landfill gas emissions of 140,9 Mio ton CO₂ eq. by 2004 (9) are approximately the same as the total of the Kyoto protocol gases of industrial origin (see table 10). There, the landfill gas emissions account for 34 percent of all anthropogenic methane emissions.

The global growth is estimated to 19 percent between 2005 and 2020, mostly due to the raising amounts of waste to be deposited under poor landfill management conditions in emerging countries and China, whereas industrialized countries mostly have strict regulations to reduce methane emissions. Examples are the US Landfill Rule (from 1999), or the EU Landfill Directive (from 2002). They principally include waste management improvements, such as

- waste reduction, re-use and recycling, such as reduction of organic content of waste by source separation of organics,
- pre-treatment of waste to reduce organic content prior to deposition, such as waste combustion or mechanical-biological pre-treatment,
- capturing landfill gas especially with use of its energy content in energy recovery systems for electricity production.

10.4.1.1 Basics of landfill gas production

The processes of landfill gas production and emission are as follows: Organic compounds of waste such as paper, food discharges, or yard trimmings are decomposed in a landfill just after being deposited in the landfill body. Initially they are decomposed by aerobic micro-organisms. This process lasts as long as oxygen is available in the waste mass, normally some months.

After its depletion, anaerobic processes start, which decompose the residual complex organic compounds into smaller molecules by hydrolysis. In a two stage process, specialised bacteria produce organic acids, hydrogen (H₂), and CO₂. Acidic acid as well as hydrogen are the substrates for the methane producing (methanogenic) bacteria, which convert it into methane and CO₂, which are the constituents of the landfill gas.

Typically, the landfill gas consists of 50 percent of methane and CO₂ respectively, similar to biogas from organic residues. In the case of landfill gas, the methane content is lower than in biogas due to dissolving of

the CO₂ in the landfill moisture. Landfill gas production in significant amounts starts about one to two years after waste disposed in the landfill. Its formation continues for about some decades, depending on the composition of the waste.

Though methane from landfills is biogenic in origin, it is not considered as climate neutral, but as a greenhouse gas, because degradation in nature would not result in methane, but mostly in carbon dioxide. In opposition to this, CO₂ produced in the landfill is not counted for GHG effects, because in nature it also would be produced through natural decomposition of organic material. Besides a very small amount of “biodegradable plastics”, plastics from fossil resources are not degraded by bioprocesses. Metals do not directly contribute to the GHG emissions.

Additionally, landfill gas contains NMVOCs by one percent at maximum. Amongst them, also climate relevant gases occur, which may have a very high greenhouse gas effect.

The magnitude of methane production (as well as the other negative effects on landfills), depends on the quantity, type and moisture content of the waste and the design and management practices at the landfill site.

10.4.1.2 Effects on methane production of organic residues composition

The more organics are contained in the waste, the higher is the production of methane and thus the contribution of the waste to the greenhouse gas effect. Some figures of the landfill gas production by organic material containing solid waste components are given by table 30.

Tab 30 Methane yield for solid waste components (7)

Waste component	Average measured methane yield (l/kg dry mass)	Methane yield (t CO ₂ eq./wet ton)
Corrugated cardboard	152,3	1,969
Magazines/Third class Mail	84,4	1,978
Newspaper	74,2	0,950
Office Paper	217,3	4,426
Food discards	300,7	1,228
Grass	144,3	0,785
Leaves	30,5	0,609
Branches	62,6	0,623
Mixed Municipal solid waste	92,0	1,049
		0,7-1,0

Also other important factors with relevance to climate are influenced by the organic content, as the production of leachates, and landfill settlings, which may cause instabilities of the landfill body.

Therefore the waste should be pre-treated before its deposition in the landfill. In many countries, as e.g. in European Union, waste has to be pre-treated before deposition takes place. In Germany and some other countries of the EU, the organic content of the waste is limited to a certain value (5 percent measured by incineration loss).

This can be managed by different technologies, as mechanical biological pre-treatment MBP (see chapter 11.6), as well as incineration of waste, which also is a technology to produce waste from energy (and thus using the energy content of waste to produce electricity and heat, thus replacing fossil fuels and avoiding GHG gases caused by burning from fossil fuels).

10.4.1.3 Influence of landfill management

A main factor in reducing methane emissions from the landfill body is to collect the landfill gas before it is released into atmosphere from the landfill body. This is possible by use of gas recovery systems, which may include a gas flare or a combustion system.

In the case of a flare, the gas is burned only, so that the energy content of the gas is lost. Alternatively, the gas can be used beneficially. This includes the use of the gas as fuel in energy recovery facilities, such as internal combustion engines, gas turbines, micro-turbines, steam boilers, or other facilities that use gas for electricity production. By this means, up to an average of 70 percent of the gas produced can be captured and transformed into electricity and heat.

Besides the direct avoidance of greenhouse gas emissions by the landfill processes, landfill gas recovery can be considered as avoiding greenhouse gas emissions caused by the fossil fuel needed for production of the equivalent of electricity and heat.

One quarter of the methane generated in the landfill cannot be captured by gas recovery systems or is emitted after finishing the gas collection due to economical reasons. It is emitted diffusely. A portion thereof can be oxidized in a landfill surface layer with a methane oxidizing substrate, such as compost or residues from mechanical-biological waste treatment. By this means, the residual methane emissions can be reduced by about 60 percent in the case of the deposition of MSW.

In the case of waste pre-treated by the MBP technology the emission characteristic is different: in this case, the emissions potential is 10 to 45 Nm³/t dry matter waste. Methane production starts already after one month rather than one to two years in the case of untreated waste, and will finish earlier, so that long lasting emission effects of the landfill do not take place. The methane oxidation potential of a landfill cover exhibits the landfill gas production. Hence, practically no emissions will occur from the landfill after deposition of MBP pre-treated waste.

10.4.2 Carbon storage by solid waste deposition

The organic waste components, as yard trimmings, food discards, and paper are not completely decomposed by the microbial processes, especially by the anaerobic bacteria. Thus, residues of organics remain in the landfill. Under normal natural conditions every organic component is decomposed as a function of time in the photosynthetic cycle, and no storage would occur. Therefore, the amount of carbon stored in the landfill body is considered as an anthropogenic sink of carbon, which reduces the burden of CO₂ emissions.

The amount of plastics, which remain in the landfill, also is a storage of carbon. But it is not counted as a sink, for it is of fossil origin.

Table 31 indicates the carbon storage efficiency of some selected organic residues in landfills.

Tab 31 Carbon storage of selected waste components

Waste component	Amount of carbon stored (t CO ₂ eq./wet ton)
Corrugated cardboard	0,81
Magazines/Third class Mail	1,06
Newspaper	1,32
Office Paper	0,15
Food discards	0,07
Grass	0,44
Leaves	1,43
Branches	0,77
Mixed Municipal sold waste	0,37

10.5 Climate effects of waste combustion

10.5.1 Technological background - waste to energy (WtE)

Combustion of waste traditionally is a method of pre-treatment of waste prior to deposition, which results in a minimisation of the waste to be deposited by about 70 to 80 percent, but leaves residues such as ash and slag in an amount of about 20 to 30 percent, which have to be deposited if not used as construction material under certain environmental constraints. Presently, this waste minimisation orientation of combustion changed into an energy recovery approach, whereby the energy content of the waste is used for the production of power and heat. Such combustion facilities are defined as waste-to-energy (WtE) plants. They comprise mass burners, modular plants, and refused derived fuel (RDF) incinerators.

The mass burner generates electricity and/or steam from the combustion of mixed municipal solid waste with an average heating value of about 4 to 6 MJ/t. The capacity is in the range of several hundreds of kilotons per year. In Germany, about 60 mass burners with a total capacity of 15 million tons municipal solid waste exist. In the USA, about 70 facilities process about 21 million tons annually.

Modular WTE plants are similar to mass burners, using MSW, but are lower in capacity. They normally are pre-fabricated and established on site, so that they are more flexible in application.

RDF facilities are specially tailored to the treatment of refused derived fuel, which is a fuel derived from MSW by special processing steps. They include separation steps to remove material with little or no heating value, as well as waste components containing fast decaying organics which produce odours. The resulting fraction has a high calorific value, which typically lies in the range of 15 MJ/t. This fuel fraction is more uniform than MSW and can be stored over a certain time.

If RDF fractions are produced by Mechanical-biological Waste Pre-Treatment (MBP) (see 10.6.) a typical composition of an RDF fraction after table 32 results.

Tab 32 Output flow of the dry stabilate process (6)

Output fraction	Percent of total input
Fraction for industrial re-use	
RDF (calorific value 15-18 MJ/kg)	53
Ferrous metals	4
Non-ferrous metals	1
Batteries	0,05
White glass	5
Brown glass	0,5
Green glass	0,5
Minerals	4
Others	
Fine grain and dust (to be deposited)	4

10.5.2 Climate effects by Combustion

Combustion is a chemical process which needs oxygen. Normally, oxygen is supplied by air, which in the process is transferred into a waste gas containing the combustion products as well as non combusted residues from the original waste. The amount of waste gas produced is about 5700 m³/t.

Climate effects by waste combustion result from

- Direct emissions of CO₂, pollutants, and indirect emissions,
- Avoidance of greenhouse gas emissions caused by production of electricity and steam as well as recovery of metals, glass, and other recyclables

Net greenhouse gas emissions result from addition of these effects.

10.5.2.1 CO₂ and pollutant emissions

During the incineration process in the combustor, nearly all carbon substances of the waste are transferred into CO₂. Also in this case, the CO₂ from the biogenic portion of the carbon in the waste is not counted as a greenhouse gas. The average portion of biogenic organics is about 60 percent. Specific climate effect of CO₂ from combustion is about 0,7 t CO₂ eq./t MSW. In Germany, were about 15 million tons combusted, this for instance amounts to 7,5 million t CO₂ equivalents emitted annually.

Besides CO₂, a broad variety of pollutants are emitted. Some of them are climate relevant, others are indirect climate gases. A selection of such substances is given in table 33.

Tab 33 Emissions caused by waste combustion (10)

Pollutant	Emission load (mg/m ³ waste gas)
Anorganic substances	
SO ₂	6,72
NO _x	111
CO	25,4
NH ₃	5,4
Organic substances	
Dichlormethane	0,014
Hexachlorbenzene	0,00010
Polychlorated biphenyls	0,00015
Trichlormethane	0,000900

Indirect emissions occur from supporting processes such as fuel supply in the case of poor heating value of the waste combusted, and natural gas in an amount of 11 m³ per ton of waste for waste gas treatment, as well as for transporting processes in the facility.

10.5.2.2 Benefits by recovery

Recovery activities refer to electricity and steam production as well as material recovery.

Electricity production is a result of the combustion in facilities with energy recovery such as WTE and RDF facilities. The benefits on climate of this process results from the fact, that CO₂ emissions are avoided, which would otherwise be provided by an electricity utility power plant, which burns fossil fuels.

The energy produced in waste combustion plants is used as a substitute for primary fuels. In Germany fuels are substituted for power productions, for district heating, and process steam in different portions (see table 34).

Tab 34 Substitution of primary energy by waste combustion in Germany

Primary fossil fuel	Power generation	District heating	Process steam generation
Hard Coal	25	25	
Lignite	27	25	
Natural Gas	6	45	65
Nuclear power	36		
Hydro energy	4		
Heavy Oil	1		35
Others	1		

Compared to the regular fossil fuels, MSW as a fuel has the lowest CO₂ emissions per unit of energy, due to the fact, that it by about 60 percent consists of non fossil components (see table 35).

Tab 35 Carbon origin in residual wastes

Waste	Carbon content (kg Carbon/ t wet waste)				
	total	biogenic		fossil	
		kg /t	%	kg/t	%
German Waste 1 (Neuwied)	215,4	150,3	69,7	65,2	30,3
German Waste 2 (Quarzbichl)	277,6	145,5	52,4	132,1	47,6
German Waste 3 (Ostprignitz)	254,8	154,0	60,5	100,8	39,5

If regular fuels are substituted by RDF, a massive avoidance of CO₂ equivalents therefore can be envisaged. To come down with a generalised result, the average mix of fuels should be considered. The value depends on the situation in a national economy, and amounts e.g. to 0,0549 and 0,0794 t CO₂ eq. per GJ for Germany and U.S., respectively (see chapter 12.1). In this case, for every ton of waste combusted instead of the mix given, a GHG avoidance of about 0,8 to 1,2 t CO₂ eq. results.

Benefits of recovery of recyclable fractions can be estimated after the concrete amounts separated and the emission factors given in chapter 11.7.

10.6 Climate effects of Mechanical-biological waste pre-treatment

10.6.1 Technological background

Mechanical biological waste pre-treatment comprises the processing or conversion of waste from human settlements, and waste that can be management like waste from human settlements, with biodegradable organic components, via combination of mechanical and other physical processes (e.g. cutting or crushing, sorting) with biological processes (rotting, fermentation), on which

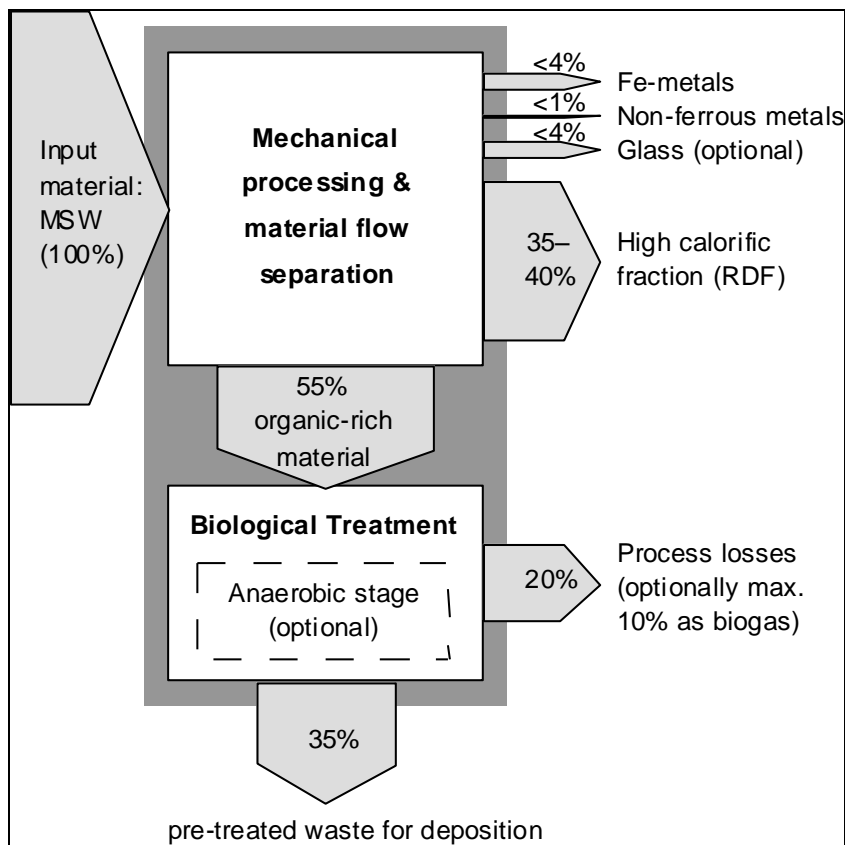
- biologically stabilized waste is produced, in pre-treatment for storage or prior to thermal treatment,
- thermally valuable components or substitute fuels are obtained, or
- biogas is generated for energy recovery (27).

The technology has been fully established in Europe since 2001, especially in Germany and Austria (10). In Germany, a capacity of about 6 million tons is operated in about 60 facilities.

The typical process is characterized by mechanical separation steps to produce i) the RDF fraction, which typically amounts to about 50 percent of the original waste. As another resulting waste fraction with of about 35 percent by mass ii) the fine fraction is produced, which is rich in organics, but has a low heating value. This fraction is biologically treated to reduce the organic content to a low value, so that MPB waste can be deposited at low risks of emissions (6). The residual organic must not exceed a level defined by a so called assimilation activity (AT₄<5 mg/g d.m.) or alternatively a gas formation in a laboratory test (GB₂₁ <20l/kg d.m.). The upper thermal value of the waste deposited must be lower than 6000 kJ/kg, thus, a energy rich fraction is separated.

A typical process schema is given in figure 11

Abb. 11 Process schema of RDF production by mechanical biological waste pre-treatment



Two types of processes for the biological treatment or combinations thereof can be applied according to the MBP technology: aerobic and anaerobic processes. In the case of aerobic processes, in analogy to composting, the organic residues are oxidized. But the product is not “compost” because its quality is poor due to heavy metals and toxic substances. The energy content of the waste in this case is lost. If the biological treatment is executed by an anaerobic process, methane is produced and can be transformed into electricity to cover the needs of the process itself or for energy marketing.

Also variants which only produce RDF and no waste for deposition are established. As another important aspect, in these facilities a material recovery takes place. Especially ferrous and non-ferrous metals are recovered by about 4 and 1 percent, respectively. Optionally a recovery of glass is possible and is applied depending on the market needs. The recovery of these materials avoids climate effect in the production processes and is thus considered as a climate benefit of waste pre treatment. The output flow of such a process is characterized by the production of about 66 percent of fractions for industrial re-use; only 4 percent are deposited (see table 32)

10.6.2 Climate effects by MBP technology

Climate effects caused by MBP technology can be addressed to several sources - see table 36.

Tab 36 Climate effects by MBP technology

Technological step	Climate effect source	Tendencies of effects
MPB processing	Energy need of processes such as ventilation and transportation	Negative
	Recovery of metals and glass	High CO ₂ avoidance potential
	Emissions of process gases	Emission are limited by law (23): N ₂ O < 100 g/t waste, Total carbon < 55 g/t waste
	Biogas production in an anaerobe process technology	positive
Deposition of pre-treated waste	Emissions from landfill	Negative due to GHG, but improved compared to deposition of waste without treatment
Use of RDF fraction	Combustion in a WtE-facility	Positive effects mostly due to biomass content, but also due to substitution of fossil fuel combustion for energy production

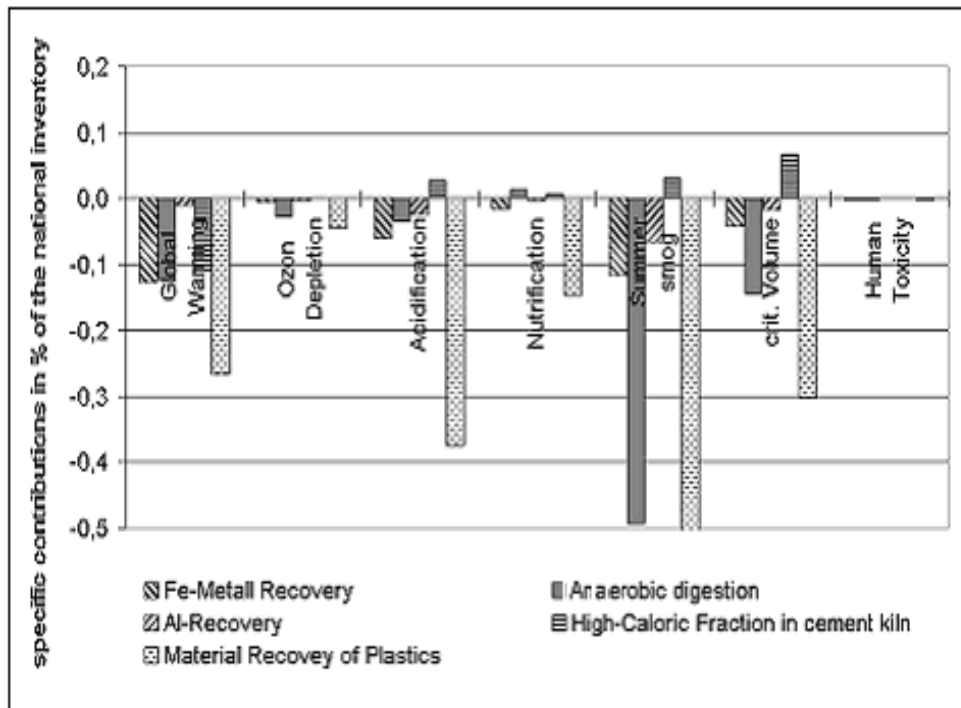
10.6.2.1 Climate effects of material recovery

The ecological assessment of the material recovery of iron, non-ferrous metals, and plastics, as well as the energetic use of biogas from anaerobic treatment steps, and of the RDF fraction is given in figure 12.

Following pre-conditions were assumed for this study:

- The amount of metals in the residual waste varies between 2,5 to 10 mass percent. The share of ferrous metals is about 75 percent or higher. After crushing and homogenisation about 95 percent of the ferrous metals may be recovered by magnetic separators.
- The share of non-ferrous metals is about 0,6 to 2,6 mass percent. It contains about 30-50 percent of aluminum. The efficiency of the eddy current separation has been reported as high as 98 percent.
- In the case of anaerobic processing of organic residues in the MBP plant, a gas yield of 25 to 125 m³/t MBP-Input is assumed. The gas produced has a methane content of about 60 percent.
- The percentage of plastics within the residual waste is between 7-15 mass percent. Plastic consists of polyethylene only, of which 80 percent is recovered, and 70 percent of the recovered plastic is recyclable.
- The high calorific fraction has a heating value of 15.000 kJ/kg. It consists of plastics, paper, and packaging material. It is used in a cement kiln.

Abb. 12 Results of complex LCA of MBP recovery options (47)



After figure 12, environmental benefits result in most of the criteria even if one considers the additional burdens for the separation and recovery.

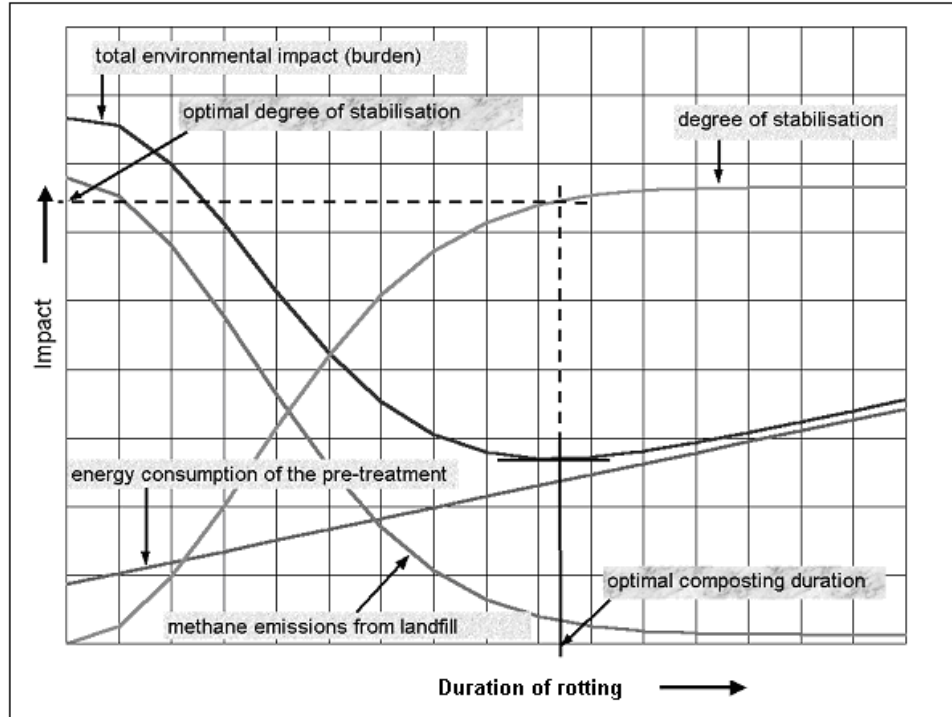
Climate effects of all options are positive. Best results are possible by material recycling of plastics, but only if a high value end use of the recycled plastic is guaranteed. The benefits of ferrous meals recovery are as high as that of use of RDF fraction in a cement kiln, and the power production from biogas. The improvement potential of the aluminum recovery is of minor relevance in comparison with the other recovery options.

The benefits in the impact categories result from the substitution of primary materials and energy resources which would otherwise be produced and used with the correspondent environmental impacts. But the recycling oriented residual waste treatment strategy requires a market which is open for the recovered resources and a material management, which takes care that the recovered materials comply with requirements of the recycling industry. It is for example very important to use the waste heat of RDF incineration and the biogas burning processes, otherwise the ecological benefit is very restricted.

10.6.2.2 Optimising the GWP of the MBP technology

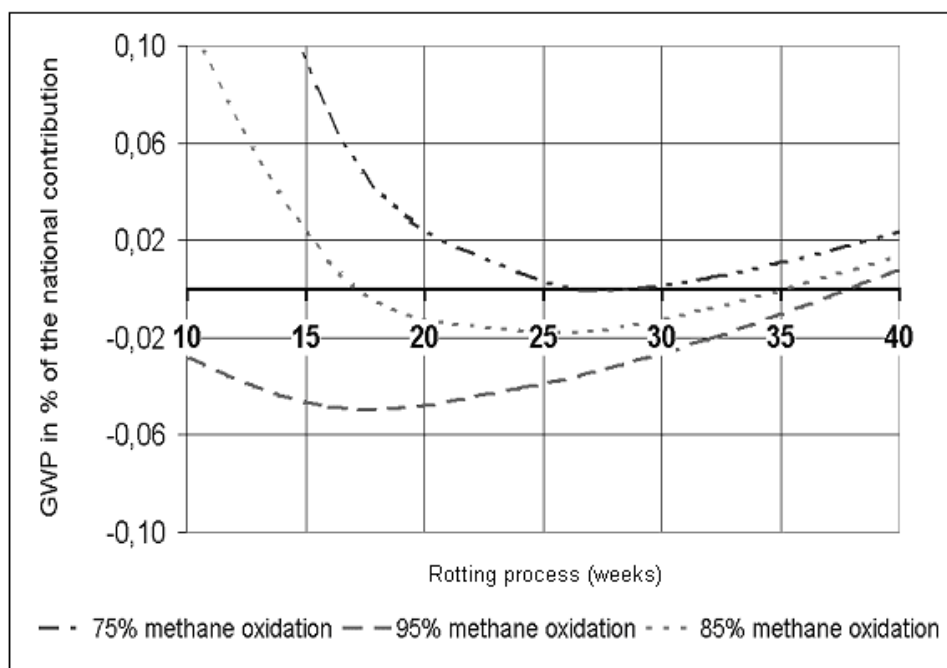
As was shown in figure 11, MPB technology besides the recycling material including the RDF fraction leads to a product, which after biological treatment has to be deposited. For suitable information on the GWP of MPB the effects on the landfill of the deposited material has to be taken into consideration. Here we have to state, that a better pre-treatment comes up with lower organic residues and, thus, with lower landfill gas emissions. On the other hand, a longer treatment requires higher energy input, e.g. for aeration, which as a consequence leads to enhanced greenhouse gas emissions. Obviously, this is a typical compromise situation. Best solution is to be achieved only if both effects are considered simultaneously in a holistic manner (see figure 13).

Abb. 13 Compromise situation for GHG emission optimization



In the case of the GWP, figure 14 shows, that it is not useful to stabilise the waste to the maximum degree, as the overall results gets worse with longer process duration due to higher total energy input. Dependent on the methane oxidation capacity of the landfill cover the rotting duration in this case is best between 16 to 28 weeks.

Abb. 14 Minimum total GWP by best rotting duration



10.7 WARM - a tool for climate gas evaluation of waste management strategies

WARM (WAste REduction MOdel) was created by the U.S. Environmental Protection Agency (EPA) to support solid waste managers and organizations in planning waste management strategies under the climate aspect. It is available in a Web-based calculator format and as a Microsoft EXCEL spreadsheet (20).

WARM calculates GHG emissions for waste management practices, including source reduction, recycling, combustion, composting, and deposition. In every calculation case, a baseline and an alternative option are compared. The GHG emission factors were calculated following the LCA methodology (see chapter 8). A wide range of material is considered (see table 37).

Tab 37 GHG emission data of waste components used in WARM model (20)

Material	GHG Emissions of materials (t CO ₂ eq./t)				
	source reduced	recycled	deposited	combusted	composted
Aluminum Cans	-8,97	-14,93	0,04	0,06	
Steel Cans	-3,21	-1,79	0,04	-1,53	
Copper Wire	-7,55	-5,08	0,04	0,06	
Glass	-0,58	-0,28	0,04	0,05	
HDPE	-1,81	-1,41	0,04	0,90	
LDPE	-2,29	-1,71	0,04	0,90	
PET	-2,12	-1,55	0,04	1,07	
Corrugated Cardboard	-2,63	-2,74	0,59	-0,66	
Magazines/third-class mail	-4,30	-2,70	-0,23	-0,48	
Newspaper	-4,06	-3,49	-0,80	-0,75	
Office Paper	-3,64	-2,48	2,27	-0,63	
Phonebooks	-5,23	-3,34	-0,80	-0,75	
Textbooks	-4,82	-2,74	2,27	-0,63	
Dimensional Lumber	-2,02	-2,45	-0,39	-0,79	
Medium Density Fiberboard	-2,23	-2,47	-0,39	-0,79	
Food Scraps			0,84	-0,18	-0,20
Yard Trimmings			-0,15	-0,22	-0,20
Grass			0,03	-0,22	-0,20
Leaves			-0,10	-0,22	-0,20
Branches			-0,39	-0,22	-0,20
Mixed Paper, Broad		-3,17	0,52	-0,66	
Mixed Paper, Resid.		-3,17	0,42	-0,66	
Mixed Paper, Office		-3,06	0,64	-0,60	
Mixed Metals		-7,27	0,04	-0,47	
Mixed Plastics		-1,51	0,04	0,97	
Mixed Recyclables		-2,87	0,28	-0,62	
Mixed Organics			0,33	-0,20	-0,20
Mixed MSW			0,58	-0,13	
Carpet	-4,10	-7,36	0,04	0,37	
Personal Computers	-58,07	-2,46	0,04	-0,20	
Clay Bricks	-0,29		0,04		
Aggregate		-0,01	0,04		
Fly Ash		-0,87	0,04		

To use the model, it is necessary to define the waste management practices to be compared and to gather the waste management data, especially the type and amount of waste components at the existing waste management practice as well as in a prospected alternative scenario. For all technological characters of waste management processes, WARM model proposes certain values (see table 38), which may but changed if wanted.

Tab 38 Choices for technological items in WARM

Waste management practice	Program standard	Possible choices by customers
Benefits of source reduction	Current mix of virgin and recycled inputs (see table ...)	100% virgin input (represents an upper limit of possible effects)
Landfill gas recovery	National average based on the emission proportions of landfills with landfill gas control in 2000	Landfill gas recovery No Landfill gas
		Recover or energy Flare only
	Landfill gas efficiency after national average: 75%	Actual or predicted efficiency
Waste transportation distances	Estimated distances from the curb to the landfill or to a waste treatment facility, as combustion, recycling or composting : 20 miles	Actual distances

As a calculation example, a waste is considered, which consists of Aluminum and steel cans, glass, plastics (HTPE, PET), corrugated cardboard, as well as three types of organic matter, such as yard trimmings, grass, and leaves. The composition of the waste is given in table 40. The total mass is 800 tons.

The greenhouse gas effects were calculated under the following assumptions:

- The waste was deposited in a landfill, which is equipped with a landfill gas recovery system for electricity production. Land fill gas collection efficiency is 75 percent.
- Greenhouse gas emissions of deposition, recycling, combustion, composting, and source reduction are calculated after table 37.
- Benefits of recycling were calculated in comparison to the current mix of recycled and virgin matter in manufacturing (see figure 6)

Following scenarios were studies (see table 39):

Tab 39 Description of scenarios

Scenario	Description
0	Reference scenario: whole waste deposited
1	recycling of 50 percent of the waste components, without organic green matter
2	Same as 1, but total composting of the organic matter
3	Same as 2, but 50 percent of the plastics and the corrugated cardboard are combusted
4	Same as 3, but no recycling, 100 percent combusted
5	Same as 2, but no combustion, 100 percent recycling
6	Same as 2, but 25 percent of aluminum and steel cans deposited and 25 percent source reduced

Tab 40 Mass balances of the scenarios

Waste material	Waste mass	Scenario					
		0	1	2	3	4	5
		Recycling	Composting	Combustion	Combustion	Recycling	Source reduced
Aluminium cans	100	50					25
Steel cans	60	30					15
Glass	40	20					10
HDPE	100	50		50	100	100	
PET	100	50		50	100	100	
Corrugated cardboard	100	50		50	100	100	
Yard trimmings	100		100				
Grass	100		100				
Leaves	100		100				
CO₂-effect	0	-1128	-1165	-1134	-783	-1484	-1764

The results are given in figure 15.

Abb. 15 Greenhouse gas reduction by various scenarios

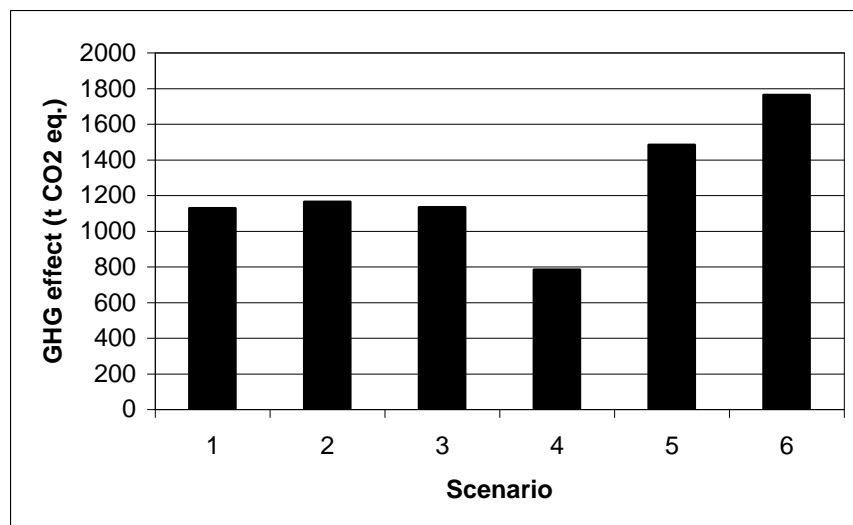


Figure 15 indicates that each waste scenario other than deposition on the landfill improves the greenhouse gas balance considerably.

Recycling of 50 percent of metals, glass, and plastics fraction, results in 1.128 t CO₂ eq. reduction (Scenario 1). Organics are deposited in this scenario. If organics are fully composted (Scenario 2), an only small improvement in the CO₂ balance occurs (1165). If 50 percent of the plastics are combusted instead of deposited (Scenario 3), nearly no effect results compared with scenario 2. Obviously, in this case, the amount of GHG produced at landfill and at combustion is nearly the same.

But if a fraction of 50 percent of plastics is combusted instead of recycling (Scenario 4), the result is much worse, due to the fact that GHG emission reduction by recycling no longer exists. This becomes even more evident, if a 100 percent recycling is considered (Scenario 5). In this case, a high reduction in GHG emissions occurs. Also very positive effects can be achieved, if a portion of the metal and glass fraction is source reduced (Scenario 6). In the case considered, 50 percent are recycled, but 25 percent are deposited and other 25 percent source separated.

11 Energy related greenhouse gas emissions

11.1 Energy contribution to GHG emissions - overview

Energy related activities are the primary source of anthropogenic greenhouse gas emissions. They are mainly caused by direct greenhouse gases, such as CO₂, CH₄ and N₂O. Also indirect greenhouse gases, such as NO_x, CO, and NMVOCs are emitted. The majority of these emissions come from fossil fuel combustion, with CO₂ being the primary gas emitted in an amount of about 25.575 million tons CO₂ equivalents annually on global scale (11).

Globally, following can be observed with reference year 2002 (see table 41):

Tab 41 Energy related greenhouse gas emissions

Emission source	Contribution to emissions	Facts and trends
Liquid and solid fuels	76,8% of emissions from fossil-fuel burning	
Combustion of gas fuels (e.g. natural gas)	19,3% of total emissions of fossil fuel	1348 million ton carbon gradually increasing global utilization of natural gas
Cement production	3,5% of fossil fuel burning and cement production	245 million tons of Carbon, doubled since mid 1970s
Gas flaring	<1%	Reducing trend; 2% in the mid 1970s

The increase in energy consumption on base of fossil fuels is a world trend. An increase of 2 percent between 2000 and 2002 was recorded.

The contribution of the national economies is very different, in total, structure, and in per capita numbers.

- The contribution of the United States in the CO₂ emissions is about 23 percent of the global emissions (28). Energy related activities accounted for 86 percent of total U.S. emissions (in 2004), measured on CO₂ eq.-base, amongst them CO₂-emissions contribute to 82 percent, whereas non-CO₂-emissions from energy related activities represent only 4 percent. 97, 39, and 15 percent of the nation's CO₂, CH₄ and N₂O emissions, respectively, are included in this number. US energy mix is based on 40,1percent petroleum, 22,5% coal, 23,0% natural gas, 8,2% nuclear, and 6,1% renewable. U.S. power plant GHG emissions total to 2,65 billion tons of CO₂ eq.(22). The emissions of the national average fuel mix for electricity is 0,0549 t CO₂ eq./GJ electricity produced (or 15,79 kg carbon eq. per million Btu).
- In Germany, fossil-fuel emissions of CO₂ have declined 18,1 percent since 1990 to about 800 million ton of CO₂ eq. (in 2002). This means an average per capita emission of about less than 10 ton of CO₂, which is comparable to mid 1950s levels. Largest fraction of emissions (40,4 percent) is from burning of solid fuels. Natural gas burning is 21,5 percent of the total emissions. The energy mix for power production is given in table 42. From the date by using an energy efficiency factor for power production of 28,6 percent, a factor of 0,0794 t CO₂ eq./GJ results.

Tab 42 Power production energy mix in Germany (in 2000) (%) (10)

Hard coal	Lignite	Oil	Natural gas	Nuclear energy	Hydro Power	Others
25	27	1	6	36	4	1

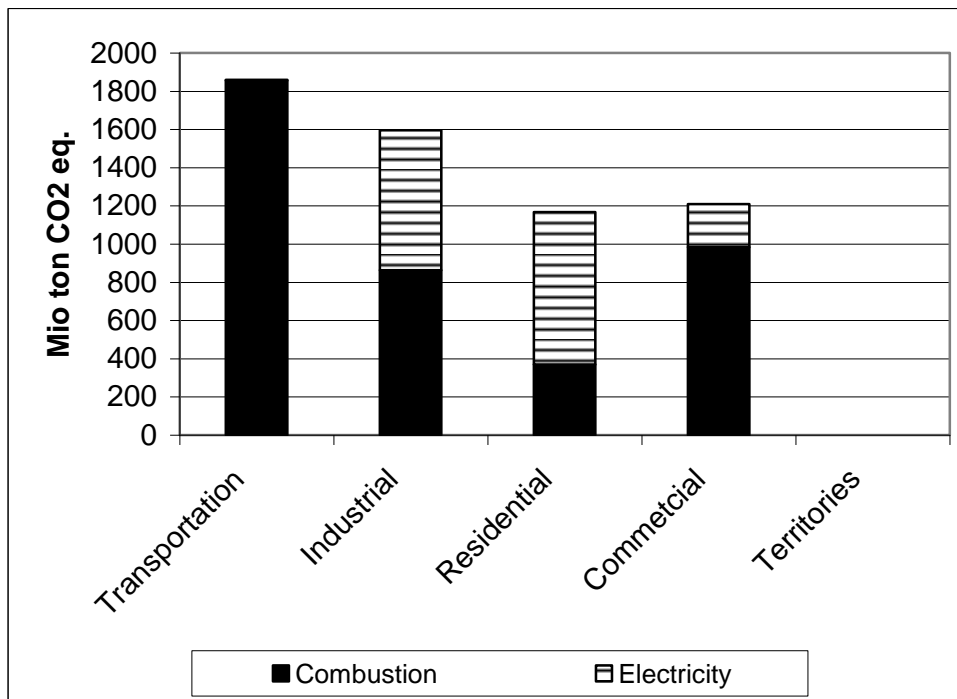
- Amongst other Western European Countries, United Kingdom is emitting about 15,7 ton CO₂ per capita annually (2002), compared to France with only about 6,2 (22).
- Africa's fossil-fuel CO₂ emissions are low in both absolute and per capita terms. They are not reaching 900 million ton of CO₂ eq. in 2002. Per capita emissions are only about 5 percent of the comparable value for North America. Fuels account for 15,6 percent. The emissions are mostly due to the activities of only a few countries, amongst them South Africa accounts for 40% of the continental total, and another 44% of the CO₂ comes from Egypt, Algeria, Nigeria, Libya and Morocco combined.
- In Thailand, the total consumption of fossil fuels is about 232 million tons CO₂ eq. annually (2002) with a per capita rate of 3,7 ton per head. The consumption more the doubles very 10 years. Cement production actually contributes to less than 2 percent.

Besides combustion of fuel, also all other energy related activities such as production, transmission, storage, and distribution of fossil fuels, emit greenhouse gases. These emissions mostly originate from fugitive methane from natural gas and petroleum systems, and coal mining. During these processes, also CO₂ as a direct greenhouse gas, as well as CO, NO_x and NMVOCs are emitted, but in smaller quantities.

The industrial end use sector includes activities such as manufacturing, construction, mining, and agriculture. Manufacturing is the largest consumer of energy. Six industries comprising petroleum refineries, chemicals, primary metals, paper, food, and nonmetallic mineral products, represent the majority of energy use.

In the case of the United States, the industrial end use sector accounts for 28 percent of CO₂ emissions from fossil fuel combustion, from which 54 result from the direct consumption of fossil fuels for steam and process heat. The other part (46 percent) is used for consumption of electricity for uses such as motors, electrical furnaces, and lighting - see figure 16.

Abb. 16 U.S. GHG emissions from fossil fuel consumption by end use sector (in 2004, Mio tons CO₂ eq.) (7)



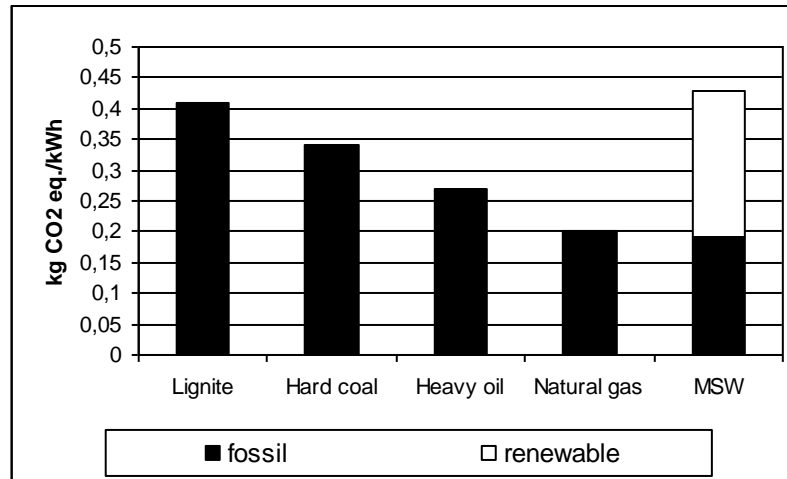
11.2 Potentials of emission reduction by fuel substitution

11.2.1 GHG emissions by fuels

Higher energy efficiency and a reduced energy input into the economy are favorable means of reducing energy related emissions. But despite this, the reduction of energy related emissions is also possible by a substitution of fuels. The fact behind is, that fuels are different by the energy content per unit mass, but also by the CO₂ emissions per energy unit, defined as specific emissions (e.g. t CO₂ eq./GJ). Thus, an improved climate situation may result from a shift from high emitting to low emitting fuels.

In the case of fossil fuels as well as biomass fuels, the GHG emissions are dependent upon the carbon content of the fuel and the fraction of carbon that is oxidized. In general, the carbon content is highest for coal products, followed by petroleum, but lowest in the case of natural gas - see figure 17.

Abb. 17 Specific CO₂ emissions of fossil fuels



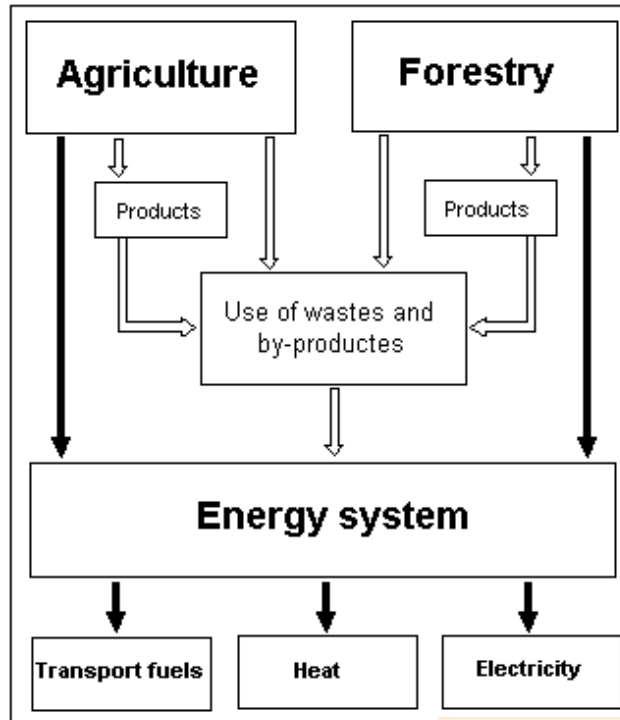
Other energy sources may be directly or indirectly carbon neutral; their specific carbon dioxide emission factors are 0 g CO₂ eq./kWh. Energy generated from nuclear sources, as well as renewable resources, such as wind, hydropower, and solar radiation, do not result in direct emissions. Geothermal energy is not CO₂ neutral, since small quantities of CO₂ are normally released from the geological formations tapped for this energy form.

It is to be mentioned that so called Clean Coal Technologies are under study as innovative technologies for coal fired power stations which aim to capture all carbon dioxide potentially emitted and store it in suitable geological formations (on shore storage). A first of such power stations with a capacity of 450 MW is planned for a start in 2014 (48). This may be considered as a CO₂ sequestration technique, which would make possible a climate neutral power supply in the nearer future. The fact of the long term depleting of fossil resources will but not be affected.

11.2.2 Climate effects of the substitution of fossil fuels by bio-fuels

Fossil fuels can be substituted by biogenic fuels, which may be derived from agriculture and forestry directly, or via the waste route from wasted material of biogenic origin. Principal routes see figure 18.

Abb. 18 Principal pathways from biogenic material into the energy system (after 41)



The combustion of biomass, biomass-derived fuels, or biogenic wastes, such as wood, bio-ethanol, bio-diesel, and biogas, also results in greenhouse gases emissions. But these emissions are not addressed to climate change. As emissions are from biogenic material (and if the materials are grown on a sustainable basis), those emissions are considered to close the loop of the natural carbon cycle. The reason is, that they origin from atmospheric carbon dioxide from which they were taken by photosynthesis. CO₂ produced from biogenic sources under natural conditions will return to the atmosphere at the same amount. If there are metabolites or results from processes other than CO₂, such as methane, N₂O, NO_x, etc., than these substances are considered climate relevant and their greenhouse gas effects must be balanced.

With reference to the fraction of carbon that is oxidized, it is to be stated, that most combustion processes are not 100 percent energy efficient. The numbers are estimated to about 1 and 0,5 percent, for petroleum and natural gas, respectively. Only in the case of motor fuels, 100 percent combustion is assumed. The carbon contained in the fuel not emitted into the atmosphere as CO₂, remains as a constituent of soot, ash, or slag. It is assumed, that the combustion products are finally oxidized to CO₂ in the atmosphere.

11.2.2.1 Biofuels - facts and definitions

The most effective option for reduced greenhouse gas emissions in the energy sector - and hence due to its very important influence on the global greenhouse balance - is to be seen in a substitution of fossil fuels by renewable sources.

Types of bio-fuels in the market are given in table 43.

Tab 43 Bio-fuels types and market products

Bio-fuel	Liquid or gaseous fuel for transport, produced from biomass
Bio-mass	Biodegradable fraction of products, waste and residues from agriculture including vegetal and animal substances, forestry and related industries, as well the biodegradable fraction of industrial and municipal waste
Synthetic bio-fuels	Synthetic hydrocarbons or mixtures of synthetic hydrocarbons produced from biomass, e.g. SynGas produced from gasification of forestry biomass or SynDiesel
2 nd generation bio-fuels	Bio-fuels made from willows, and Fischer-Tropsch diesel made from wood crops via gasification of the biomass
Liquid bio-fuels	
Bio-ethanol	Ethanol produced from biomass and/or biodegradable fraction of waste, for use as bio-fuel. Specification: E"x" contains x% ethanol and (100-x)% petrol, e.g. E5 and E95
Bio-diesel	A methyl-ester produced from vegetable oil, animal oil, or recycled fats and oils of diesel quality, for use as bio-fuel (PME, RME, FAME). Specification: B"y" contains (100-y)% petroleum-based diesel and x% bio-diesel, e.g. B5, B30, and B100 (non-blended bio-diesel)
Bio-methanol	Methanol produced from biomass, for use as bio-fuel
Bio-ETBE	Ethyl-Tertio-Butyl-Ether, produced from bio-ethanol, used as fuel additive to increase the octane rating and reduce knocking. Percentage volume of bio-ETBE calculated as bio-fuel: 47%
Bio-MTBE	Methyl-Tertio-Butyl-Ether, produced from bio-methanol, used as fuel additive to increase the octane rating and reduce knocking. Percentage volume of bio-MTBE calculated as bio-fuel: 36%
BtL	Biomass to Liquid (2 nd generation bio-fuels)
Pure vegetable oil	Oil produced from oil plants through pressing, extraction or comparable procedures, crude or reined but chemically unmodified. Usable as bio-fuel, if compatible with the type of engine involved and the corresponding emission requirements

Gaseous bio-fuels	
Bio-DME	Dimethylether produced from biomass, for use as bio-fuel
Biogas	A fuel gas produced from biomass and/or the biodegradable fraction of waste (in technical equipment, such as MBP technology, or as landfill gas), used as a fuels for power stations. Can be purified to natural gas quality for use as bio-fuel or woodgas.
Bio-hydrogen	Hydrogen produced from biomass and/or the biodegradable fraction or waste for use as bio-fuel

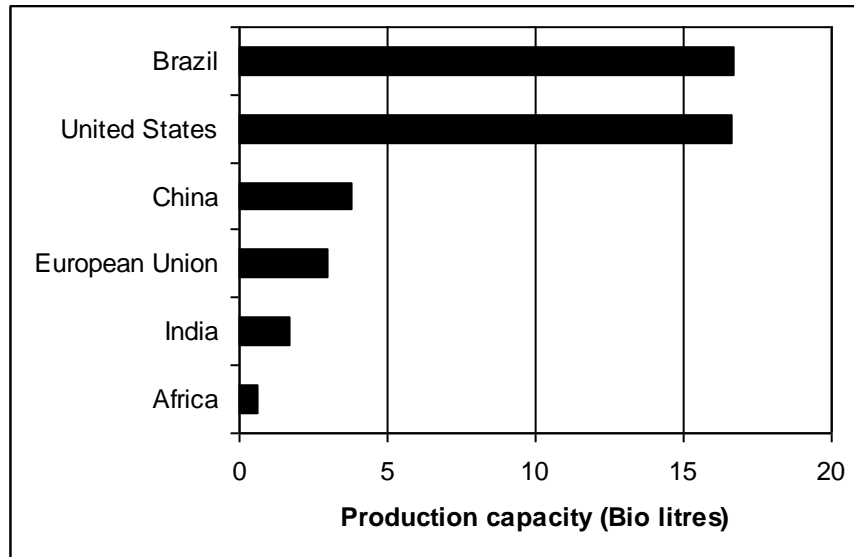
Amongst these types of bio-fuels, bio-fuels of the 1st generation are applied and will be more intensively introduced into the markets until 2010. Afterwards, bio-fuels of the 2nd generation will come into application after 2010 to 2020 as a result of intensive research, which is already in the state of demonstration projects (see table 44).

Tab 44 Renewable fuels applicability timescale in U.K. (35)

Commercial applicability	Bio-fuel	Possible sources
To 2010	Bio-ethanol	Starch and sugar crops: Wheat grain, sugar beet, sugar cane, sorghum, corn
	Bio-diesel	Oil crops and wastes: Rapeseed, sunflower, soybean, palm oil, jatropha, waste vegetable oil, waste animal fat
	Bio-gas	Organic waste from agriculture (animal farming), wet energy crops
2010-2020	Bio-diesel, bio-ethanol and bio-gas	As 2010
	Bio-ethanol	Lignocellulose biomass: straw, wood, biodegradable municipal solid waste
	Fischer-Tropsch diesel	
	Hydrogen	Electrolysis of water using renewable electricity. Biomass feed-stocks (lignocellulose wastes, wet feed-stocks)

Production capacities for bio-fuels are already considerably as a result of the policy measures. Recently, total bio-fuel production amounted to about 35 billion litres world wide. It develops very progressively; growth rates of more than 10 percent per year are envisaged. Bio-ethanol is the world's main bio-fuel which was around 30 billion litres. This represents 2 percent of the global petrol use. World bio-ethanol production is given in figure 19.

Abb. 19 World ethanol production (2004) (29)



Bio-diesel is mostly produced in the EU, by 1,9 mio tons annually (in 2002) . especially in Germany (1,035 mio ton in 2004), followed by France and Italy.

11.2.2.2 Current policies promoting climate efficient bio-fuels

The statements made in the previous chapter should be considered by policies promoting bio-fuels. Such policies moreover are necessary, since most bio-fuels are still more costly than fossil fuels and thus have to be encouraged e.g. by financial and organisational support. Some examples in different countries are as follows:

- A *Bio-fuels directive* (32) for bio-fuel use was developed by the European Commission, with the objectives of i) reducing climate effects on an acceptable cost-benefit relation, ii) avoidance of environmental damages by the production of the bio-fuels as well as of its raw materials, and iii) guarantee, that no extra burdens on ecology or technical problems arise. Other aims are the diversifying the fuel supply sources and development of long-term replacement of fossil fuel (29). Moreover, it is expected to offer new income and employment in rural regions. The bio-fuels directive had set reference values of 2 percent market share for bio-fuels in 2005, which was but not achieved in his reference year. In 2010, a 5,75 percent share is planned. To implement the directive, some EU members are relying on tax exemptions, which are facilitated by the *Enquiry Taxation Directive* (33). Other measures are bio-fuel obligations, requiring fuel suppliers to incorporate a certain percentage of bio-fuels in the fuel marketed.
- In Germany, Governmental In is to double the use of renewable energies by 2010, compared with 2000. For electricity, an enhancement of 12,5 percent is envisages, and 4 percent of primary energy use. In the long run, by the year 2030, renewables could cover a quarter of the total energy needs by biomass feedstocks.
- With respect to the reducing road transport sector CO₂ emissions, “low fossil carbon fuels” are recommended by the CARS 21 group (30), and 2nd generation bio-fuels (see table 43) are seen as particularly important.
- A number of countries other than EU member states also have set targets for incorporation into conventional fuel of bio-fuels. Amongst the measures, there are mandatory mixing percentage (e.g. Brazil, 25% mandatory; Canada: 3,5% target for 2010; in Ontario 5% for 2007), tax credits or incentives to bio-fuels producers or reduced fuel taxes (India: purchasing policy, 5% oil from indigenous plants in 2006, rising to 20% in 2020), or tax credits for vehicles (Brazil and Thailand for cars run on bio-fuels; Thailand supports the development of a green vehicle) (29).
- Most simulating for bio-fuels was the Brazil Proalcool programme, launched in this country after the energy crisis of 1975. An extra aim was to develop a use for surplus sugar production. In Brazil currently all petrol is sold by an ethanol component of 20 to 26 percent. A new legislation on bio-diesel was implemented in 2004.
- In the United States, which is the world’s second largest bio-ethanol producer, a series of tax measures and incentives were followed by an exponential rise in the production. In 2004 the *Volumetric Ethanol Excise Tax Credit (VEETC)* extended the existing tax incentives until 2010. In 2005, as part of a new energy bill, a *Renewable Fuels Standard (RFS)* was introduced, with a target rising 4 billion gallon in 2006 to 7,5 by 2012. A coming *Bio-ethanol Bill* will require a 5 percent blend of bio-ethanol within two years after coming the act into force, and other 5 percent in the following two years (29).

11.2.2.3 Climate consequences of bio-fuels

Positive effects of bio-fuels are primarily due to the reduction of greenhouse gas emissions. At the same time the reduction of the demands of fossil material sources is considered, and hence, the enhancement of the lifetime of this scarce and expensive resource. Moreover, it supports the development of the agriculture in rural regions, broadens the activity field of farmers, and opens new markets for products such as sugar. In many cases, residues from agriculture as well as from industry can be used as raw material sources of bio-fuels, thus also contributing to reduce negative environmental effects of poor wastes management.

Not in every case the intended positive effects will fully occur, and negative effects also have to be considered. Under the sustainability aspect, following argumentation speaks for a detailed analysis of the environmental benefits of bio-fuels (31):

As was discussed above, the production of bio-fuels is considered mostly carbon-neutral, since the plants capture CO₂ from the atmosphere during their growth. But this is not realised by 100 percent. Some bio-fuels are not grown environmental friendly, because they need pesticides and fertilizers, which besides production efforts (see chapter 8), give rise to water and air pollution.

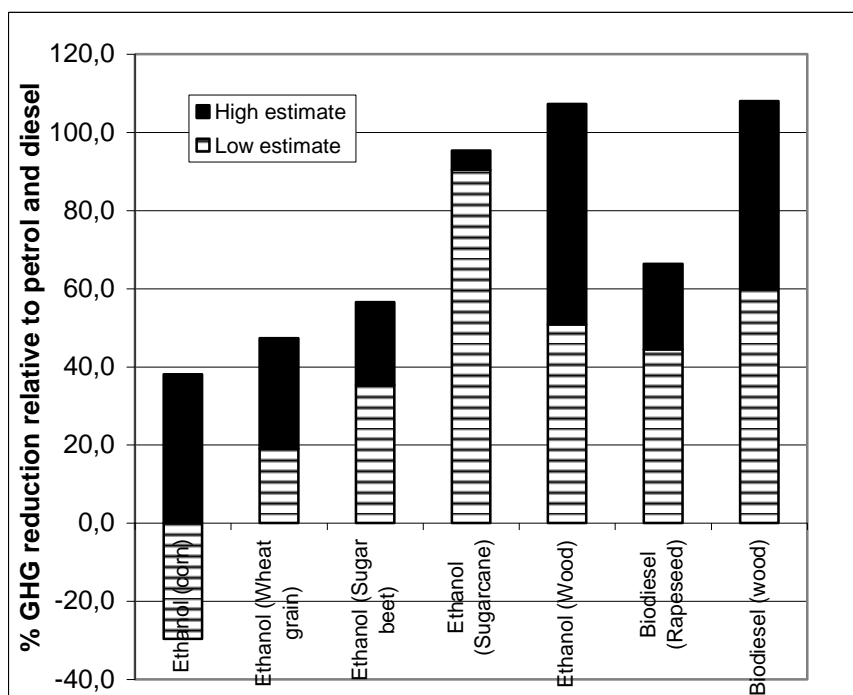
Concern is about possible negative impacts on biodiversity if areas of monoculture result. In the international context, the main environmental risks are likely to be those concerning any large expansion in bio-fuel feedstock production, and particularly in Brazil for sugar cane and South East Asia for palm oil plantations. Growing demand for palm oil may be effectively contributing to clearance of rainforest in countries like Malaysia and Indonesia (34). Moreover, energy is needed to grow the plants and to produce the bio-fuels from the crop. CO₂ is emitted out of the soil (see chapter...); after use of nitrogen fertilizers, considerable emissions of N₂O occur.

Ecological balancing of bio-fuels (34) indicates in the case of the production of bio-ethanol and bio-diesel that the result may cover a wide range of GHG emissions after the specific conditions given on site.

Figure 20 indicates the reduction potentials for bio-ethanol and bio-diesel after values form a literature survey (35), which covers a wide range of conditions. Best and worst results of the studies are shown. GHG emissions of actual cases would lie between these extremes. The results are presented as differences between bio-fuels and fossil based petrol or diesel.

In general they elucidate, that GHG emissions range is between negative values and more that 100 percent. Negative values indicate that more GHG emissions occur compared the fossil fuel production. A value of more than 100 percent means, that not only the GHG emissions from fossil fuels are compensated, but a bonus results from benefits of by-products such as renewable energy generated during the fuel production. In some cases there is more energy transformed into power than into bio-fuel resulting.

Abb. 20 Estimate of the GHG effects of bio-fuel production variants (35)



Bio-ethanol

For bio-ethanol in figure 20 five variants of feed-stocks are shown with improving results ranging from minus 30 to 110 percent. Worst case is corn, followed by grain and sugar beet. Sugar cans and wood are best suited. Bio-ethanol-production from corn as a feed-stock is connected with a high input of agrochemicals and pesticides, but also with high power needs or the production. Wheat and sugar beet are in the medium range. Best values are reached with sugar cane or wood. Sugar cane is the basic feed-stock for the Brazilian Bio-ethanol programme (Proalcool).

This is due to the fact that favourable cultivation conditions pre-dominate under the Brazilian climate. The assessment after a “well-to-wheel” approach indicates, that even the GHG efforts for the long transport from South America to Europe do not compensate the positive effects. The positive results using wood as a feedstock are the result of a gasification of wood and the transformation into ethanol by a Fischer-Tropsch process.

A more detailed approach to an analysis of the GHG emissions of the bio-ethanol production is given in table 45 in the case of wheat. The table contains every process step and a range of concrete GHG emission values as well as the key variables, which influence the process result.

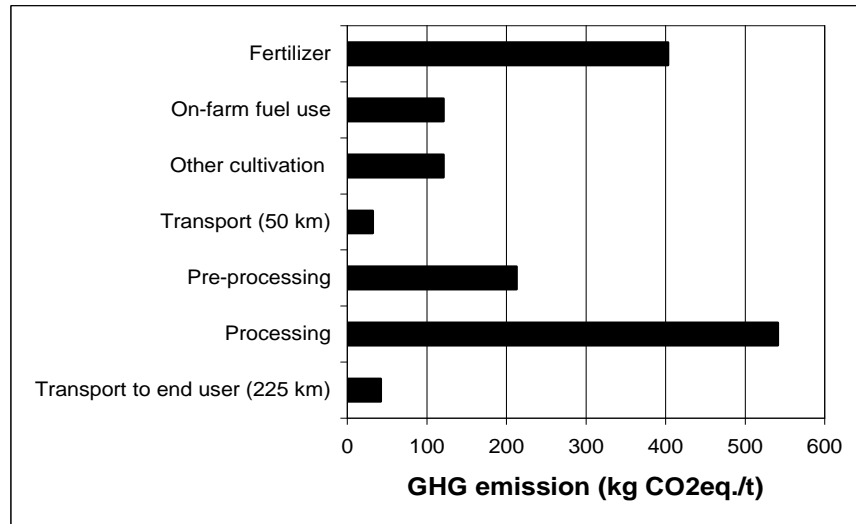
Tab 45 Factors effecting greenhouse gas emission of bio-ethanol (after 35)

Source of emission	Emission (kg CO ₂ eq./t bio-ethanol)		Key variables
Feedstock-production			
Land use change	0	>1000	Type of vegetation replaced (Only significant were deforestation or vegetation change occur)
Fertilizer manufacture	0	450	Type of fertilizer, fertilizing regime; crop yield, co-products
Emissions from soil	0	100	Soil conditions, climate, fertilizer applied, co-products
Fossil fuel used for cultivation	60	180	Tillage methods, tractor efficiency, co-products
Fossil fuel used for drying and storage	10	100	Farm equipment, energy used for drying, co-products
Transport and processing			
Fossil fuel for transport	20	50	Distance from farm process, mode of transport

Processing			
Fossil fuel used for processing such as crushing, cleaning, drying	50	250	Type of crusher, moisture content, fuel used to power crusher, co-products
Hydrolysis, fermentation, distillation	-700	550	Type of process, export of heat and/or electricity
Transportation of product (Bio-ethanol)	20	80	Distance from farm to process, mode of transport
Total range	-540	>2900	Extremes are unlikely but possible
Unleaded gasoline		3135	

The resulting GHG emissions numbers range from -540 to 2900 kg CO₂ eq./t bio-ethanol produced. Extremes are unlikely, but possible. Typical values from a bio-ethanol production from wheat under British conditions are given in figure 21.

Abb. 21 Typical GHG emissions for bio-ethanol production from Wheat (35)



Bio-diesel

With bio-diesel, the improvements after figure 20 even in the worse case are in the range of more than 50 percent. Best result with effects of more than 100 percent would also here be reached in the case of processing of wood in a Fischer-Tropsch synthesis, where by-products of the process, as power production, are considered.

With rapeseed as a feedstock of bio-diesel (as RME) the life cycle assessment comes down with the benefits for the greenhouse gas balance, but with disadvantages in the other assessment criteria such as nutrition potential, photochemical ozone formation potential, and ozone depletion potential (with a number of 119) (see figure 22).

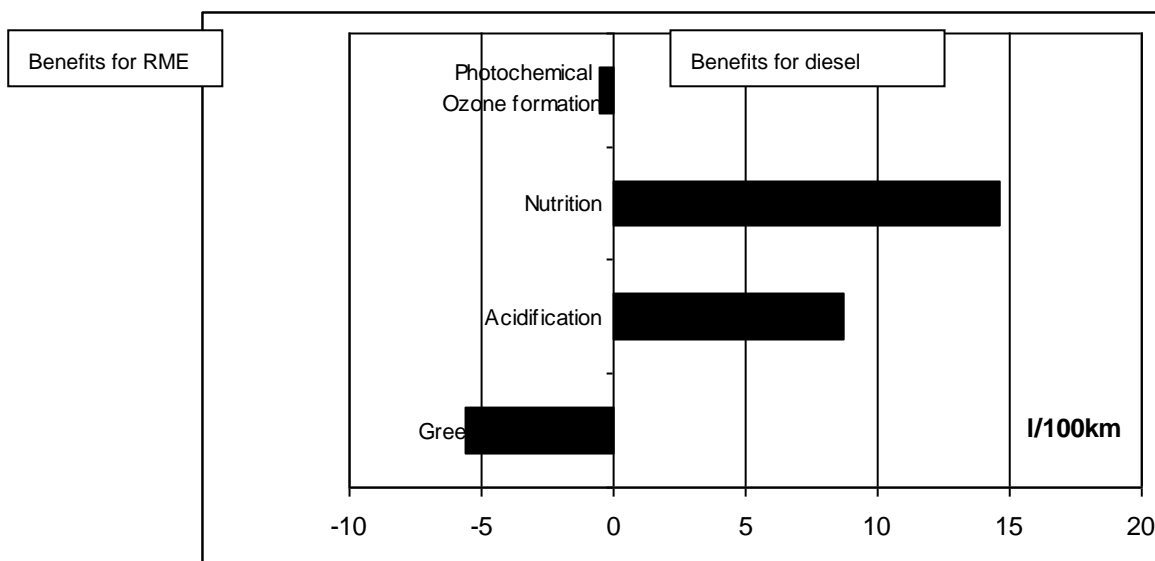


Abb. 22 Comparison of Bio-diesel (RME) and diesel after LCA (44)

The figure indicates the effect of the use of bio-diesel instead of fossil based diesel, relative to 100 km driving distance. In the case of the greenhouse effect, the emissions of 6 litres of diesel produced are avoided at a distance of 100 km driven by bio-ethanol, which in absolute numbers amounts to about 2,2 kg CO₂ eq. per litre RME. This means a clear climate related advantage for bio-diesel. But we have to notice, that some LCA criteria, such as nutrition, acidification, as well as ozone depletion, come down with disadvantages for bio-diesel. With photochemical ozone formation no clear advantage is seen. Therefore, considering all effects, a simple scientifically based decision pro bio-diesel is not possible. Only if climate effects alone are considered important, than bio-diesel is the favourite solution.

As a consequence a full reduction of greenhouse gas emissions compared to petrol or diesel is possible only if considering combined processes. Thus, such technology developments are to be supported, instead of simple replacement of fuels. If a replacement is envisaged in a first approach, it is recommended to focus on such feed-stocks, which result in a more than 50 percent emission reduction throughout the total supply chain. In future, 80 percent reduction should be envisaged as the target. Moreover, the production of bio-fuels should also fulfil criteria concerning the origin, the production chain, and social aspects, especially when imported from lower developed countries (31).

12 Personal activities

The information contained in the previous chapters may have given an insight into the climate change problems and some of the approaches to reduce climate burdens, especially if applied in the fields of industry, energy production, waste management, or agriculture. It is the task of the managers in the companies, the scientists and the engineers, the waste managers, or the farmers, to start activities to improve the situation in the field of their own responsibility.

But what about the people in everyday life?

Following, there are a few simple things each of us can do und thus supporting reduction of climate burdens (46):

Reduce, re-use, recycle

Buy products that feature reusable, recyclable, or reduced packaging to save energy required to manufacture new containers.

Use recycling systems provided by Your waste management company. By recycling all of Your home's waste newsprint, cardboard, glass, metal, and organics, carbon dioxide emissions can be reduced by about 500 kg CO₂ eq. annually.

Reduce fossil fuel consumption

Think about giving Your car a day off. Consider transportation alternatives such as mass transit, carpooling, bicycling, and telecommunicating. By leaving Your car at home two days a week, You can reduce carbon dioxide emissions by 800 kg CO₂ eq. a year. When You do drive, keep Your car tuned up and its tires properly inflated to save fuel costs. Reduce speed.

Consider a fuel-smart car. When buying a car, purchase a fuel-efficient vehicle - one that gets more miles to the litre of fuel than Your current vehicle.

Tune up Your home

Go solar. Install a solar thermal system in Your home to help provide Your hot water, and thus reduce Your carbon dioxide emissions by about 400 kg CO₂ eq. annually.

Encourage Your utility to do its part. Many local utility companies offer energy from clean sources such as high efficiency natural gas-fired power plants, or renewables such as solar and wind.

Insulate Your home, caulk windows and doors, and tune up Your furnace by changing to cleaner or renewable energy.

Get involved at public and in work

Plant trees. Trees absorb carbon dioxide from the air. Join family members, neighbours, or community service groups in planting trees in Your yard, along roadways, at schools, and in parks.

Educate others. Encourage others to take practical, energy-saving steps that save money while protecting the environment and help reduce climate burdens.

Your company can save money by joining waste recycling programs and buying office equipment with environmental proof labels.

Exercise:

A communal waste manager may have to decide, in which way the waste management practice of the community is to be changed to considerably reduce the GHG emissions. The waste amount is 10.000 tons annually, the waste composition is given after table 46.

Tab 46 Waste composition example

Waste component	Percentage
Aluminum cans	10
Steel cans	10
Glass	10
HDPE	5
LDPE	3
PET	2
Corrugated Cardboard	6
Newspaper	8
Magazines/third-class mail	4
Dimensional Lumber	8
Medium Density Fiberboard	8
Food Scraps	8
Yard Trimmings	8
Grass	7
Leaves	3

For this situation it is to be calculated, which benefits in terms of CO₂ equivalents result from a changing from a 100 percent deposition of the whole waste in a MSW sanitary landfill to variants of source reduction and recycling activities. Check source reduction rates and recycling rates of 25 and 50 %, both, as well as 100 percent composting of the compostable matter.

Are there variants to reduce the GHG emissions in total by 50 percent? Which of them would be most favourable?

For the resulting CO₂ reduction calculate equivalents of driving diistances with a middle class car (petrol use about 10 litres per 100 km).

For calculation You may use the WARM programme.

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