GREENHOUSE GASES REDUCTION THROUGH WASTE MANAGEMENT IN CROATIA

by

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The climate change policy is one of the key factors in the achievement of sustainable development in the Republic of Croatia. Control and mitigation of greenhouse gases is correlated with all economy activities. Waste management is one of the main tasks of environmental protection in Croatia. The Waste Management Strategy of the Republic of Croatia and the Waste Management Plan in the Republic of Croatia define the concept of waste management hierarchy and direct and indirect measures as criteria for sustainable waste management establishment. The main constituent of this system is avoiding and minimizing waste, as well as increasing the recycling and recovery level of waste and landfill gas, which also represent greenhouse gases mitigation measures. The Waste Management Plan consists of several direct and indirect measures for greenhouse gases emission reduction and their implementation also affects the greenhouse gases emissions. The contribution of the methane emission from landfills amounts to about 2% of the total greenhouse gases emissions in Croatia. The climate change control and mitigation measures as an integral part of waste management sector strategies represent the measures of achieving the national objectives towards greenhouse gases emission reduction which Croatia has accepted in the framework of the Kyoto Protocol.

Key words: *waste management, greenhouse gases, Kyoto protocol*

Introduction

In the last few decades, municipal solid waste (MSW) management has become major concern and it is presently one of the main public issues under discussion [1]. This is probably due to the considerable increase in MSW production in both absolute and per capita values.

Although the combustion of fossil fuels is the main source of greenhouse gases (GHG) emissions into the atmosphere, which is the main cause of climate change [2], the emissions caused by MSW flows contribute as well. In fact, direct GHG emissions from waste management in the year 2005 represented 2.6% of total emissions in the European Union (EU) –15 [3].

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Approximately one-third of anthropogenic emissions of methane in the EU can be attributed to MSW landfilling, whilst less than 0.5% of carbon dioxide emissions are associated with MSW treatment or disposal [4].

According to the Intergovernmental Panel on Climate Change (IPCC) report it is assumed that the waste sector is a significant contributor to GHG emissions which account for approximately 5% of the global greenhouse budget [5].

In the last ten years, in Croatia, an increase in net GHG emissions has had upstream tendencies, about 3% per year, and net emission of methane from MSW landfills is around 2%.

In spite of the general consensus that CO_2 from waste decomposition is of biogenic origin and hence does not add to the overall GHG emissions that contribute to global warming [5, 6], it is necessary to take into consideration the potential emissions of GHG from the waste management system [7]. The impact of landfills on the climate change is in their emissions of carbon dioxide (CO_2) and methane (CH_4), along with several other gaseous components. CH_4 is a by-product of anaerobic decomposition of organic waste, characteristic of conventional landfills, and has a tendency to accumulate within the landfill [6]. Gas emissions represent one of the main concerns related to the operation and after-care of landfills. In particular, the unit value is assigned to the global warming potential of CO_2, while CH_4 is twenty-one times more potent than the same mass of CO_2 [4, 8]. Therefore, by reducing the amount of CH_4 emitted from landfills, a positive effect is elicited in terms of reducing the impact on the climate change by solid waste management [4]. Apart from safe treatment of waste and waste disposal, the reduction of GHG must be implemented within the waste management system while it is being established [9]. Consequently, the climate change mitigation measures in waste management should become an integral part of the sector strategies and at the same time represent the measures for achievement of national objectives towards GHG emission reduction which are of great importance in the perspective of Croatia's obligations concerning the Kyoto Protocol. Croatia ratified the Kyoto Protocol in 2007 (Official Gazette of the Republic of Croatia – International Agreements (OG RC), 05/07) [10], which is one of the requirements in the process of accession to the EU. Upon its ratification and entering into force, Croatia has accepted the obligation to reduce its GHG emissions by 5% in relation to the base year 1990, over a commitment period from 2008 to 2012 [11].

Poor management of waste can also lead to the contamination of water, soil, and atmosphere and to major impact on public health. As science and technology developed, the management and disposal of ever increasing volume of waste has become a very organized, specialized and complex activity [12-14]. According to the Waste Management Strategy of the Republic of Croatia (WMS) (OG RC 130/05) [15] and the Waste Management Plan in the Republic of Croatia (2007-2015) (WMP) (OG RC 85/07) [16], a framework for the waste generation reduction and sustainable waste management has been established.

Within the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol, a pattern for greenhouse gas emission reduction in the period after the one defined by Kyoto protocol, 2008-2012, is being considered. In order to determine the reduction levels for each Party to the Protocol (the Republic of Croatia is a Party from 28. 8. 2007), countries are obliged to prepare greenhouse gas emission projections till 2020, with trends up to 2030 and 2050; and to analyse potentials and measure costs for greenhouse gas emission reduction and the scope of commitments that can be accepted after 2012, taking into account market and economic potentials. Utilization of municipal solid waste as renewable energy source is evaluated as one of priority measures. By means of material and energy recovery of municipal solid waste GHG emission reduction could be achieved.

The purpose of this paper is to analyse the impact of the existing and planned activities in the MSW management system of Croatia in 2050 on the atmosphere and GHG emission control through the methane emission calculation, and to calculate the total mitigation potential in 2020.

Waste management activities in Croatia

An integrated approach to MSW management requires a series of actions and techniques aimed firstly at minimizing the waste production at the source, then at reducing the risk to public health and the environment and finally at improving its treatment ability [17]. Systematic consideration of waste management in Croatia started with the WMS, which sets up the basis for achieving and maintaining integral waste management.

The need to avoid direct landfilling of biodegradable residues is shared by the whole technical community. In the EU this statement has been recognized since the promulgation of the Council Directive 1999/31/EC on waste landfilling (Landfill Directive) [18]. The Landfill Directive, as part of the measures undertaken to improve the waste management sustainability, forced the member states to reduce the amount of biodegradable fractions contained in municipal solid waste destined to sanitary landfills [19]. In Europe, one of the key issues of the Landfill Directive was to substantially reduce the biodegradable municipal waste going to the landfills and thus reduce the uncontrolled emissions of CH_4 [20]. The Landfill Directive regulates the collection, processing and/or utilization of landfill gas from disposal sites where biodegradable waste is disposed. Whereas the Landfill Directive prohibits the landfilling of waste with a high content of biodegradable materials, there is a need to establish alternative ways for treating the respective waste fractions [21], which means increasing of recycling and recovery level of waste and landfill gas.

By enforcing the WMP, WMS is consolidated with the EU standards and requirements in such a way as to maximally avoid and/or decrease waste generation, as well as limit the impact of waste on human health, environment, and climate. The entire system is adjusted to means of the principle of sustainable development.

WMS is supported by a wide range of regulations related to waste management. The policy and the entire *acquis communautaire* of MSW management in Croatia have been implemented according to the laws and regulations adopted during the last ten years. The Waste Law (OG RC 178/04, 111/06, 60/08, 87/09) [22] emphasises the infrastructure development for an integral waste management system.

The WMP predicts the rehabilitation and closure of all the existing landfills in Croatia by the year 2010, and the establishment of a county/regional waste management system. In the rehabilitation process and closure until 2007, there were 298 MSW landfills in Croatia, and 30 thereof were totally rehabilitated, which means that GHG emissions in the environment were reduced or eliminated for 1.000.000 m^3 of waste [23]. Active degasification and flare combustion were planned for the landfills which included more than 10.000 m^3 of untreated waste. Biofiltration has already been proposed as an effective, passive method for the reduction of CH_4 emissions either from raw MSW landfills in the initial phase of operation or from old landfills in which CH_4 flow is no longer suitable for utilization or flare combustion [19]; therefore, passive degasification with biofiltration was proposed for the landfills with less than 10.000 m^3 of untreated waste. Both systems can remove up to 50% of CH_4 produced.

More than 500 wild landfills are in the process of rehabilitation (273 were rehabilitated by the year 2007). It is estimated that on the territory of Croatia there are still more than 700 wild landfills [15]. Their rehabilitation is planned to be completed till the end of 2010, depending on financial resources. Apart from the organization of the WMS, the WMP consists of several direct and indirect measures for GHG emission reduction, including the regulations for separate collection of special categories of waste (tab. 1), and their implementation also affects the GHG emissions [24]. However, the objective of separate collection is not only the separation of useful

Table 1. Measures and their effect on the atmosphere in MSW management system

Measure	Impact on the atmosphere	Document
Remediation and closure of all existing MSW landfills using active/passive degasification system.	CH_4 emissions decrease up to 50% based on previous conditions.	WMP [16] Regulation on ways and conditions for waste disposal, categories and landfill operation conditions (OG RC 117/07) [25].
Targets set up for reducing biodegradable MSW going to the landfill (35% of biodegradable amount of waste produced in 1997).	CH_4 emission reduced due to decrease of amount of disposed biodegradable waste.	WMP [16]
Primary separation of MSW components – separation of segments that could be recycled or reused.	Saving on resources and energy needed to produce the particular product, which can otherwise end up on landfill.	Regulation on waste electrical and electronic equipment (WEEE) (OG RC 74/07) [26] Regulation on end of vehicle maintenance life cycle (OG RC 136/06) [27] Regulation on old batteries management (OG RC 133/06) [28] Regulation on waste oil management (OG RC 124/06) [29] Regulation on waste tyres management (OG RC 40/06) [30] Regulation on packaging and waste packaging management (OG RC 97/05) [31]
MSW must be treated before landfilling.	During the treatment of waste, control waste management of MSW is provided, and therefore, CH_4 emissions are reduced.	Regulation on ways and conditions for waste disposal, categories and landfill operation conditions (OG RC 117/07) [25]
Waste Management Centre (WMC) establishment, where the MSW is treated, reused and disposed under controlled conditions, with implementation of environmental protection measures.	Biogas or energy is produced, or gases are burnt in a flare.	WMP [16] Regulation on ways and conditions for waste disposal, categories and landfill operation conditions (OG RC 117/07) [25] Directive on limited emission values of airborne pollutants from stationary sources (OG RC 21/07) [32]
Mechanical biological treatment (MBT) – refuse derived fuel (RDF) and organic inactive component from waste is produced [2]	RDF is used as an energy source as substitution for the fossil fuel. Biogas is produced from inactive organic waste component (also a substitution for fossil fuel).	WMP [16] Directive on limited emission values of airborne pollutants from stationary sources (OG RC 21/07) [32]

materials but also the reduction of the MSW impact by removing from waste the flux items containing dangerous substances, such as batteries, waste from electric and electronic appliances and drugs [17]. Although the promotion of waste minimization and separate collection – recycling are important components of a modern MSW management strategy, even when applied to their full potential, the residual waste may contain considerable quantities of biodegradable matter and consequently, with the above mentioned concept, should be treated before landfilling [17, 19].

Establishing of a county/regional waste management system implies the construction of one WMC per county or per region (two or more consolidated counties): the WMCs accept waste collected through the collection network of WMC catchment area or collected at the transfer stations. Different activities related to the waste treatment before it is disposed at a non-hazardous landfill are conducted at the WMC, such as acceptance, treatment of sorted or unsorted waste, collection of waste that could be reused or recycled and collection and forwarding of hazardous waste, collection and distribution of waste that could be used for other purposes, energy use of some waste fractions and final disposal of waste. The MBT with bioreactor landfill is the fundamental technology proposed in the WMP (fig. 1).

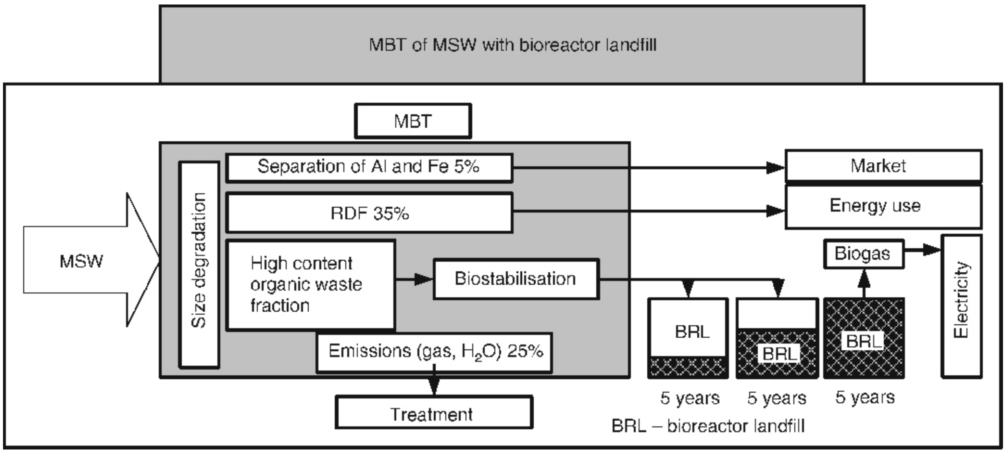

Figure 1. Scheme of MBT with bioreactor landfill

Several studies have confirmed that the management strategy based on MBT leads to a significant reduction of gas emissions from landfills as compared to the raw waste [19]. The MBT technology with bioreactor landfill is taken into consideration in the WMP for the system cost estimation. According to this technology up to 35% of the original waste matter can be separated in the form of RDF in mechanical treatment phase. After drying, the rest of the waste is partially stabilised to organic fraction, representing around 35% of the input waste amount, deposited then into the bioreactor landfill, where further anaerobic process is induced due to CH_4 production [33]. This technology makes it possible to separate 5% of metal and about 25% of water from the waste (fig. 1).

The bioreactor landfill is constructed according to the non-hazardous landfill requirements. During the filling, the methanogenic processes are mainly stopped due to low moisture content, and the process is activated with the purpose of adding water, after the field has been filled up and closed with an upper impermeable cover. The landfill gas is collected and used for energy production [34]. The size of the field is predicted for a 5-year fill-in. After further 5-year gas exploitation of one field, the organic matter from waste is completely decomposed.

Methodology of methane emission calculation from MSW landfills

The GHG emission estimation has been performed according to the guidelines proposed by the United Nations Framework Convention on Climate Change (UNFCCC) using the IPCC methodology [35]. The degradation of organic waste at the sites causes CH_4 emissions during long periods of time so that the kinetic model of the first order decay (FOD) is used for emission estimation. The quantity and composition of waste, conditions in landfills, treatment at the disposal, temperature, humidity, oxygen concentration, atmospheric pressure, and meteorological conditions significantly influence the organic waste degradation rate. The FOD model is based on eqs. (1) and (2):

$$CH_{4GENERATED}\,[\text{Gg*/year}] = S_x\{[A\cdot k\cdot MSW_T(x)\cdot MSW_F(x)\cdot L_0(x)]e^{-k(t-x)}\} \quad (1)$$

$$CH_{4\,EMITTED}\,[\text{Gg/year}] = [CH_{4\,GENERATED} - R(t)](1 - OX) \quad (2)$$

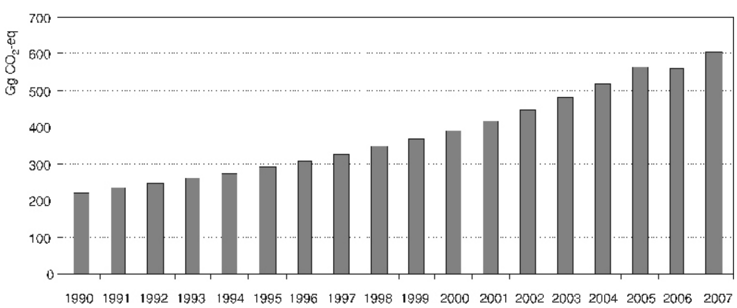

Figure 2. CH_4 emissions from MSW landfills (1990-2007)

The annual quantities of waste disposed at the MSW landfills and other parameters which are included in the FOD model as well as CH_4 emissions are provided in the National Inventory Report (NIR), 2009. The resulting CH_4 emissions (expressed in Gg CO_2-eq**) are presented in fig. 2.

Results and discussion

GHG emission projections in waste management

The baseline scenario (the *without measures* scenario) of municipal waste management assumes that the amounts of municipal solid waste would constantly increase as result of the rising standards of living, but this increase would gradually decline due to the effects of the measures undertaken to avoid/reduce and recycle waste as well as due to the increase of the population involved in the MSW collection system. This includes the implementation of improvements regardless of the climate change mitigation program requirements.

* In the context of Greenhouse Gas Inventory publications, *e. g.* IPCC Guidelines, the International System is used, and therefore 1000 tonnes will be 1 Gg

** CH_4 emission is multiplied by proper Global Warming Potential (GWP). The GWP is a measure of the impact on greenhouse effect of the certain gas compared to CO_2 impact which is accordingly defined as a referent value. In that case the emission of GHG is presented as the equivalent emission of carbon dioxide (CO_2-eq). GWP (CH_4) = 21

The *without measures* scenario includes the following basic measures defined by the WMS:
- avoiding and reducing of MSW generation,
- reduction of disposed MSW,
- enhancement of separately collected and recycled MSW, and
- increase in the population involved in the MSW collection system.

The mitigation scenarios (*with measures* and *with additional measures* scenario) are environmentally oriented scenarios starting from the assumption that the global problem of GHG effect and the sustainable development concept will cause a re-orientation in general to energy efficient technologies and renewable energy sources. The mitigation scenarios of municipal waste management assume the implementation of additional measures and quantitative objectives defined by the WMS and WMP. The difference between the *with measures* and *with additional measures* scenarios is that the additional measure projections could provide some information on how governments expect the planned and additional policies to contribute to reducing GHG emissions. The *with additional measures* scenario assumes the implementation of maximal mitigation potential.

Priority is given to avoiding and reducing waste generation and reducing its hazardous properties. If waste generation can neither be avoided nor reduced, waste must be re-used, recycled and/or recovered; reasonably unusable waste must be permanently deposited in an environmentally friendly way. These objectives include the assumed time-lags with respect to the Landfill Directive.

The *with measures* scenario includes the following measures:
- decrease of disposed biodegradable MSW,
- landfill gas flaring/utilization of landfill gas for electricity production, and
- utilization of RDF in cement industry.

The *with additional measures* scenario includes the following measure:
- thermal treatment of MSW.

The GHG emission projections until 2050 from waste management are presented in fig. 3.

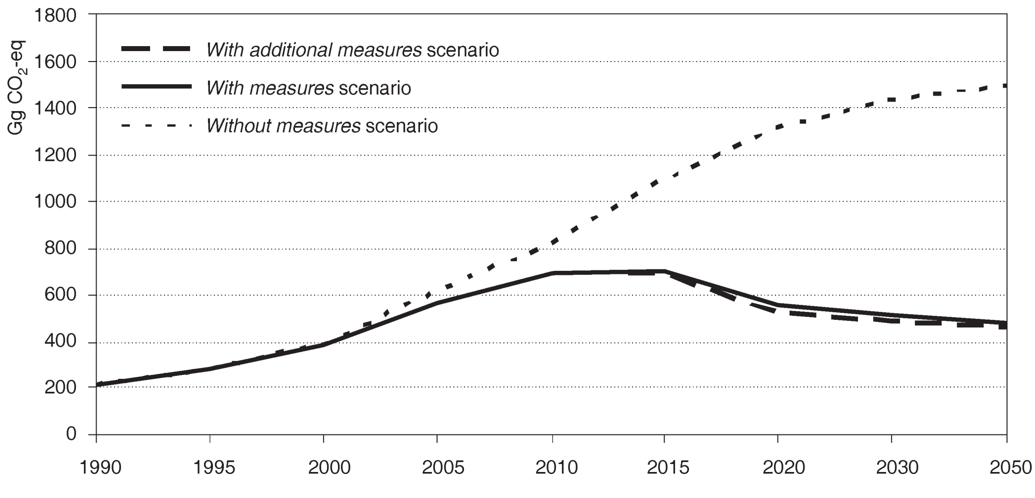

Figure 3. GHG emission scenarios in waste management

The landfill gas collection from landfills with biodegradable waste is prescribed by the Landfill Directive. The collected gas which cannot be used for energy utilization must be burnt in a flare, which contributes to the CH_4 emission reduction. Combustion of waste with fossil fuel in cement kilns and/or thermal treatment of MSW contributes to fossil fuel saving. Thereby, the CO_2 emission, which is the result of combustion, is reduced because the organic component of the MSW is considered as CO_2 neutral. Due to the reduced quantity of waste, the CH_4 emission (as result of anaerobic degradation) is also reduced. Utilization of waste for energy production is one of the main objectives of the WMP. The MSW technological treatment and landfill gas recovery will be performed at waste management regional and county centres, which will represent the central places for waste treatment and disposal.

Table 2 shows the estimated CH_4 emissions (expressed in Gg CO_2-eq) for *without measures*, *with measures* and *with additional measures* scenarios.

Table 2. CH_4 emissions from waste management (Gg CO_2-eq)

CH_4 emission	Gg CO_2-eq					
	2005	2010	2015	2020	2030	2050
Without measures scenario	615	819	1095	1317	1432	1495
With measures scenario	563	695	698	556	513	479
With additional measures scenario	563	695	690	520	487	467

The potentials of reducing CH_4 and CO_2 emissions (expressed in Gg CO_2-eq), which could be achieved by the year 2050 by applying the measures involved in *with measures* and *with additional measures* scenarios are presented in tabs. 3 and 4. The common influences of these measures affect the resulting potentials of emission reduction presented in the scenarios.

Table 3. CH_4 emission reduction potentials in waste management (Gg CO_2-eq)

CH_4 emission reduction potentials	Gg CO_2-eq					
	2005	2010	2015	2020	2030	2050
Decrease of disposed biodegradable MSW	–	28	155	352	250	149
Landfill gas flaring/utilization of landfill gas for electricity production	52	81	153	235	379	484
Utilization of RDF in cement industry	-	15	88	174	290	383
***With measures* scenario**	**52**	**124**	**396**	**761**	**919**	**1016**
Thermal treatment of MSW	–	–	9	36	26	12
***With measures + with additional measures* scenarios**	**52**	**124**	**405**	**797**	**945**	**1028**

Table 4. CO_2 emission reduction potentials in waste management (Gg CO_2-eq)

CO_2 emission reduction potentials	Gg CO_2-eq				
	2010	2015	2020	2030	2050
Utilization of RDF in cement industry	87	119	133	186	265
Thermal treatment of MSW	–	140	139	135	130

An effective strategy must simultaneously address both the individual and the global scales [36], but long-term planning in the time period until 2050 includes a number of uncertainties. The emission trends can be expressed at a level of aggregated data and factors [37]. The EU has already set the indicative goal, a 50% emission reduction in relation to 1990, which has been accepted by some member countries. This objective implies deep changes in the economy and the habits towards a non-carbon economy [38]. A new system needs to be developed, that will stimulate the development and implementation of new technologies.

According to projections, a significant GHG emission reduction in Croatia can be expected after the year 2020. In year 2020, the GHG emission reduction of 11% can be achieved by *with measures* scenario, and 19% by 'with additional measures' scenario (in relation to *without measures* scenario). The total mitigation potential in Croatia in 2020 will amount to 9.473 Gg CO_2-eq [36]. The total GHG emission reduction potentials in waste management amount to 1.069 Gg CO_2-eq, thereof 272 Gg CO_2-eq refer to the substitution of fossil fuels (belonging to energy sector potentials*) and 797 Gg CO_2-eq refer to CH_4 emission reduction. If only CH_4 emission reduction potential is considered, the contribution to the total mitigation potential in 2020 will amount to about 8%.

Conclusions

The WMS and the WMP define the concept of waste management hierarchy and direct and indirect measures as criteria for sustainable waste management establishment. Apart from the organisation of WMS, the WMP consists of several direct and indirect measures for GHG emission reduction and their implementation also affects the GHG emissions. With the implementation of the prescribed measures, a significant GHG emission reduction in Croatia can be expected to be realized after the year 2020. The total mitigation potential in Croatia in 2020 will amount to 9.473 Gg CO_2-eq. If only CH_4 emission reduction potential from waste management is considered, the contribution to the total mitigation potential in 2020 will amount to about 8%.

Nomenclature

A – normalisation factor which corrects the summation (= $1 - e^{-k})/k$
$CH_{4\,EMITTED}$ – CH_4 emitted in year t
$CH_{4\,GENERATED}$ – CH_4 generated in year t
DOC(x) – degradable organic carbon (DOC) in year x (fraction) [GgC/Gg waste]
DOC_F – fraction of DOC dissimilated
F – fraction by volume of CH_4 in landfill gas

* National GHG emissions represent the sum of emissions from different sectors; therefore, mitigation potential is realized at the sector level.

k – methane generation rate constant [1/year]
$L_0(x)$ – methane generation potential ($MCF(x) \cdot DOC(x) \cdot DOCF \cdot F \cdot 16/12$), [$GgCH_4$/Gg waste],
$MSW_T(x)$ – total MSW generated in year x [Gg/year]
$MSW_F(x)$ – fraction of MSW disposed at landfills in year x
$MCF(x)$ – methane correction factor in year x (fraction)
OX – oxidation factor (fraction)
$R(t)$ – recovered CH_4 in year t [Gg/year] – CH_4 that is burnt in a flare or energy recovery device
t – year of inventory
x – years for which input data should be added
16/12 – conversion from C to CH_4

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