# WASTE MANAGEMENT IN LOW INCOME AND EMERGING COUNTRIES

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**Abstract.** Waste management situation in low income and emerging countries is mostly on a poor level, yet. The major reasons for the little progress during the last decades are significant demands in technical knowledge and political commitment, what generally outcomes in a crucial under financing of waste management activities. To achieve significant improvements it is essential to develop effective, reasonable technical solutions and to balance them with the financial means. Technical measures should aim on optimizing both environmental and economic benefits. Most recent developments proved that additional revenues may be obtained most likely from advanced recycling activities, from appropriate waste treatment techniques like MBT and from CDM. Useful measures in those three fields of waste management will be addressed in this paper.

**Keywords:** waste management, environmental benefits, material recycling.

## 1. Introduction

The approach for the sustainable usage of natural resources should lead to improved resource efficiency at the same time as a decrease of the negative ecological consequences of resource usage [1]. Following this approach, the instruments of waste management are also to be subject to a critical examination – this applies to highly developed countries as well as to developing countries to the same extent. In this document, classifications of various waste management instruments are planned with respect to a sustainable use of resources and consequences for waste management measures in developing and emerging countries are developed.

A.M. Bahadir and G. Duca (eds.), *The Role of Ecological Chemistry in Pollution Research and Sustainable Development*,
© Springer Science + Business Media B.V. 2009

## 2. Sustainability of different recycling methods

### *2.1. Main recycling methods*

A high degree of importance is to be awarded to the judgement of the principally applied recycling with respect to a sustainable use of resources. Fundamentally, according to European nomenclature, two forms of recycling can be defined: material recycling and energy recycling.

*Material recycling* is the substitution of raw materials through the gaining of material from waste, the use of the material characteristics of waste for the original purpose or for other purposes with the exception of the direct energy recovery. Under this we subsume material recycling, raw material recycling and biological recycling with composting (aerobic process) and fermentation (anaerobic process).

For the *energy recycling* of waste, the main purpose of the measure has to lie in the use of the waste. As a rule in energy recycling, waste products are utilized which are transferred by preceding mechanical pretreatment steps into high-value products, characterized by high heating values and low pollutant contents.

### *2.2. Assessment of the utilization options*

The sustainability of waste management strategies is to be judged via the topics:

- Resource efficiency
- Damage to the environment

For resource efficiency and damage to the environment, the cumulative consumption/yield and damage to the environment are to be considered – from the cradle to the grave. Whereby not only the direct consumption of resources and yields or damage to the environment of the various recycling processes including the measures necessary for record keeping are to be considered. The effects which result from the use of primary raw materials compared to secondary raw materials during the creation of new products are also to be included in the observations.

To judge the material and energy recycling processes for recycling, the resource energy with the consequences of its use is to be categorized as a main indicator. As a rule, climatic effectiveness can also be categorized here.

The judgement of various recycling strategies in relation to a sustainable use of natural resources is of particular relevance in the waste fractions of paper and cardboard as well plastics and metals. The question about the type of recycling for metals is asked against the background of whether and with which quantity and quality the various metals can be separated from the waste stream and recycled.

### 2.2.1. Paper/Cardboard

The cumulated energy (Table 2.2.1.1.) demand for the production of fresh fibre paper of northern origin (e.g., Norway, Finland) amounts to approx. 39 MJ/kg [11]. According to the latest details from the paper industry, it was possible to somewhat reduce the energy demand for the production of fresh fibre paper. The cumulated energy demand for the production of fibre from recycled paper comes to approx. 15 MJ/kg. During the energy recycling of waste and secondary fuels in waste incineration plants and specially constructed power plants with energy efficiency factors of approx. 21% (pure electricity generation) up to approx. 76% (pure steam generation, steam use or combined heat and power (CHP) can be reached.

**Table 2.2.1.1.** Cumulated energy demand during the production of paper on the basis of fresh fibres and recycled paper fibres as well as energy savings during material and energy recycling at different energy efficiency factors – declaration of values according to the framework conditions in Germany.

| Cumulated energy demand (CED) fresh fibre paper production | Cumulated energy demand (CED) fibre production from recycled paper | Energy saving using fibres from recycling paper compared to fresh fibres | Combustion enthalpy/ calorific value of paper in MSW | Energy saving using energy recycling with energy efficiency of 21% | Energy saving using energy recycling with energy efficiency of 39% | Energy saving using energy recycling with energy efficiency of 76% |
|---|---|---|---|---|---|---|
| 39 MJ/kg | 15 MJ/kg | 24 MJ/kg | 13.2 MJ/kg | 10 MJ/kg | 5.2 MJ/kg | 2.8 MJ/kg |

Together with the energy efficiency of the material recycling compared to the energy recycling which is clearly better, the climatologically effects of material recycling are also to be categorized more favourably [11, 15, 20]. Other environmental benefits of material recycling are:

- Significant reduction of demand for processed water of approx. 20 $m^3$/t paper compared to the production of fresh fibre paper with a demand of approx. 50 $m^3$/t paper
- Reduction of the amount of waste water
- Lower contribution to acidification through lower content of sulphur in the waste lye

The indicators shown in the sector resource efficiency demonstrate – for the resources of energy and water – significant advantages of material recycling compared to energy recycling of the Paper/cardboard fraction. Also in the sector on damage to the environment, advantages are to be listed, especially in the air emissions (climate relevance) and water pollution.

### 2.2.2. Plastics

Kindler and Nikles [14] investigated the energy demand for the production and processing of plastics. Despite the age of these studies, the energy demanded ought to differ only insignificantly from the consumption which is usual today. Kindler and Nikles calculated, e.g. an energy demand of 51 MJ/kg for PVC. A current study by PlasticEurope from 2008 [16] estimates a value of 55 MJ/kg. For polypropylene (PP) this value is at 72 MJ/kg, for Polyamide-6 even 166 MJ/kg. Per tonne of plastic produced, between 1.5 and 4 times of crude oil equivalent are consumed. Energy demands for the preparation of polymers (finished products) are not yet included in the values cited on polymer production.

The combustion enthalpy demonstrates large ranges for the different polymers, such as, e.g., PE and PP 43 MJ/kg, PVC 18 MJ/kg. Our own analyses of plastic waste from MSW, performed in the framework of analyses of MSW, resulted in an average calorific value of 23.2 MJ/kg for films and 26.7 MJ/kg for high-density (HD) plastics. The relatively low calorific values resulted from residuals of various waste components (organic, mineral, water) as well as the remains of liquids in the containers.

The following table shows the relationship of the energy demand required for the production of various polymers to the achievable energy yield through energy recycling at different energy efficiency factors. The differences between cumulated energy demand for the production of the different polymers and of the usable potential for energy recycling show that energy recycling in general demonstrates a limited potential for energy saving. Whether an advantage to the benefit of material recycling will arise from this is initially dependant on whether the individual polymers are used in a high value material recycling. Polymers, such as polyethylene (PE), polypropylene (PP), polyethylenterephthalat (PET) and polyvinylchloride (PVC), which form the vast majority of the elements in plastic packaging, are basically suitable for high value material recycling.

The energy demand influences recording Collection, transport, sorting and refining (granulate/powder) as well as transport to the processor. For these process steps, the energy demands are clearly under 1 MJ/kg. Depending of the sorting intensity and the plastic product [9] indicate energy demands of 0.3–3.2 MJ/kg. The material-related energy losses are of prime importance. These are essentially caused by non- recoverable plastics in the sorting facility and qualitatively low value plastic fractions (polymer purity, contamination) in the output of the sorting and refining facility.

The indicators shown in the sector on resource efficiency demonstrate the advantages of material recycling compared to energy recycling for the resource energy, this applies particularly to packaging plastic with large parts. The advantages of material recycling are also predominant [9] in the sector on damage to the environment.

### 2.2.3. Metals

The significance of metal recycling for the resource of energy is explained using the examples of steel, aluminium and copper, the predominant metals in MSW. In household and commercial waste, the metals fraction demonstrates the highest specific potential for saving energy and protecting the environment [9,;13,15]. The achieved separation of ferrous material by using magnetic separator and nonferrous material by using eddy current separation has a considerable influence on energy and resource saving. For sorting plants, the separation of ferrous metals is estimated to be up to 98%, and up to 84.7% for nonferrous separation (Al) [9]. The estimated ferrous separation is characterized as extraordinarily high according to the authors. The authors' own mass balances in mechanical processing steps of MBT facilities, gave values of up to a maximum of 86% for ferrous separation [7]. The ferrous and nonferrous separation from slag is fundamentally the best available technology available [12, 18]. Data about describe the efficiency of separation efficiency from slag is rarely available. The shortage of data available especially for nonferrous metals is, among other things, due to slag processing as a rule not taking place at the waste incineration facility. Tin plate and aluminium films are crushed during the incineration process and to fine grain and agglomerated with the slag according to Urban (spoken communication, 2008). Separation by means of the eddy current separation is, if at all, thus only possible to a very limited extent. According to [9] it is to be assumed that proportions of nonferrous metals – depending on the thickness of the film – are oxidized during the incineration process. IFEU [12] states a value of 66% for the ferrous- coverage rate. For ferrous metals, energy recycling performs only minimally more unfavourably than separate collections and/or sorting from raw waste, under the condition that there is a high ferrous covering rate via ferrous separation from slag (Tables and 2.2.3.1 and 2.2.3.2).

**Table 2.2.3.1** Cumulated energy demand in the production of polymers on the basis of primary raw products and plastics out of waste as well as energy savings in the material and energy recycling at different energy efficiency factors.

| Cumulated energy demand (CED) polymer generation [14][a] | Cumulated energy demand (CED) polymers of recycling plastics | Energy saving using polymers out of Waste compared to primary raw materials | Combustion enthalpy/ calorific value of diverse plastics[a] | Energy saving using energy recycling with energy efficiency of 21% | Energy saving using energy recycling with energy efficiency of 39% | Energy saving using energy recycling with energy efficiency of 76% |
|---|---|---|---|---|---|---|
| LD-PE 68 MJ/kg | Up to 15 MJ/kg | 53 MJ/kg | 43 MJ/kg | 32.7 MJ/kg | 16.8 MJ/kg | 9.0 MJ/kg |
| PVC 51 MJ/kg | up to 15 MJ/kg | 38 MJ/kg | 18 MJ/kg | 13.7 MJ/kg | 7.0 MJ/kg | 3.8 MJ/kg |

[a] Without energy demand for the production of the finished (consumer) product.

**Table 2.2.3.2.** Comparison of the cumulated energy demand in producing selected metals from primary and secondary raw materials.

| Metal | Energy demand steel production | | Energy saving through recycling |
|---|---|---|---|
| | Primary raw material | Secondary raw materials | |
| Crude steel [13] | 16.2 MJ/kg | 6.1 MJ/kg (steel: recycling old cars) | 62% |
| Oxygen steel [13] | 20.4 MJ/kg | 6.5 MJ/kg (tin plate: packaging) | 68% |
| Aluminium [13] | 211.8 MJ/kg | 17.9 mean value | |
| | | 15.3 MJ/kg (recycling old cars) | 93% |
| | | 16.4 MJ/kg from (recycling packaging) | 94% |
| Copper | Pipes 32.1 MJ/kg [4] | | |
| | Sheets 31.8 MJ/kg [4] | 3.4–9.2 MJ/kg | 80–92% |
| | Wire 50.4 MJ/kg [4] | | |
| | Mean v. 46 MJ/kg [18] | | |

# 3. Market development and revenue situation of selected secondary resources

In recent years a clear price increase of secondary resources has been recorded. This applies in particular to metallic materials. This development is attributed to the rise in the demand for resources in the Asian market, coupled with the growing cost of resource development and production – caused by the massive rise in the cost of energy (Table 3.1).

**Table 3.1.** Revenue for selected secondary resources stemming from waste.

| Secondary resources | Revenues |
|---|---|
| Mixed paper | 55–70 €/t |
| Cardboard | 85–100 €/t |
| LDPE plastics (granulate, natural) | 350–450 €/t |
| LDPE plastics (films, bale) | 320–400 €/t |
| PVC foil (mixed, bale) | 60–100 €/t |
| PET (light blue, bale) | 150–210 €/t |
| PET (coloured, bale) | 20–40 €/t |
| Steel scrap | 180–245 €/t |
| Copper | 7,000–8,000 €/t |
| Aluminium | 2,000–3,000 €/t |

The improved revenue situation for recycled plastics or rather recycled polymers in particular, has created more favourable preconditions for high value material recycling. Increasing demand for crude oil at the same time as a shortage in its availability will also continue to drive up the price of crude oil in the medium and long term. The high energy demand for polymer production and the demand for crude oil as the base material will further improve the revenue situation for polymer secondary resources in the medium and long term. High energy demands for the generation of paper fibres and massive competition for the use of the raw material wood due to its function as a regenerative energy source, allow similar developments to be expected for paper and cardboard, as they have been shown for polymers.

The usage of FE metals in the packaging sector is strongly declining. The average revenue for steel scrap (Variety 2) came to 395 €/t in August 2008 – an increase of almost 400% compared to 2003. Aluminium is the most frequently used metal after steel worldwide. Due to its quantity, the consumption sector of packaging material (films and thin tapes, small containers and screw-on lids; food tins and drinks cans, tubes and aerosol cans) is of relevance for household and commercial waste. The consumption of aluminium in the packaging sector is strongly declining, as is the case for tin plate. The price of aluminium scrap has risen by approx. 30% compared to 2003 and is thus moderate in its rate of increase in comparison to ferrous and copper scrap. Following iron and aluminium, copper is utilized the most frequently. The range of resources is indicated at 32 years by Gerling and Wellmer (2005). The decrease of copper mining is predicted from 2008 onwards. Copper is one of the materials, which can be recycled without any loss of quality. Industry's demand for copper is increasingly being met from recycled material. Currently, around 12–13% of copper is produced from copper scrap worldwide, in the industrialized countries even up to 50% (Germany 35% – data from 2005). Copper existing in construction, machinery, equipment and various wastes, which can be used for recycling and recovery, is the largest and most economic copper mine in the world. In old waste disposal sites, using the most modern methods, copper has recently been processed in Switzerland. These disposal sites contain a copper content about twice as high as the average natural copper deposits. In particular deposited slag from waste incineration plants contains high copper levels. In the medium and long term, because of the very high energy demand in producing copper, in conjunction with its shortage, increasing revenue for copper scrap is to be expected in the medium and long term.

## 4. Consequences for waste management

The recycling of material in the material groups of paper and cardboard as well as plastic products has clear advantages over thermal recycling processes in the energy efficiency sector. Coupled with this as a rule, the climate change effect is also to be classified as lower. The same applies to the glass fraction. Also the covering rate of metals from raw waste is classed as high value compared to that from slag from the view of resource efficiency, as higher covering rate are gained in separate collecting and/or sorting of metals from raw waste than in removal from slag; this applies particularly for the nonferrous metals fraction (Fricke et al. 2008).

Which consequences can be drawn from these facts for waste management in developing countries?

Material recycling must be intensified to include the above-mentioned groups of material. For the material groups of paper/cardboard, plastics, metals and glass its is apparent that material recycling can be massively increased through intensifying the separate collecting systems and making them more flexible, in conjunction with an intensive use of sorting technologies. Collection and sorting systems are to be coordinated with each other. The goal of the whole system must be the reaching of an optimum between covering rate which is as high as possible and a high quality of recyclable material.

Triggered by the market development for secondary resources, the status of the self-financing resource economy has been reached in Germany for the material groups of paper/cardboard and metals. In the medium term this will also be the case for plastics. The improved market conditions create clear guidelines for the orientation of waste management concepts for developing countries, too.

## 5. Intensifying separate collection

Despite the good economic conditions for separate collections and existing, adapted collection and transport systems, these are only practiced on a low scale – as a rule informally/by the informal sector and are therefore often badly organized, irregular and selective. The collection rate achieved, thus only reached values between 5% and 8%.

A well organized municipal or private separate collection system does not, in comparison, exist or only exists on a small scale. This is to be traced back to, among other things, the shortage of specific information at stakeholders and among the technical experts regarding:

- The market for secondary resources, e.g., revenues, quality requirements and demand
- Waste quantities and qualities
- Appropriate technologies for collection and transport, efficiency of existing collection systems
- Instruments for economic modeling of the various available waste management instruments

- Knowledge of the acceptance in the population of participating in separate collecting systems
- To increase separate collections, the following preparatory measures are necessary
- Qualification measures
- Making available data relevant to planning, among other things, waste amount/ waste quality, recyclable material revenue/requirement
- Required and existing collecting systems
- Extent of preparatory measures, e.g., evaluating amount and type spaces for drop off systems, publicity required
- Economic studies, e.g. comparison of varieties of different waste management systems, sensitivity analyses focus on recycling specific revenues

Following approximate studies and experience from developing countries, which are mainly available for urban areas, the following measures are to be classified as suitable, under economically favourable conditions high rates of collecting and recovering are to be realised:

- Support of the informal sector including long term guarantees of revenue, making collecting equipment available, training
- Integration of the informal sector into the total system of waste management
- Setting up systems of drop off points for paper and cardboard, glass, metals, HD-plastics
- Setting up systems of curbside collection (bins and/or bags
- Integration informal sector for separate collection

Setting up a curb-side collecting system with several refuse bins/bags is to be aimed at, but is - in most cases - not realisable in developing countries for reasons of cost. In a few municipalities, waste and recyclable material collections are practiced using curb-side collecting systems with several refuse bins. As a rule these are then the 2-refuse bin system with separate collections of dry and wet waste or compost and residual waste. In a well-known case, a collecting bin is alternately used for wet and dry waste. A sorting plant is obligatory when implementing a curb-side collecting system. Separating material leads to an improved sorting capability and, as a consequence, to increased utilization rates.

## 6. Establishing assorting facilities

Sorting the recyclable material left over in waste takes place in sorting plants, which are preferably integrated into or used prior plants for waste treatment before disposal, such as mechanical–biological pre-treatment (MBT) and thermal waste treatment (IP). The target fractions are paper and cardboard, plastics, glass, metals and wood.

Against the background of low personnel costs and the generally prevailing labour policy goal of creating jobs, waste processing and sorting plants are to be adapted to correspond to these conditions. Personnel intensive sorting concepts are to be preferred to automatic process technologies. Other premises ought to be in line with appropriate issue of health and safety at work. As is also the case for separate collecting, the informal sector is to be integrated, e.g., as sorting staff. Flat bunkers are to be preferred for deliveries. This delivery concept offers the possibility of storing specific qualities of waste temporarily in special bunker sections, in order to add them to the waste stream in a targeted manner or to be able to supply to special sectors of the sorting plant. Separating off impurities, contaminants and harmful substances as well as large pieces of recyclable material manually and by using loading devices is also possible. The transfer of the material to the processing and sorting stage can take place by means of wheel loaders or mobile excavators with polyp gribber. In the most simple plants with small processing capacities, a manual approach (shovel/pitch fork) is also practical. Before being handled on the sorting belt the mixture of material ought to be processed with an aggregate for the opening of the bags and agglomerates (bag opener) and a device to separate material (screening stage with sieving section of approx. 80–100 mm). The coarse grain, concentrated on waste packaging, is placed on the sorting belt and sorted manually. The fine grain and the remnants of the coarse grain are taken on to the residual waste treatment.

# 7. Waste treatment before landfill

## *7.1. Conceptions*

Conventional waste disposal meets its limits throughout most of the world with increasing waste generation and rising proportions of packaging and toxic compounds in MSW. Landfilling of waste leads to pollutant emissions over long periods of time and requires sophisticated emission control and treatment methods. The consequences are long after-care periods for abandoned landfills. Furthermore, in many countries it is increasingly more difficult to find suitable locations for landfills which are accepted by the population. These circumstances are to be found all over the world and make new strategies for waste management necessary. The promotion of waste minimisation and recycling are important components of modern waste management strategies. Nevertheless, even when the minimisation and recycling potentials are fully exploited, there is still a residual fraction which has to be disposed of. The burdens resulting from landfilling can be minimised by pre-treating the waste and thus limiting its emission potential. Several options are available for residual waste treatment:

- Mechanical–biological pre-treatment (MBT) of residual waste
- Thermal waste treatment (IP)

The selection of a treatment process suitable in a specific case results from the financial and infrastructural framework conditions, the waste quantities and, above all, the waste composition. Due to the relatively low costs, the high flexibility of the process and the possibility of centralised and decentralised application, MBT processes are gaining importance also in developing and threshold countries. With waste treatment of MSW before landfilling, the following objectives can be attained:

- Minimisation of landfilled masses and volume (e.g., prolonged landfill life-span)
- Inactivation of biological and biochemical processes in order to avoid landfill-gas (Greenhouse Gases) and odour emissions
- At the same time landfill settlements are reduced
- Immobilisation of pollutants in order to reduce leachate contamination
- Recycling efforts, e.g., the separation of recyclable fractions, fractions with high calorific value or the production of landfill construction material could and should be integrated in the treatment process if there is a demand for these materials.

## *7.2. Climate-relevants*

Methane is generated during final disposal of waste management as a consequence of anaerobic decay of organic waste components. Basically two options exist to avoid methane emissions: On one hand active degasification of the landfill with subsequent flaring of LFG (landfill gas). On the other hand the stabilization of organic compounds in a biological treatment facility prior to landfilling aiming on a significant reduction of long term decay processes. Both options vary in terms of efficiency, sustainability, costs and potential CDM-revenues (Figs. 7.2.1 and 7.2.2).

The landfill degasification requires significant less invest and shows lower operational costs. However, the effect regarding gas recovery is limited, common collection hardly rarely exceed 50%, while a significant portion of LFG disappeares via the landfill surface. Additionally, flaring meets a technical bottom line with decreasing methane concentrations. The entire system of LFG is poorly sustainable, because the source of methane generation, i.e., the degradable organic matter is not removed.

Biological pretreatment in MBTs and digesters is the alternative. By means of spending more financial efforts, organic components will be stabilized prior to landfilling, what applies the same way to incineration plants. Biological decay processes, which otherwise happen inside the landfill will be carried out in advance under controlled technical conditions and in significantly reduced time. Hence, the gas generating processes will be sustainably reduced or even entirely avoided. The difference in terms of climate relevance of both methods becomes obvious when evaluating the potential gas emissions from landfilling.

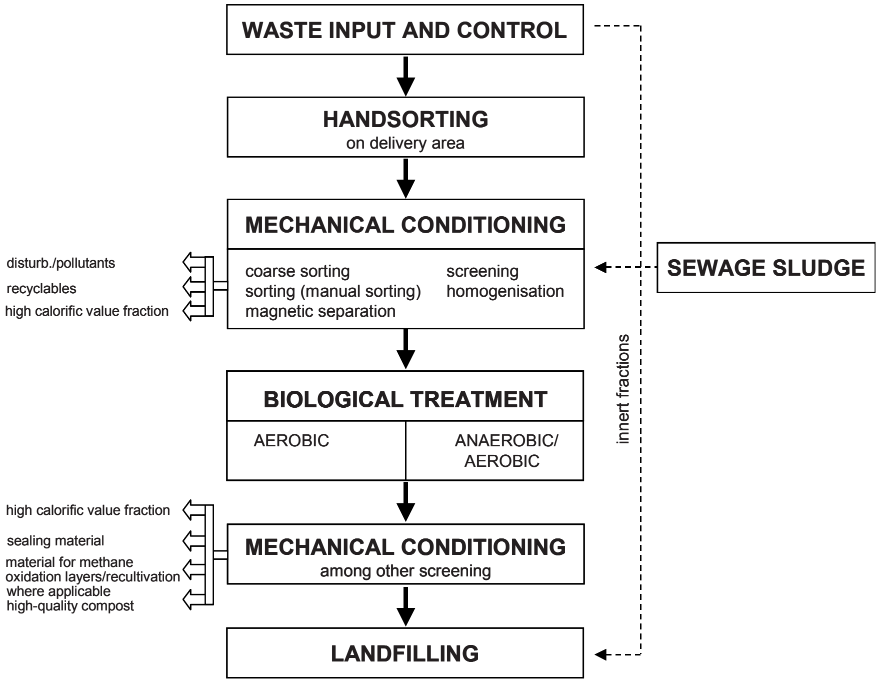


**Fig. 7.2.1.** A typical mechanical-biological waste treatment sequence.

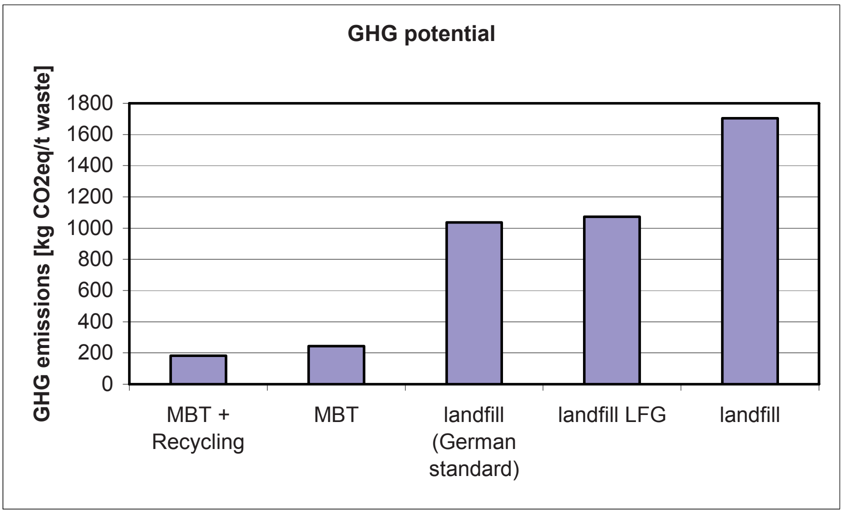


**Fig. 7.2.2.** GHG potentials by different waste management activities.

### *7.3. Clean development mechanism (CDM)*

Generally waste management activities generate Greenhouse Gases, both methane (landfills) and $CO_2$. Therefore, improvements in waste management may result in significant reduction of GHGs. According to data from German Federal Ministry of Environment in former times 36% of total methane emissions in Germany are related to landfills. Between 1990 and 2004 numerous measures like landfill closures, reduction of waste for disposal and utilization of landfill gas have been implemented in Germany. In total methane generation has been reduced by 21 Mio. t $CO_2$eq, what is equal to 50% of the reduction goals of German industry between 1998 and 2012 (45 Mio. t). The ministry still has identified a reduction potential of another 12.4 Mio. t $CO_2$eq just in German waste management. Considering the poor technical level of the waste management systems in low income countries, it seems obvious that the potential for emission reduction is huge.

Climate relevant waste management projects may be registered as emission reduction projects, according to the regulations of the UN-Framework Convention on Climate Change. Beside the political-symbolic aspect this measure has also significant economic criteria. CERs (Certified Emission Reductions) are to be produced and sold to the international market, to lift the total profitability of the project over a critical investment threshold. The legal basis of Certified Emission Reduction (CER) trading is the Article 12 of the Kyoto Protocol, called the Clean Development Mechanism (CDM). The CDM mechanism allows industrial nations to meet their quantitative reduction goals for greenhouse gas emissions by carrying out emission reduction projects in developing countries. The trading market for the CERs is basically governed by European legislation and its conversion to the member states. Particularly the EU emission trading system with its participants from energy-intensive enterprises and power plants offer the opportunity to pool the CERs into the EU-system and to sell them to other participants. The Federal Republic of Germany administrates the national conversion of the EU guidelines by the Project-Mechanism-Law (ProMechG, Project-Mechanism-Law). The law permits operators of large power plants to cover up to 22% of the granted emission rights in the period 2008–2012 by emission certificates from Kyoto projects. That corresponds with approximately 90 million tons of $CO_2$-equivalents per year in Germany.

In accordance with Article 17 of the Kyoto protocol CERs from climate protection projects may be also subject to national purchase programs of countries, which may accomplish a part of their obligations to reduce greenhouse gas emissions. States like, e.g., the Netherlands, Austria, Japan or Spain are strongly involved with national purchase programs from CDM projects. Currently CERs from CDM projects are traded in the European Union market and in national purchase programs for approx. 8–10 €/ t $CO_2$-equivalent, on basis of future delivery obligations (*forward contracts*). A third option for carbon trade is provided by the voluntary market for the compensation of $CO_2$-emissions. By investing in emission certificates from climate protection projects, unavoidable emissions may be compensated and neutralized, like for flights, fair meetings or production enterprises. The price is self regulated by the market and reflects the quality of the projects and the demand of the market.

Within the validation process the emission reduction process will be monitored, validated and finally certified. For the approval as a climatic protection project it requires several steps involving various institutions. The process opens with compiling a draft report, the so called PDD (Project Design Document). The PDD explains how and in what amount the greenhouse gases are going to be reduced. Beyond the technical concept other project-relevant aspects such as additionality, sustainability, environmental impact and socio-economic benefits are addressed in the PDD. One important element of the PDD is the monitoring concept, which facilitates how real greenhouse gas reductions during the lifespan of the project later will be determined. The project presented in the PDD must be officially validated by an independent UN-accredited institution (a so called DOE, Designated Operational Entity). At the same time the host country is requested to approve the project. After the validation by the DOE and the "Kyoto permission" of the host country's authorities the project can be submitted for registration at the UNFCCC. A registration is finalized automatically after 8 weeks, if no veto is inserted by the expert panel of the CDM executive board.

Generally, CDM projects may be acknowledged and registered only in case the meet the so called additionality-criteria. In order to prevent from "stick-in effects", it must be ensured that the designed project faces certain barriers, which would not be overcome without the CDM implementation. The additionality can be proven economically (e.g., lack of profit) or by outlining technical barriers. After establishing the MBT-plant, the real avoided emissions will be measured and calculated as determined in the approved monitoring concept, then verified by a further DOE and registered as CERs at a temporary account of the UNFCCC. Then the CERs can be transferred to accounts of international buyers. In waste management are two large groups of potential CDM projects:

- Directly reduction of the generation of methane
- Improvements in energy efficiency

There are a number of measures to improve the energy efficiency of waste management activities, such as material recycling instead of energetic reutilization or substitution of fossil energy resources and so on. Compared to direct methane reduction those measures are technically more complex and economically less reasonable. Most activities take place in industrial countries. Direct reduction of methane generation or emission shows a significantly larger potential for CDM due to the poor present emission situation. Basically 4 different project activities may be attractive for CDM:

- Gas extraction and flaring/recovery for old, existing and new landfill sites
- Methane avoidance due to mechanical biological pre-treatment

- Methane avoidance due to composting activities
- Methane avoidance due to methane oxidation of residual emissions from old landfills

For all components except the last one consolidated methodologies are available from UNFCCC. For the methane oxidation a new methodology is expected to be registered at UNFCCC in the near future. Since there is a quick progress in developing CDM methodologies, more project ideas may be expected.

## 7.4. Landfill gas projects

LFG projects were the first CDM projects in waste management at all. One reason is that LFG projects promised to be highly reasonable with significant revenues from CER trading contributing to up to 80% of total project costs. Meanwhile LFG projects are state-of-the-art; all landfills in metropolitan areas are object to contracts and purchase agreements. However, all LFG projects under perform. From 13 early registered projects, 7 obtain less than 60% of the expected reductions, the other 6 less than 30%. It does not require extraordinary technical excellence or expensive western experts to compile a LFG CDM-project. The procedure may follow the consolidated UNFCCC methodology ACM0001. However, getting a project approval from UNFCCC does not necessarily mean CER revenues, because at first the gas needs to be extracted from the landfill. And this may become a tough task, particularly in tropical countries.

## 7.5. Composting and mechanical biological treatment (MBT)

Uncontrolled methane emissions that would occur at a waste disposal site are avoided by the biological stabilization of the waste. Stabilized biomass (SB) does not (or to a smaller extent only) turn into anaerobe condition when disposed to a landfill. Hence, the methane generation and emission will be significantly smaller. The CDM application for a MBT will be compiled using applied methodologies (AM0025), the PDD template, its guidelines to fill in, as well as calculation tools. All can be downloaded on the Website of the UNFCCC. The compiled Small Scale PDD consists of the following main topics:

- A description of the project with its effect for climate and sustainable development
- Determination of the reference scenario without the project (baseline)
- Calculation of the baseline emissions, project emissions and emission reduction which can be expected (ex-ante)
- Monitoring concept with calculation methods for the verification of the real greenhouse gas reductions based on measurements (ex-post)
- Demonstration of the project additionality
- Environmental impact analysis including local stakeholder's comments

The methodology AMS III.F (Avoidance of methane production from decay of biomass through composting) provides the base of the baseline study and the monitoring concept for a MBT project. For calculations a useful tool is separately available, the "Tool to determine methane emissions avoided from dumping waste at a solid waste disposal site". In the greenhouse gas balance of the entire project, the emissions which result from the project activities are considered as a negative impact. Total $CO_2$ emissions of engines and electric machines are summarized and balanced with the baseline emissions, which are the avoided $CH_4$-emissions from the waste disposal. The calculation algorithms for both scenarios - baseline and project – are to a certain extent determined by the existing methodologies and tools. For the calculation of the virtual methane emissions due to waste disposal, a biological degradation of the deposited waste is simulated over several years by a layer model. With this model the highest methane emissions in a layer emerge during the first years and decrease in the subsequent years. Table 7.5.1 illustrates the preliminary calculation of the emissions for the MBT project Gaobeidian (China), a facility with a capacity of 40,000 t, for a period of 10 years.

**Table 7.5.1.** Emission calculations of the MBT Gaobeidian.

| Year | Project emissions [t $CO_2$eq] | baseline emissions [t $CO_2$eq] | Emission reductions [t $CO_2$eq] |
|---|---|---|---|
| 2008 | 497 | 2,339 | 1,842 |
| 2009 | 537 | 4,376 | 3,839 |
| 2010 | 577 | 6,156 | 5,579 |
| 2011 | 616 | 7,714 | 7,097 |
| 2012 | 655 | 9,081 | 8,426 |
| 2013 | 694 | 10,284 | 9,590 |
| 2014 | 732 | 11,345 | 10,613 |
| 2015 | 770 | 12,283 | 11,513 |
| 2016 | 807 | 13,114 | 12,306 |
| 2017 | 845 | 13,852 | 13,007 |
| Total | 6,729 | 90,541 | 83,812 |

The forecasted generation of emission certificates amounts to 83,812 t $CO_2$-equivalents for the project period 2008–2017. Presently, due to Kyoto regulation certificates are only tradable until 2012. In this period CERs of 26.783 t $CO_2$-equivalents may be generated. Based on current rates, CDM revenues 210,000 and 250,000 € may be expected. The calculations of benefits represent an estimation based on the emission reductions which are expected. Real revenues may differ clearly depending on the plant capacity, the waste composition and on the trading rate of the certificates. In the context of the monitoring process, all data that were used for the calculation of the emissions, if not constant, have to be determined or measured ex-post, in order to obtain the actual emissions during the lifetime of the project. Data comprise of, e.g., the power and fuel consumption, as well as the waste composition, which has to be monitored several times in the year.

### *7.6. Methane oxidation layer*

A methane oxidation layer (MOL) is placed on top of an existing dumpsite in order to turn methane emissions passing through the layer into $CO_2$. From this point of view a MOL has the same effect as a LFG system (collection and flaring/oxidation). However, the emission reduction cannot determine in the same matter like with LFG projects, because the amount of methane oxidized in the MOL cannot be monitored directly (like in a LFG project next to the flare). Just an indirect monitoring might be possible. Therefore, the central parameter describing the gas generation (and flux) as given in the baseline formula of the UNFCCC-tool may be monitored at two different locations, one with and one without MOL. The general concept for the MOL verification is not to rely on virtual emissions (from model calculation) but to monitor the baseline emissions in a testing area.

MOLs can be constructed using SB or compost or similar blended materials. Therefor, it is easy to combine a MOL and a MBT project. Total CDM revenues from MOL may be small, but maintenance and operation costs for a MOL are heading towards zero, what makes it generally reasonable.

## 8. Conclusion

At present, develop and emerging market countries increase their efforts to handle waste management and waste disposal issues. A number of measures are available and have been pointed out starting from source separated collection up to more climate friendly waste treatment and disposal methods. The various options have distinguished relevance and feasibility depending on the geographic and climate conditions in the countries. Currently, recovery of recyclables is the most reasonable activity due to booming markets for secondary resources. Recovery can be carried out by either establishing material recovery facilities (MRF) or source separated collection (SSC). However, it should be noted that markets for recyclables are volatile and may be subject to quick changes. The reuse techniques for the recyclables are object to future developments increasing material reuse aiming on significant savings of primary energy. This progress may increase the attraction of advanced recycling technologies. Regardless to what extent the recycling activities may be improved residual waste needs to be disposed. Dumping of untreated waste is still the most common disposal policy in emerging market countries. Various biological treatment technologies for residual waste are available such as aerobic MBT. In the past valuable but non monetary benefits could be materialized with MBT facilities, in particular landfill airspace savings and reduction of emissions on water and atmosphere. Since the establishment of the CDM, the reduction of methane emissions may be turned into so called Certified Emission Reductions (CERs) which are tradable and may be cashed in. With this additional funding investment barriers may be cracked at least for low cost technical solutions. Hence, it can be expected that CDM will push the waste treatment as measure prior to landfilling and will contribute significantly to a cleaner environment.

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