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Interim Report **IR-04-078**

The GAINS Model for Greenhouse Gases: Emissions, Control Potentials and Control Costs for Methane

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December 21, 2004

Abstract

This report estimates current and future emissions of methane in 42 regions in Europe, assesses the potential for reducing emissions and quantifies the costs of the available emission control measures. The report identifies 28 control measures, ranging from animal feed changes over waste management options to various approaches for gas recovery and utilization. For each of these options, the report examines country-specific applicability and removal efficiency and determines the costs.

As a result, methane emissions in Europe are estimated for the year 1990 at 64,200 kt CH_4. Assuming the penetration of emission controls as laid down in the current legislation, emissions would decline up to 2020 by 11,700 kt CH_4 per year. Full application of the presently available emission control measures could achieve an additional decline in European methane emissions by 24,000 kt per year. 75 percent of this potential could be attained at a cost of less than two billion €/year or 50 €/t CO_2–equivalent, while the further 5,000 kt CH_4/year would require costs of 12 billion €/year.

Acknowledgements

The authors gratefully acknowledge the financial support for their work received from the Netherlands' Ministry for Housing, Spatial Planning and the Environment.

The authors are also indebted to Martin Adams, Judith Bates and Ann Gardiner (AEA-Technology, Harwell, UK), Chris Hendriks (ECOFYS, Netherlands), Martha van Eerdt (RIVM), Jan Bresky and Jerker Enarsson (STORA-ENSO), G.J. Monteny (Agrotechnology and Food Innovations B.V., Wageningen), and Holger Ecke (IIASA) for contributing important information.

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1 Introduction

1.1 Interactions between air pollution control and greenhouse gas mitigation

Recent scientific insights indicate that a more systematic approach for the integrated assessment of greenhouse gases and traditional pollutants might reveal more cost-effective control strategies than the traditional approach, where these problems are considered independently from each other.

The Regional Air Pollution Information and Simulation (RAINS) model has been developed by the International Institute for Applied Systems Analysis (IIASA) as a tool for the integrated assessment of emission control strategies for reducing the impacts of air pollution. The present version of RAINS addresses health impacts of fine particulate matter and ozone, vegetation damage from ground-level ozone as well as acidification and eutrophication. In order to meet environmental targets for these effects in the most cost-effective way, RAINS considers emission controls for sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC), ammonia (NH_3) and fine particulate matter (PM).

Considering the new insights into the linkages between air pollution and greenhouse gases (Swart et al., 2004), work has begun to extend the multi-pollutant/multi-effect approach that is presently used in RAINS for the analysis of air pollution to include emissions of greenhouse gases. This extended "Greenhouse and Air pollution Interactions and Synergies" (GAINS) model could potentially offer a practical tool for designing national and regional strategies that respond to global and long-term climate objectives (expressed in terms of greenhouse gas emissions), while maximizing the local and short- to medium-term environmental benefits of air pollution. The emphasis of the envisaged tool is on identifying synergistic effects between the control of air pollution and the emissions of greenhouse gases. Initial results of this work were published in Klaassen et al (2004).

1.2 Objective of this report

The objective of this report is to describe the methodology and data used in the GAINS model to describe emissions of methane and the potential and costs for controlling them.

1.3 Structure of the report

The report has the following structure: Chapter 2 describes the calculation methodology of the RAINS and GAINS models in general and of methane emissions and control costs in particular. Chapter 3 presents emission factors and activity levels used for calculating sectoral emissions. In Chapter 4, the control options available for each sector are listed along with application rates, removal efficiencies and costs. The chapter also contains a detailed description of the assumptions made for application rates and costs. Chapter 5 presents results and Chapter 6 concludes the report.

2 Methodology

2.1 Introduction

A methodology has been developed to assess, for any exogenously supplied projection of future economic activities, the resulting emissions of greenhouse gases and conventional air pollutants, the technical potential for emission controls and the costs of such measures, as well as the interactions between the emission controls of various pollutants. This new methodology revises the existing mathematical formulation of the RAINS optimisation problem (Amann and Makowski., 2001) to take account of the interactions between emission control options of multiple pollutants and their effects on multiple environmental endpoints (see Klaassen et al., 2004).

This chapter first describes the existing RAINS methodology, which has also been used for GAINS. Subsequently, the method to calculate future emissions, in particular of methane, is explained. Then the costing methodology is described.

2.2 The RAINS methodology for air pollution

The RAINS model combines information on economic and energy development, emission control potentials and costs, atmospheric dispersion characteristics and environmental sensitivities towards air pollution (Schöpp *et al.*, 1999). The model addresses threats to human health posed by fine particulates and ground-level ozone as well as risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated ambient levels of ozone. These air pollution related problems are considered in a multi-pollutant context (Figure 2.1) quantifying the contributions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), non-methane volatile organic compounds (VOC), and primary emissions of fine (PM2.5) and coarse (PM10-PM2.5) particles. A detailed description of the RAINS model, on-line access to certain model parts as well as all input data to the model can be found on the Internet (http://www.iiasa.ac.at/rains).

The RAINS model framework makes it possible to estimate, for any given energy- and agricultural scenario, the costs and environmental effects of user-specified emission control policies. Furthermore, a non-linear optimisation model has been developed to identify the cost-minimal combination of emission controls meeting user-supplied air quality targets, taking into account regional differences in emission control costs and atmospheric dispersion characteristics. The optimisation capability of RAINS enables the development of multi-pollutant, multi-effect pollution control strategies. In particular, the optimisation can be used to search for cost-minimal balances of controls of the six pollutants (SO_2, NO_x, VOC, NH_3, primary $PM_{2,5}$, primary $PM_{10\text{-}2.5}$ (= PM coarse)) over the various economic sectors in all European countries. Simultaneously, user-specified targets are achieved for human health impacts (e.g., expressed in terms of reduced life expectancy), ecosystems protection (e.g., expressed in terms of excess acid and nitrogen deposition), and maximum allowed violations of WHO guideline values for ground-level ozone. The RAINS model covers the time horizon 1990 to 2030, with time steps of five years. Geographically, the model covers 47 countries and regions in Europe. Five of them are sea regions, 38 are countries and four are regions in the European part of the Russian Federation. These are Kaliningrad (KALI), Kola-Karelia

(KOLK), S:t Petersburg (SPET), and remaining European Russia west from the Ural (REMR). The models cover Europe from Ireland to the European part of Russia and Turkey. In a north-south perspective the model covers all countries from Norway down to Malta and Cyprus.

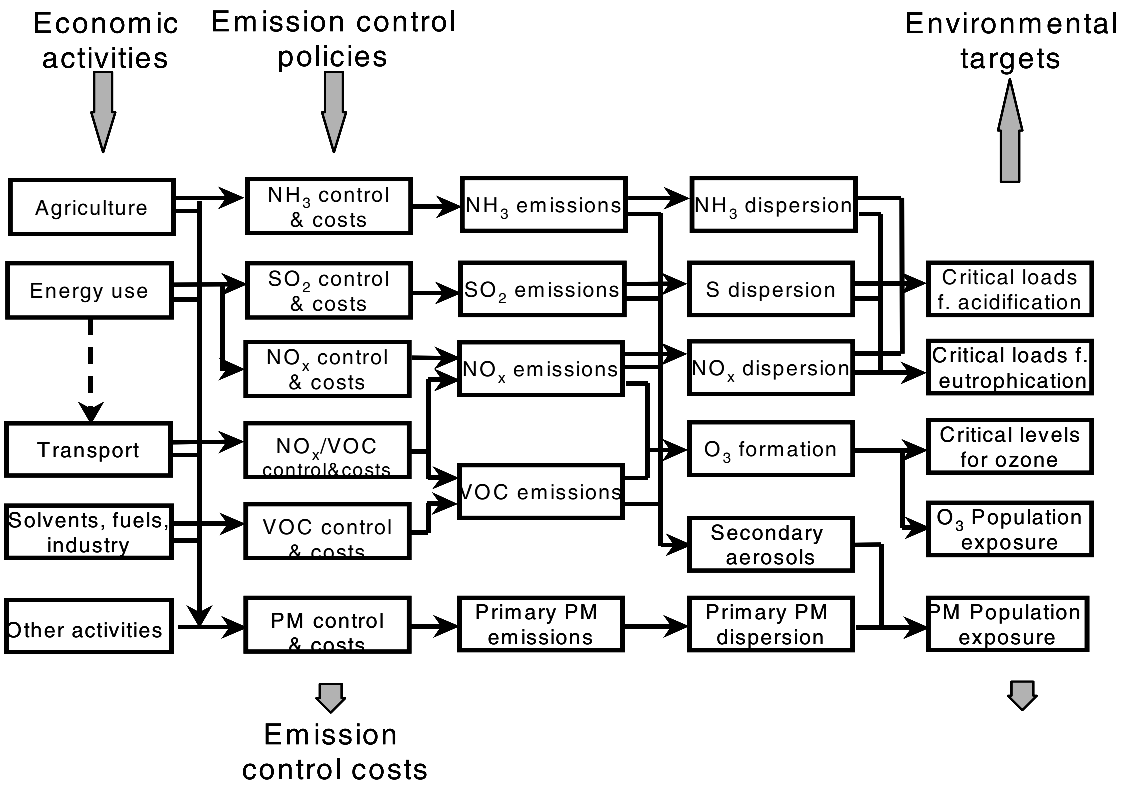

Figure 2.1: Flow of information in the RAINS model

The GAINS calculations of methane include only the land regions and not the sea regions. Methane emissions from off-shore oil and gas platforms have been included in the land emissions under the relevant sector.

2.3 Emission calculation

The methodology adopted in GAINS for the estimation of current and future greenhouse gas emissions and the available potential for emission controls follows the standard RAINS methodology. Emissions of each pollutant p are calculated as the product of the activity levels, the “uncontrolled” emission factor in absence of any emission control measures, the efficiency of emission control measures and the application rate of such measures:

$$E_{i,p} = \sum_{j,a,t} E_{i,j,a,t,p} = \sum_{j,a,t} A_{i,j,a} ef_{i,j,a,p} (1 - eff_{t,p}) X_{i,j,a,t} ,$$ Equation 2.1

where

i,j,a,t	country, sector, activity, abatement technology
$E_{i,p}$	emissions of the specific pollutant *p* in country *i,*
A	activity in a given sector,
ef	"uncontrolled" emission factor,
eff	removal efficiency, and
X	actual implementation rate of the considered abatement.

If no emission controls are applied, the abatement efficiency equals zero ($eff = 0$) and the application rate is one ($X = 1$). In that case, the emission calculation is reduced to simple multiplication of activity rate by the "uncontrolled" emission factor.

2.4 Emission control scenarios

In this report, emissions are calculated for two different scenarios, the current legislation case (CLE), and the maximum technically feasible reduction case (MFR). The CLE case is defined as emissions when control measures required in the current legislation of each country are applied. The MFR case is defined as emissions when all currently available control measures are applied to attain maximum emission reductions irrespective of control costs. The baseline emission level is defined as emissions for 1990 in the CLE case.

Emissions are calculated using IPCC emissions factors (Houghton et al., 1997a), to the extent possible complemented by emission factors from other sources when necessary. Emission factors are defined taking into consideration differences across countries in the implemented legislation. For example, emission factors often distinguish between Western and Eastern Europe, thereby taking into account that legislation and the resulting implementation of control options have come further in Western than in Eastern Europe. For the current legislation (CLE) case, emissions are calculated by considering the present and future implementation of control measures that will reduce unit emissions below the level already assumed in the IPCC emission factors. For example, starting point for determining emission factors from paper waste are published emission factors for paper that is disposed of to uncontrolled landfill. For the CLE case, account is taken of the current levels of paper recycling, incineration and gas recovery at landfills, as well as expected future emission reductions from legislation requiring increased waste diversion. The emission factor is modified accordingly.

For this report, the CLE case only includes (national or international) legislation in place as of mid 2004 . This implies that measures that were proposed for national or EU-wide legislation at that time are not included in the CLE-scenario presented in this report. In particular, the EU-wide legislation currently considered in the estimations of the CLE scenario for methane includes:

- The EU Landfill Directive (adopted by the European Council in April 1999).
- The EU Common Agricultural Policy (adopted by the EU agricultural ministers in June 2003) has been included through the choice of control options to mitigate methane

emissions from enteric fermentation. Expected effects from the CAP reform on the number of animals have not yet been regarded in the activity data.

- The EU Wastewater Directives (adopted in May 1991 and February 1998).

Effects on animal numbers of the EU Nitrate Directive (adopted in December 1991) and from the reform of the EU Common Agricultural Policy have not been taken into account, because it is beyond the scope of the RAINS/GAINS model to assess country-specific impacts of this legislation on the agricultural systems.

2.5 Cost calculation

2.5.1 General approach

Just like in the RAINS model, the cost evaluation in GAINS attempts to quantify the values to society of diverting resources to reduce emissions in Europe (Klimont *et al.*, 2002). In practice, these values are approximated by estimating costs at the production level rather than at the level of consumer prices. Therefore, any mark-ups charged over production costs by manufacturers or dealers do not represent actual resource use and are ignored. Any taxes added to production costs are similarly ignored as subsidies as they are transfers and not resource costs.

A central assumption in the GAINS (and RAINS) cost calculation is the existence of a free international market for (abatement) equipment that is accessible to all countries at the same conditions.

The net expenditures for emission controls are differentiated into

- investments,
- operating and maintenance costs, and
- cost-savings.

From these three components, GAINS calculates annual costs per unit of activity level. Investments include fixed capital costs associated with the control option. Operating and maintenance costs include all variable costs. These are usually made up by material, energy, and labour costs for operation of the abatement equipment, but include also, e.g., waste separation and collection costs. Cost-savings include, e.g., the savings from reduced gas leakages, utilization of recovered gas as energy, and income from compost sold. Avoided costs for waste disposal when waste is recycled or composted are also included as cost-savings. Subsequently, the costs are summed up and expressed per ton of pollutant abated.

Some of the parameters are considered common to all countries. These include technology-specific data, such as removal efficiencies, unit investment costs, and non-labour operating and maintenance costs. Country-specific parameters used in the calculation routine include labour costs, energy prices, animal fodder prices, paper collection rates, composting rates and emission factors.

All costs in GAINS are expressed in constant € in 2000 prices.

2.5.2 Costs for emission control options

2.5.2.1 Investments

Capital investments (*I*) have been annualized according to the following equation:

$$I^{an} = I * \frac{(1+q)^{lt} * q}{(1+q)^{lt} - 1}$$

Equation 2.2

where q is a four percent discount rate and lt is a technology-specific lifetime of the installation.

2.5.2.2 Operating and maintenance costs

Operating and maintenance costs (OM) include all variable costs associated with a control measure. These include operating costs of paper recycling plants, farm-scale anaerobic digestion plants, large-scale composts, and waste incineration plants, as well as costs for operating installations for recovery and utilization or flaring of gas. Apart from costs for operating control equipment, the OM costs also include waste separation and collection costs. Unless stated otherwise in the text, the OM costs are assumed to consist of 80 percent labour costs and 20 percent material costs. Thus, the annual operating and maintenance cost is defined as:

$$OM = L + M = a_L * OM + a_M * OM ,$$

Equation 2.3

where L are annual labour costs, M are annual material costs, and α_L and α_M are their shares of total OM cost, respectively.

The material costs are not assumed to vary between countries, while labour costs are country-specific. The labour cost index from the RAINS model (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/) was used here.

2.5.2.3 Cost-savings

Cost-savings from methane control options emerge primarily from utilization of recovered gas and reduced gas leakages. Enteric fermentation control options imply cost-savings in the form of productivity increases. Other sources of cost-savings arise in the waste sector, where virgin pulp in paper production can be substituted for cheaper recycled pulp, good quality compost may be sold in the market, and any diversion of waste away from landfills implies saved costs from not having to landfill the waste.

When the cost-saving arise from a utilization of recovered gas or from reduced gas leakages, it is defined as follows:

$$CS = E_{ton} * g_u * p_{gas}, \qquad \text{Equation 2.4}$$

where E_{ton} is the amount of methane gas recovered in tonnes, γ_u is the share of recovered gas that is utilized and p_{gas} is the future consumer price of gas (without taxes) for power plants, retrieved from the GAINS CO_2 module (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/). This price is based for the past on IEA statistics and for the future on the price index of the baseline projection used by the PRIMES energy model (European Commission, 2003). Unless otherwise stated in the text, it is assumed that the utilization rate, γ_u, is 80 percent of the recovered gas use and that it is possible to find use for the recovered gas in the vicinity of the recovery installation without any need to transport the gas over long distances. In cases where E_{ton} is the amount of gas saved through reduced leakages, the utilization rate, γ_u, is 100 percent. If part of the energy is utilized as heat instead of electricity (as is the case for waste incineration and farm-scale anaerobic digestion plants), the benefit is assumed to be 25 percent of the gas price.

2.5.2.4 Unit cost per ton methane reduced

The total cost per ton of methane removed is defined as the sum of the unit investment cost, the unit operating and maintenance cost, and the unit cost-saving:

$$c_{ton} = \frac{\left(I^{an} + OM - CS\right)}{E_{ton}}. \qquad \text{Equation 2.5}$$

3 Methane emissions

3.1 Introduction

Methane (CH_4) is the second most important greenhouse gas and accounts for 17 percent of the contribution of anthropogenic gases to an enhanced greenhouse effect (IPCC, 1996). Methane has a global warming potential of 23 times that of CO_2 over a 100 years time horizon (Houghton et al., 2001). Due to its relatively short average atmospheric lifetime of approximately 12 years before it is consumed by a natural sink, methane concentrations can be relatively quickly and easily stabilized (USEPA, 1999). Many of the available options to reduce methane emissions involve recovery of emissions for use as an energy source. Where this re-use is applicable, the revenues can considerably reduce control costs. This chapter provides an overview of the major sources of methane emissions, outlines the methodology for estimating anthropogenic methane emissions, the technical reduction potential to reduce these emissions, and the associated costs for a time horizon of 1990-2030. The spatial scale is the country level.

Methane emissions arise from natural (e.g., wetlands) and anthropogenic sources (e.g., agriculture, landfills, and natural gas emissions). Of the estimated global emissions of 600 Mt in 2000, slightly over half of the emissions originate from anthropogenic sources.

Figure 3.1 shows the contributions of the major sources of methane emissions for the EU-25, Europe and the World in 1990 as shares of total methane emissions in the respective regions, based on UNFCCC contributions (EU-25) and the EDGAR 3.2 database by RIVM (Europe and the World). According to these estimates, the largest contribution in the EU-25 comes from enteric fermentation followed by waste disposal, coal mining, distribution of natural gas, and manure management, while other sources make less important contributions. For global emissions the order is different and emissions from gas extraction and transmission, rice cultivation and wastewater play a more important role than in the EU.

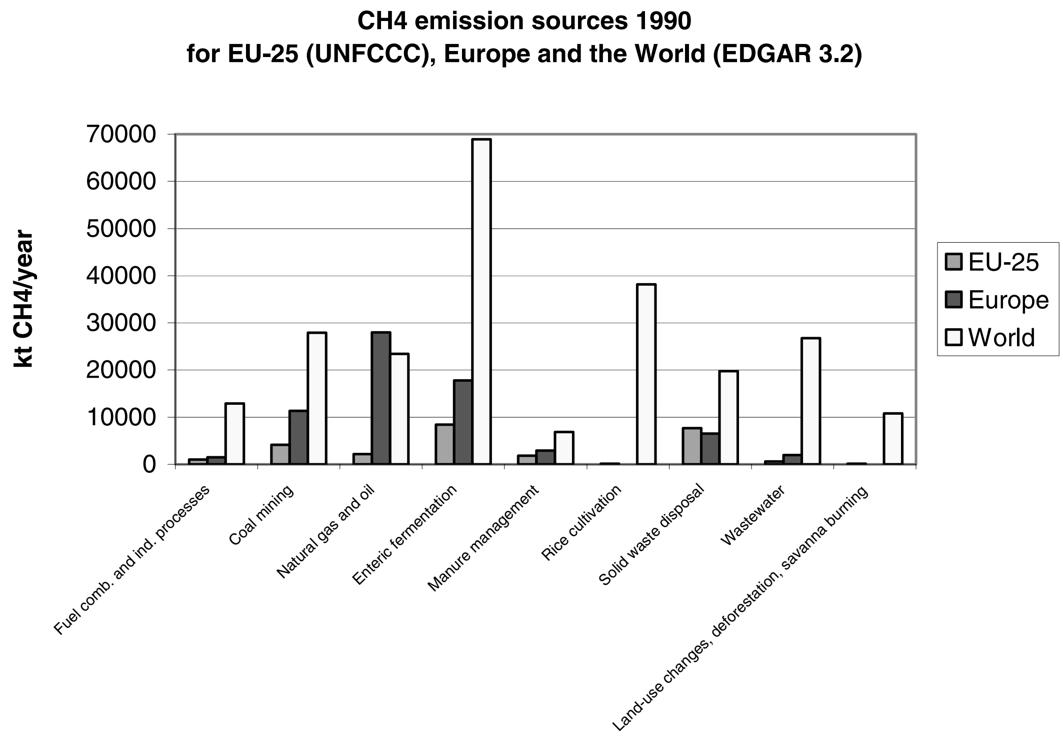

Figure 3.1: Major sources of methane emissions in EU-25 and the World in 1990. Sources: UNFCCC (2004), Olivier *et al.,* (2001).

3.2 Emission source categories

Emissions of methane are released from a large number of sources featuring a wide range of technical and economic circumstances. Emission inventory systems, such as the inventory of the United Nations Framework Convention on Climate Change (UNFCCC), distinguish more than 300 different processes causing methane emissions. The UNFCCC database contains emission inventories for Annex I and non-Annex I countries for the years 1990 to 2000 that are based on national submissions (*national communications*). EDGAR 3.2 (Olivier *et al.*, 2001) is the most comprehensive global database providing sector specific methane estimates on a country level for 1990 and 1995.

The main sectors contributing to methane emissions are listed in Table 3.1. Other sectors, such as the iron and steel industry and fossil fuel combustion from stationary and mobile sources, make minor contributions and are not yet accounted for in this study.

Table 3.1: Sectors distinguished in the GAINS database for methane emissions.

GAINS sector	GAINS sub sector	UNFCCC category (Houghton et al., 1997a,b)
Livestock	Enteric fermentation	4 A
	Manure management	4 B
Rice cultivation		4 C
Waste	Biodegradable solid waste	6 A
	Wastewater	6 B
Coal mining		1 B1
Gas	Gas production	1 B2
	Gas consumption	1 B2
Oil production		1 B2
Biomass	Biomass consumption	1 A1
	Agricultural waste burning	4 F
	Savannah burning	4 E
	Forest burning	5 A

Table 3.2: Data sources for activity data for methane used in GAINS.

Sector	Activity	Sources of activity data
Agriculture -Enteric fermentation -Manure Management	Animal numbers	RAINS database, FAO (2004)
Rice cultivation	Area rice fields	FAO (2002)
Waste - Solid	Municipal biodegradable solid waste, i.e., paper, food and garden waste	CEPI (2002), Pulp and paper international (1998), AEAT (1998), Houghton et al. (1997a)
- Wastewater	Population (urban in transition and developing countries)	RAINS database
Coal production	Mining	RAINS database
Gas	Gas production and consumption	RAINS database, IEA (2002a,b), Russian Federation Ministry of Energy (2003)
Oil production	Oil production and processing	IEA (2002a,b), Russian Federation Ministry of Energy (2003)
Biomass - Biomass consumption	Biomass (OS1) consumption	RAINS database
- Agricultural waste burning	Agricultural waste burned	RAINS database

3.3. Emission factors and activities

GAINS primarily relies on emission factors provided in the revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Houghton *et al.*, 1997a,b). These guidelines provide a common methodology for estimating anthropogenic emissions of the major greenhouse gases and define explicit methodologies for calculating methane emissions for all sectors. In addition, other databases, such as the EDGAR 3.2 database (Olivier *et al.*, 2001), were used to validate emission factors.

3.3.1 Enteric fermentation and manure management

Methane emissions from animal husbandry are generated through enteric fermentation during the digestive process of herbivores and through manure management under anaerobic conditions. Emission factors are presented below separately for enteric fermentation and manure management. In order to simplify calculation procedures, the GAINS model use the sum of the emissions from the two processes per animal head instead of treating them separately. The activity unit used is number of animals. Alternatively, activity units based on the amounts of milk, meat, or wool produced could have been used. While such units would better reflect the effect on emissions on efficiency enhancements, in order to facilitate a quantification of interaction with ammonia and other pollutants in RAINS, the same activity unit is used here as for the other pollutants.

Enteric fermentation is a by-product of the digestive process of herbivores. The amount of methane emissions is determined primarily by:

- The digestive system. Ruminants (i.e., animals with a four compartments stomach) have the highest emissions, because of the high level of fermentation that occurs in the rumen. Main ruminants are cattle, buffalo, goats, sheep and camels. Pseudo-ruminants (i.e., horses, mules, asses, which have stomachs with three compartments) and monogastric animals (e.g., swine) have lower emissions as less fermentation takes place in their digestive systems (Houghton *et al.,* 1997a).
- The level of feed intake. Methane emissions are proportional to feed intake (Houghton *et al.,* 1997a).

Western European emission factors from Houghton et al. (1997a) were used for countries in the EU-15, Cyprus, Malta, Norway and Switzerland. For all other countries in the UNECE region, Eastern European emission rates from the same source were used. Emissions from buffaloes and camels have only been recorded for Turkey and not for other UNECE countries, where their numbers are very small.

Table 3.3: Calculation of emissions from enteric fermentation in GAINS

GAINS sectors	AGR_COWS	DL,DS	Dairy cattle (liquid and solid manure managem.)		
	AGR_BEEF	OL,OS	Other cattle (liquid and solid manure managem.)		
	AGR_PIGS	PL,PS	Pigs (liquid and solid manure managem.)		
	AGR_OTANI	SH	Sheep and goats		
	AGR_OTANI	HO	Horses		
	AGR_OTANI	BS	Buffaloes		
	AGR_OTANI	CM	Camels		
Activity rate	Number of animals				
Unit	Million animals				
Data sources	RAINS database and FAO (2004)				
Emission factors			Unit	Western Europe	Eastern Europe
	Other cattle		kt/Mheads	48.0	56.0
	Dairy cattle		kt/Mheads	100.0	81.0
	Pigs		kt/Mheads	1.5	1.5
	Sheep and goats		kt/Mheads	8.0	9.0
	Horses		kt/Mheads	18.0	18.0
	Buffaloes		kt/Mheads	..	55.0
	Camels		kt/Mheads	..	46.0
Data source	Houghton *et al.* 1997a				

Methane emissions from manure are generated when the organic content of manure is decomposed under anaerobic conditions (Hendriks *et al.,* 1998). Temperature has an important influence on the generation of methane during manure management. Different emission factors are therefore used for regions with cool (< 15°C), temperate (15-25°C) and warm (> 25°C) annual mean temperatures following Brink (2003) and Houghton et al. (1997a). Emission factors for temperate climate are used for Albania, Cyprus, Greece, Italy, Malta, Portugal, Spain and Turkey, while for all other countries in Europe the factors for the cool region are applied. A distinction is also made between solid and liquid manure management, since manure stored or treated as a liquid tends to produce more methane than manure handled as a solid (Brink, 2003, p.16). Data on the use of solid and liquid manure management was provided from the RAINS ammonia module (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/).

Table 3.4: Calculation of emissions from manure management in GAINS

GAINS sectors	AGR_COWS	DL	Dairy cattle with liquid manure management		
		DS	Dairy cattle with solid manure management		
	AGR_BEEF	OL	Other cattle with liquid manure management		
		OS	Other cattle with solid manure management		
	AGR_PIGS	PL	Pigs with liquid manure management		
		PS	Pigs with solid manure management		
	AGR_POULT	LH	Poultry, laying hens		
		OP	Poultry, other		
	AGR_OTANI	SH	Sheep and goats		
		HO	Horses		
		BS	Buffalo		
		CM	Camels		
Activity rate	Number of animals				
Unit	Million animals				
Data sources	Data on animal numbers are taken from the RAINS-Europe database (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/) and FAO (2002).				
Emission factors			Unit	Western Europe	Eastern Europe
for cool climate	Dairy cattle, liquid		kt/Mheads	29.9	24.1
	Dairy cattle, solid		kt/Mheads	3.0	2.4
	Other cattle, liquid		kt/Mheads	11.2	11.2
	Other cattle, solid		kt/Mheads	1.1	1.1
	Pigs, liquid		kt/Mheads	5.5	5.5
	Pigs, solid		kt/Mheads	0.6	0.6
	Poultry		kt/Mheads	0.078	0.078
	Sheep and goats		kt/Mheads	0.19	0.19
	Horses		kt/Mheads	1.4	1.4
for temperate	Dairy cattle, liquid		kt/Mheads	104.8	84.2
Climate	Dairy cattle, solid		kt/Mheads	4.5	3.6
	Other cattle, liquid		kt/Mheads	39.3	39.3
	Other cattle, solid		kt/Mheads	1.7	1.7
	Pigs, liquid		kt/Mheads	19.3	19.3
	Pigs, solid		kt/Mheads	0.8	0.8
	Poultry		kt/Mheads	0.117	0.117
	Sheep and goats		kt/Mheads	0.28	0.28
	Horses		kt/Mheads	2.1	2.1
	Camels		kt/Mheads	..	1.92
	Buffaloes		kt/Mheads	..	9.0
Data sources	Brink (2003), Houghton *et al.* (1997a)				

3.3.2 Rice cultivation

Emissions from rice cultivation result from the anaerobic decomposition of organic material in rice fields. Methane is released into the atmosphere mainly by diffusive transport through the rice plants during the growing season. Emissions depend on the season, soil type, soil texture, use of organic matter and fertiliser, climate, soil and paddy characteristics as well as agricultural practices. Thus, in theory a range of values for methane emission estimates is more realistic than a single number. In Europe, emissions from this source are small because only a few countries grow rice (i.e., Albania, Bulgaria, France, Greece, Hungary, Italy, Portugal, Romania, Spain and Turkey) and usually in limited quantities. No increases in future rice production are anticipated as expanding the rice paddies is generally not considered feasible (Matthews, 2002).

Emission factors were derived from the IPCC guidelines (Houghton *et al.,* 1997a). The IPCC method is based on the annual harvested area and provides various country-specific factors in the guidelines. Usually, two types of rice are distinguished:

- Upland rice (approximately 10 percent of global rice production and 15 percent of harvested area). Since the fields are not flooded, no emissions of methane occur.
- Wetland rice: irrigated, rainfed, deepwater rice (100 percent of rice cultivation in Europe).

Thus, only the area where wetland rice is grown is taken into account as the relevant activity. Emission factors derived are country-specific and vary depending on the frequency of the flooding of the fields.

Table 3.5: Calculation of emissions from rice cultivation in GAINS

GAINS sectors	AGR_ARABLE RICE
Activity rate	Harvested area
Unit	M hectares
Data sources	Houghton *et al.* (1997a, p. 4.19)
Emission factors	220-440 kt/M ha
Data source	Houghton *et al.* (1997a)

3.3.3 Disposal of biodegradable solid waste

Methane from municipal solid waste is generated when biodegradable matter is anaerobically digested at a landfill. The biodegradable waste consists of paper and organic waste, where the latter includes food, garden and other organic matter. The activity rates defined for this sector are the amount of consumed paper and the amount of organic waste that ends up in the municipal waste flow.

Data on the amount of paper consumed in 1990, 1995 and 2002 were retrieved from CEPI (2002) and Pulp and Paper International (1998). For Albania, Belarus, Bosnia-Herzegovina, Macedonia, Moldavia, the four Russian regions, Serbia-Montenegro, Turkey and the Ukraine, the average per-capita consumption of Bulgaria and Romania was assumed, i.e., 23.6 kg per person and year. Future paper consumption is estimated by using the average annual consumption increase in 1995-2002 (between -6 to +14 percent with an average of three percent per year) and assuming that this annual increase continues until 2015. After 2015 paper consumption is assumed to remain constant. For Albania, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Moldavia, Russia, Slovenia and Ukraine, where paper consumption decreased during the period 1995-2002, a two percent annual increase corresponding to the annual increase rate for Romania has been assumed for 2005-2015. The estimated paper consumption is presented in total and per-capita in Table 3.8. It is assumed that five percent of the paper consumed never ends up in the waste flow, but is scattered or burned without generating any methane emissions. The residual 95 percent of paper consumed is in the no control case assumed to end up in the waste flow and to be disposed of at a landfill. According to AEAT (1998, p.75) the methane potential of landfilled paper is 0.205 ton CH_4 per ton paper. Micales and Skog (1997) report considerably lower methane potentials when landfilling various types of paper, with an average of 0.090 ton CH_4 per ton paper landfilled. In this report, paper is assumed to generate 0.150 ton CH_4 per ton landfilled paper waste.

The amount of organic waste generated annually is calculated by multiplying the per capita municipal solid waste (MSW) generation rates by the population and the share of organic waste in MSW. For West-European countries total population is used for the calculations, while for economies in transition and for developing countries only the urban population is assumed to be participating in a MSW scheme. The per capita generation rates of MSW specified in Houghton *et al*. (1997a) were used assuming the Russian per-capita waste generation rate valid for all East European countries. Population data was retrieved from the RAINS database (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/). Shares of organic waste in the total MSW provided for the EU-12 in AEAT (1998, p.58) and vary between 21 percent and 49 percent with an average of 37 percent. This average share is assumed for all other countries. The estimated generation of organic waste presented in Table 3.8. AEAT (1998, p.76) assumes the methane generation rate of food and garden waste to be 0.082 ton per ton waste landfilled. We adopt this assumption here.

Note that the 'uncontrolled' emission factors relate to paper or organic waste landfilled on an uncontrolled landfill without waste diversion. The current legislation case (CLE) adjusts emission factors taking into account the current implementation of waste diversion options, such as recycling, composting and incineration of biodegradable waste.

Table 3.6: Calculation of emissions from landfilled paper waste in GAINS

GAINS sector	WASTE_PA NOF
Activity	Paper waste
Unit	Kt paper waste generated per year
Data sources	CEPI (2002) and Pulp & Paper International (1998)
Emission factors	Generation of CH_4 from landfilled paper waste
Unit	kt CH_4 per kt paper waste
	0.150
Data sources	AEAT (1998, p.75), Micales and Skog (1997)

Table 3.7: Calculation of emissions from landfilled organic waste in GAINS

GAINS sector	WASTE_OR NOF
Activity	Organic waste
Unit	kt organic waste generated per year
Data sources	Houghton *et al*. (1997a, p.6.6), AEAT (1998, p.58)
Emission factors	Generation of CH_4 from landfilled organic waste
Unit	kt CH_4 per kt organic waste
Data range	0.082
Data sources	AEAT (1998, p.76)

Table 3.8: Estimated paper consumption and amount of organic waste generated in total and per capita in 1990 and 2020.

Country	Paper consumption				Organic waste generation			
	1990		2020		1990		2020	
	Total kt	kg/capita	Total kt	kg/capita	Total kt	kg/capita	Total kt	kg/capita
Albania	85	27	111	36	408	124	442	124
Austria	1,283	158	3,033	374	949	123	1,009	123
Belarus	273	27	359	36	1,274	124	1,181	124
Belgium	2,090	204	4,940	482	1,721	173	1,826	173
Bosnia-H..	108	27	142	36	535	124	527	124
Bulgaria	276	34	349	43	1,083	124	826	124
Croatia	118	27	246	55	561	124	568	124
Cyprus	28	36	92	117	77	113	96	113
Czech Rep.	547	53	1,727	168	1,287	124	1,227	124
Denmark	1,068	201	1,585	298	874	170	947	170
Estonia	60	44	119	87	195	124	138	124
Finland	1,387	268	2,175	420	1,132	227	1,206	227
France	8,752	148	14,227	240	5,752	99	6,384	99
Germany	15,461	188	24,970	303	9,185	116	9,604	116
Greece	635	58	1,873	172	1,545	152	1,700	152
Hungary	557	56	1,332	133	1,287	124	1,126	124
Ireland	356	93	766	200	457	130	582	130
Italy	7,084	123	15,751	274	6,227	110	6,215	110
Latvia	77	32	156	66	332	124	263	124
Lithuania	110	31	165	47	459	124	410	124
Luxembourg	89	204	217	499	77	201	103	201
Macedonia	46	23	64	32	237	124	258	124
Malta	18	47	60	154	41	113	47	113
Moldavia	117	27	153	36	542	124	510	124
Netherlands	3,050	192	4,346	273	3,362	225	3,914	225
Norway	639	143	1,002	224	793	187	889	187
Poland	907	23	4,318	112	4,733	124	4,678	124
Portugal	758	76	1,489	149	1,268	128	1,351	128
Romania	514	23	491	22	2,882	124	2,609	124
Russl. (KALI)	23	27	31	36	125	124	109	124
Russl.(KOLK)	164	27	215	36	875	124	765	124
Russl.(REMR)	2,464	27	3,240	36	13,144	124	11,495	124
Russl.(SPET)	88	27	116	36	469	124	410	124
Serbia-M.	305	29	477	45	1,261	124	1,266	124
Slovakia	288	53	596	111	658	124	667	124
Slovenia	238	120	336	169	248	124	234	124
Spain	4,341	107	10,293	253	6,177	159	6,483	159
Sweden	1,961	221	2,755	311	1,154	135	1,235	135
Switzerland	1,448	202	1,876	261	985	147	1,063	147
Turkey	1,112	16	1,701	25	6,378	113	9,510	113
Ukraine	1,352	27	1,778	36	6,443	124	5,150	124
UK	9,361	159	14,292	243	7,984	139	8,669	139

Sources: CEPA (2002), Pulp and Paper International (1998), AEAT (1998,p.75), Houghton et al. (1997a, p.6.9).

3.3.4 Wastewater treatment

The handling of wastewater streams with high organic content under anaerobic conditions causes large amounts of methane emissions. In developed countries, most municipal and industrial wastewater is collected and treated aerobically in open lagoons with very low methane emissions (IEA-GHG, 1998). This is reflected in lower emission factors for Western Europe than for Eastern Europe (UNFCCC, 2004), where the infrastructure for wastewater treatment is less developed. Anaerobic digestion occurs primarily when large amounts of wastewater are collected and handled in an anaerobic environment. In Western Europe, where most of the population is connected to a sewage treatment system, emission estimates are based on total population figures. For Eastern Europe only the urban population is used in the emission estimates, since wastewater in rural areas is assumed to be handled in smaller quantities and without the generation of methane in an anaerobic environment.

The IPCC default methodology for calculating emissions from sewage (Houghton et al., 1997a) requires detailed data, e.g., on sector specific industrial outputs in the different countries, which is not readily available. Instead, emission factors per inhabitant have been calculated from the UNFCCC (2004) and EDGAR (2004) databases.

Table 3.9: Calculation of emissions from wastewater treatment in GAINS

GAINS sector	WASTE_SW	NOF		
Activity rate	Total population in Western Europe, urban population in Eastern European countries			
Unit	Million people			
Data sources	RAINS databases (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/)			
Emission factors		Unit	Western Europe	Eastern Europe
	Waste water treatment	kt/million people	0.83	5.60
Data sources	Based on 1990 values contained in the UNFCCC (2004) and EDGAR (2004) databases, estimating sewage emissions per head			

3.3.5 Coal mining

The process of coal formation produces methane, which is released to the atmosphere when coal is mined. Methane release is higher for underground mining. In addition, there are emissions from post-mining activities such as coal processing, transportation and utilization.

GAINS uses country-specific emission factors, taking into account the fraction of underground mining in each country and applying the appropriate emission factors for underground and surface mining as well as post-mining activities. National data on the mining structures were taken from EDGAR (Olivier *et al.,* 1996).

Table 3.10: Calculation of emissions from coal mining in GAINS

GAINS sectors	MINE-BC NOF	Mining of brown coal	
	MINE-HC NOF	Mining of hard coal	
Activity rate	Amount of coal mined		
Unit	Mt coal mined per year		
Data sources	RAINS database (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/)		
Emission factors		Unit	
	Coal mining	kt/Mt	0.9-23.9
Data sources	Using coal production structures as documented in Olivier *et al.* (1996; p. 116) to weigh IPCC emission factors given in Houghton *et al.* (1997a)		

3.3.6 Production of natural gas

During gas production, methane emissions occur at the well as fugitive and other maintenance emissions. Data for the gas production has been retrieved from the RAINS database (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/) for the EU-25 countries. For non-EU-25 countries, the data source used is IEA statistics. For regional data on Russia, gas production forecasts by the Russian Federation Ministry of Energy (2003, p.72) have been used. Only emissions from gas production west of the Ural are included, since all other gas production in Russia takes place outside the present GAINS modelling domain (up to the Ural), which is the geographical limit of this study. Emission factors were adopted from the IPCC guidelines (Houghton et al., 1997a, p.1.121). When ranges are given, the median value of the range has been used.

Table 3.11: Calculation of emissions from gas production in GAINS

GAINS sector	PROD GAS	Production of natural gas			
Activity rate	Amount of gas produced				
Unit	PJ per year				
Data sources	RAINS databases, IEA (2002) and Russian Federation Ministry of Energy (2003, p.72)				
Emission factors	Emission source	Western Europe	FSU and Eastern Europe	Rest of World[a]	Unit
	Fugitive and other maintenance emissions	0.021	0.245	0.263	kt/PJ produced
Data sources	Houghton *et al.,* 1997a,p.1.121				

[a] Values used for Turkey.

3.3.7 Leakage during transmission and distribution of natural gas

Losses of natural gas during its transport and final use are an important source of methane emissions. Emissions are calculated for the distribution to the end consumers and, for gas producing countries, for the long-distance transmission processes. To reflect these differences, the IPCC guidelines provide different (ranges of) emission factors for Western and Eastern European countries. The emission factors used here are the medians of the specified ranges. IPCC define emission factors for losses during transport and distribution as methane lost per unit of gas *consumed* for the Western European countries and per unit of gas *produced* for Former Soviet Union and Eastern European countries. Data on gas consumption and production has been retrieved from RAINS (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/) and IEA (2002a,b). Regional data for Russia on gas production was obtained from the Russian Federation Ministry of Energy (2003). For Russia, losses are calculated based total volume of gas produced in the European part of Russia and Western Siberia. Although gas fields in Western Siberia are outside of the area targeted in this study, almost all gas produced in the region is transported westwards for consumption in Russia or Europe. Thus, these emissions have been included in this analysis.

Table 3.12: Calculation of emissions from gas distribution in GAINS

GAINS sectors	GAS CON_COMB	Petroleum refinery –combustion		
	GAS CON_LOSS	Petroleum refinery –losses during transmission		
	GAS IN_BO	Industry -combustion in boilers		
	GAS IN_OCTOT	Industry –other combustion		
	GAS PP_EX_OTH	Power and district heating plants		
	GAS PP_NEW	Power and district heating plants –new		
	GAS DOM	Combustion in residential/commercial sector		
	GAS NONEN	Non-energy use of gas		
	GAS TRANS	Gas *produced* in the Former Soviet Union, and Eastern European countries. Gas *consumed* for EU-15, Norway and Switzerland.		
Activity rate	Amount of gas consumed or produced			
Unit	PJ per year			
Data sources	RAINS database, IEA Statistics (2002) and Russian Federation Ministry of Energy (2003, p.72)			
		Emission factors:		
Emission source:	Western Europe	FSU and Eastern Europe	Rest of World	Unit
Leakage at industrial and power plants	0	0.2795	0.2055[a]	kt/PJ consumed
Leakage from consumption in residential sector	0	0.1395	0.1615[a]	kt/PJ consumed
Processing, transport and distribution	0.1025	0.458	0.288	kt/PJ produced *or* consumed
Data sources	Houghton *et al.,* 1997a			

[a] These values include emissions from processing, transport and distribution

3.3.8 Crude oil production

During crude oil production, methane emissions arise from venting and flaring and as fugitive and maintenance emissions. For Western Europe, the IPCC guidelines (Houghton *et al.*, 1997a, p.1.30) report a range for the emission factor for oil production of 0.0013-0.008 kt/PJ. For all other countries the corresponding range is 0.0003-0.0015 kt/PJ. The mean values of these ranges have here been assumed as emission factors for oil production (see Table 3.13). Western European values have been used for EU-15, Cyprus, Malta, Norway and Switzerland.

Table 3.13: Calculation of emissions from oil production in GAINS

GAINS sector	PROD	CRU		
Activity rate	Amount of crude oil produced			
Unit	PJ per year			
Data sources	IEA energy statistics (2000a, 2000b), Russian Federation Ministry of Energy (2003) for data on Russian regions.			
Emission factors		Unit	Western Europe	Former Soviet Union, Eastern Europe and Rest of World
	Oil production	kt/PJ	0.005	0.003
Data source	Houghton *et al.* (1997a, p.1.30)			

3.3.9 Crude oil transportation, storage and refining

Methane emissions occur during oil transportation, refining and storage. In the IPCC guidelines (Houghton et al. 1997a, p.1.30) emission factors for oil transportation are based on the amount of oil transported, while emission factors for refining and storage are based on the amount of oil refined. Since it has not been possible to find data on the amount of oil shipped by tankers, it is assumed that the amount tankered corresponds to the amount of oil refined. Thus, the emission factors reported by IPCC for oil transported, refined and stored have been added up, resulting in a range of 0.00086-0.0023 kt/PJ. The mean value of this range has been used in the GAINS estimates.

Table 3.14: Calculation of emissions from oil production in GAINS

GAINS sectors	PR_REF	NOF	
Activity rate	Amount of oil input to refineries		
Unit	PJ per year		
Data sources	IEA energy statistics (2000a, 2000b)		
Emission factors		Unit	All regions
	Oil refined	kt/PJ	0.0016
Data sources	Houghton *et al.* (1997a, p.1.30)		

3.3.10 Biomass burning

Biomass consumption comprises the burning of biomass, wood and charcoal for energy purposes. For the time being, GAINS does not include biomass burning for non-energy purposes, e.g., natural forest fires or burning of savannas.

Table 3.15: Calculation of emissions from biomass burning in GAINS

GAINS sectors	CON_COMB	OS1	Petroleum refineries –combustion	
	IN_BO	OS1	Industry -combustion in boilers	
	IN_OCTOT	OS1	Industry –other combustion	
	PP_EX_OTH	OS1	Power and district heating plants	
	PP_NEW	OS1	Power and district heating plants –New	
	DOM	OS1	Combustion in residential/commercial sector	
Activity rate	Amount of biomass burned			
Unit	PJ/year			
Data sources	RAINS database (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/)			
Emission factor			Unit	
	Biomass combustion		kt/PJ	0.3
Data sources	Houghton *et al.,* 1997a			

3.3.11 Burning of agricultural waste

Methane emissions also originate from the (open) burning of agricultural waste. A global emission factor based on work done by Masui *et al.* (2001) is used for GAINS.

Table 3.16: Calculation of emissions from burning of agricultural waste in GAINS

GAINS sector	WASTE_AGR	NOF	Burning of agricultural waste	
Activity rate	Amount of waste burned			
Unit	Mt/year			
Data sources	RAINS database (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/)			
Emission factors			Unit	
	Agricultural waste burning		kt/Mt	0.0012
Data sources	Masui *et al*. (2001)			

4 Emission control options and costs

Several options to reduce methane emissions from anthropogenic sources were identified and included in the GAINS model. Their removal efficiencies, costs and application potentials were determined based on literature data.

4.1 Enteric fermentation

There are continuous productivity increases in milk and beef production for efficiency reasons. This occurs due to increased feed intake, to the increased penetration of genetically modified high yielding animals, and because of various changes in the diet. With enhanced productivity, a constant amount of milk and meat can be produced with a smaller livestock size. Although methane emissions per animal is likely to increase as a result of increased feed intake and diet changes, overall emissions per unit of milk and meat will decline as the livestock size is diminished. For calculating methane emissions, an alternative to using animal numbers as activity unit would be to use milk and meat production. Such activity units would allow for a more direct way of calculating the effects of various efficiency enhancing measures on emissions. However, in order to be consistent with the activity units used in the ammonia module of RAINS, GAINS will for the moment maintain animal numbers as activity units.

For the current legislation case, the assumed autonomous productivity increase in milk production implies a constant amount of milk to be produced from a smaller livestock with higher methane emissions per animal, but with lower overall emissions due to the smaller stock size. Between 1997 and 2001, milk production per animal increased on average by 3.5 percent per year in the EU New Member states, but decreased or stayed constant in the three EU Candidate countries Romania, Bulgaria and Turkey (Eurostat, 2003). For EU-15, Norway and Switzerland, milk production per animal increased on average by 1.2 percent per year between 1995 and 2000 (FAO, 2004 and RAINS, 2004). Thus, an autonomous increase in milk productivity of 3.5 percent per year is assumed for the New Member States and of 1.2 percent per year for the EU-15, Norway and Switzerland, but not in the other countries outside the EU. For EU-15, Norway and Switzerland, the productivity increase is assumed to continue until 2015 and be zero thereafter. For the New Member States, the productivity increase is assumed to continue until 2009 and be the same as for EU-15 thereafter. Over the studied periods, beef production per animal decreased by on average 0.7-0.9 percent per year in all regions (Eurostat 2003, FAO 2004, and RAINS 2004). Thus, no autonomous increase in beef productivity is assumed to take place.

No further autonomous productivity increases are considered for the “maximum technically feasible reduction” (MFR) scenario. Instead, the further productivity increases considered technically possible have been accounted for by applying the various productivity enhancing options listed below to a maximum.

In addition to the autonomous productivity increase, a number of control options are available to further reduce methane emissions from dairy cows and cattle. These options reduce emissions through various dietary adjustments. Such adjustments include changes in the feed composition by replacing roughage for concentrates, introducing more fat and non-structural carbohydrates (NSC)[1] in the feed, or increasing the general feed intake. Such changes demand controlled feeding of concentrates, which is only possible when animals are fed indoor. According to Gerbens (1998), increased feed intake is applicable to indoor fed animals with a current average feed intake below voluntary feed intake. A faster implementation of the number of high-yielding, genetically improved animals would also reduce the amount of methane generated per unit of milk or meat. Since no estimate of the effect of such on option on methane emissions could be found in the literature, the option is not considered in GAINS.

Many of the options considered above have already been applied to stall fed cattle in the EU-15 countries for efficiency reasons (ECCP, 2003). These are therefore inherent in the current legislation case (CLE) and reflected in higher emission factors per animal for Western European countries than for countries in Eastern Europe.

A legislation, which is likely to at least indirectly influence the adoption of these control options, is the Common Agricultural Policy (CAP) adopted by the EU Agricultural Ministers in June 2003 (European Commission, 2004a). The CAP aims at promoting an extensive agriculture with high environmental and animal welfare standards. This implies reduced cattle stocks in the long term and less intensive milk and meat production. In GAINS, the adjustment to CAP is assumed to imply that the number of housing days will not increase beyond the current level. The options that are considered feasible are to increase the feed intake of the animals, to change to more NSC in the diet, and a further replacement of roughage for concentrates.

The GAINS model includes the extended application of these options to stall fed cattle in regions where maximum application can be assumed not to have been attained. As an approximation of the share of cattle fed indoor to outdoor, data on the number of housing days per year from the RAINS ammonia module were used (Klimont and Brink, 2003).

In the CLE case, the option "increased feed intake" is assumed to be implemented already to stall fed dairy cows in Western Europe. For Eastern Europe, countries with an average milk production of less than 4 ton/cow/year (see Table 4.6) are assumed to still have the potential to apply the option to stall fed cows. The cost for this option is negative for dairy cows in all regions. For non-dairy cattle, the option is assumed to have been implemented to all stall fed cattle in EU-15, Norway, Switzerland, Cyprus and Malta, but not in the other regions.

In the CLE case, the option "change to a NSC diet" is assumed to be implemented already to stall fed dairy cows in EU-15, Norway and Switzerland. The costs estimated for this option are close to zero, slightly negative or positive.. For all other countries, the cost is clearly positive. This is consistent with the conclusion of the Working group on Agriculture for the European Climate Change Programme (ECCP, 2003, Annex II). They concluded that a shift in the concentrate composition to more NSC is a cost-neutral option in EU-15.

In the CLE case, the option "replacement of roughage for concentrates" is assumed to have been implemented already to stall fed cows and non-dairy cattle in EU-15, Norway and Switzerland. The cost of this option is negative except for non-dairy cattle in Eastern Europe.

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[1] A change in the composition of concentrates to more non-structural carbohydrates (NSC) implies a change towards less fibers and more starch and sugars in the concentrates.

For the MFR case these options are applied only in regions where further implementation is considered possible. Further implementation of the option “increased feed intake” is assumed possible for stall fed dairy cows in countries with an average milk production below 4 ton/cow/year and for stall fed non-dairy cattle in Eastern Europe. A shift to more NSC in the diet is assumed possible for all stall fed dairy cows in regions outside EU-15, Norway and Switzerland and for non-dairy stall fed cattle in all regions.

An increased level of feed intake and a change to a NSC diet have effects on both emissions and productivity. Gerbens (1998, p.21) calculates the effects of increasing the feed intake by one kg dry matter/day/animal and the effects of replacing 25 percent of a structural carbohydrates (SC) diet with a NSC diet. The expected emission reductions are presented in Tables 4.1 and 4.2. Gerbens assumes a constant milk and meat production per country/region and the specified emission reductions are the combined effect of livestock reductions and a metabolic change in the rumen with formation of less acetate and more propionate (a so-called VFA-shift).

Table 4.1: Assumed effects of increasing the feed intake by 1 kg dry matter/day/animal.

	Emission reduction per region (%)		Livestock reduction (and assumed reduction in marginal cost of production) (%)	
	Western Europe	Eastern Europe	Western Europe	Eastern Europe
Dairy/Milk	7.8	13.2	10.8	16.6
Non-dairy/Beef	9.6	5.4	14.1	8.8

Source: Gerbens (1998, p.27)

Table 4.2: Assumed effects of replacing 25 perecnt of SC by NSC concentrate.

	Emission reduction per region (%)		Livestock reduction (and assumed reduction in marginal cost of production) (%)	
	Western Europe	Eastern Europe	Western Europe	Eastern Europe
Dairy/Milk	13.1	10.8	1.0	0.8
Non-dairy/Beef	7.8	8.2	0.7	0.3

Source: Gerbens (1998, p.30)

Table 4.3: Assumed effects of increasing the concentrate intake by 1 kg dry matter per day and reducing the intake of roughage by 0.5 kg dry matter per day.

	Emission reduction per region (%)		Livestock reduction (and assumed reduction in marginal cost of production) (%)	
	Western Europe	Eastern Europe	Western Europe	Eastern Europe
Dairy/Milk	6.2	12.4	6.6	15.0
Non-dairy/Beef	8.2	5.4	8.7	7.8

Source: Gerbens (1998, p.28)

The cost of increasing the feed intake consists of two components: the cost for additional fodder and the cost savings from being able to produce the same amount of milk or meat with fewer animals.

The cost of increasing the feed intake by one kg dry matter/day/animal is measured as the price of fodder adjusted for an assumed dry matter content of 90 percent. For EU-15, the average price of fodder weighted by the quantity of different fodders consumed was calculated based on the prices for feed maize, feed oats, feed barley, and feed wheat in 1995-2000 (European Commission, 2004b). For the EU-15, Switzerland and Norway the average price for EU-15, 116 €/t fodder, was used. For the New Member States and other Eastern European countries, the average price of barley was taken as an approximation for the price of fodder, assuming that barley is a cereal mainly used as fodder (FAO, 2004). The average price of barley for EU New Member countries was found to be 99 €/t fodder, and this price is adopted as fodder price in all of Eastern Europe. The average increase in the operating cost per ton methane reduced in country i is calculated as:

$$OM_{ton;i} = \left[\underbrace{\frac{p_{fodder;i}}{0.90} * F * 365}_{\substack{Cost\_increase \\ per\_animal}} * \underbrace{n_{animal;i} * (1 - r_{livestock})}_{\substack{Animal\_number \\ after\_option \\ implemented}} \right] * \left[\underbrace{r_{emission} * ef * n_{animal}}_{\substack{total \\ emission \\ reduction}} \right]^{-1} \text{, Equation 4.1}$$

where p_{fodder} fodder price in €/t,
F increase in fodder consumption in t dry matter/animal/day,
n_{animal} number of animals in country before option implemented,
$r_{livestock}$ livestock reduction from option implementation in %,
$r_{emission}$ emission reduction from option implementation in %, and
ef no control emission factor for enteric fermentation.

The cost-savings are measured as a reduction in production cost when less livestock can produce the same amount of milk or beef. The producer prices of milk and beef for the year 2000 were adopted from FAO (2004). Assuming a competitive market for milk and meat, prices reflect the marginal costs of production. To express the cost-saving from the productivity increase in monetary terms, it has been defined as the marginal cost times the livestock reduction. This is taken to correspond to the costs saved when the same amount of milk or beef can be produced with less livestock. No autonomous productivity increase is assumed to take place. Unless a control option is implemented, the productivity of the animals is assumed to remain constant at the 2000 level. The production of meat for the stock of beef cattle in place (not the animals slaughtered) is measured as the amount of meat produced in 2000 divided by the beef cattle stock in the same year (FAO, 2004). Production per animal and prices of milk and meat are presented in Table 4.6. The cost-saving from increased productivity per ton of methane reduced in country *i* is calculated as:

$$CS_{ton;i} = \underbrace{p_{milk/beef;i} * r_{livestock}}_{\substack{Cost\_reduction \\ per\_ton\_product}} * \underbrace{m_{milk/beef;i} * \frac{1}{1 - r_{livestock}}}_{\substack{Product\_t/animal \\ after\_option\_implemented}} * \underbrace{n_{animal;i} * (1 - r_{livestock})}_{\substack{Animal\_number \\ after\_option\_implemented}} * \underbrace{\left[r_{emission} * ef * n_{animal}\right]^{1}}_{Total\_emission\_reduction}$$

Equation 4.2

where $p_{milk/beef}$ price of milk or beef in €/t,

m milk or beef produced per animal before option implemented,

n_{animal} number of animals in country before option implemented,

$r_{livestock}$ livestock reduction due to option implementation in %,

$r_{emission}$ emission reduction due to option implementation in %, and

ef no control emission factor for enteric fermentation.

The average total cost per emitted unit of methane for increasing the feed intake is found to vary widely between countries and between dairy and non-dairy cattle. This is mainly caused by the large variations in the cost-savings from increased production. For dairy cows in Western Europe, the total cost varies from -29,800 to -10,400 €/t CH4. For dairy cows in Eastern Europe, the range is from -11,800 to -100. For non-dairy cattle the total cost range is -18,200 to +1,200 €/t CH_4 for Western Europe and +150 to +11,000 €/t CH_4 for Eastern Europe. Using the same assumptions about emission and livestock reductions, but without country-specific assumptions about animal productivity or prices of milk, beef and fodder, Gerbens (1998 p.20) yields average cost-savings of -2,815 €/t CH_4 for Eastern Europe and -969 €/t CH_4 for Western Europe.

The cost of replacing 25 percent of structural carbohydrates (SC) diet with NSC consists of two components: the additional costs of switching to a more expensive type of fodder and the cost savings due to increased productivity when less livestock can produce the same amount of milk or beef.

The cost of replacing 25 percent of a structural carbohydrates (SC) diet with NSC is measured as the price difference between SC and NSC concentrates times the amount of feed replaced. Each dairy animal is assumed to consume 15 kg dry matter per day, while each non-dairy animal is assumed to consume 10 kg dry matter per day (Smink *et al.*, 2004, Teagasc, 2004, Kaert *et al.*, 2003). The average concentrate feed in diet is assumed to be 50 percent for stall fed animals (Gerbens, 1998, p.30). The price of NSC (147 €/t concentrate) was taken from Gerbens (1998, p.24), converted into € 2,000, and assumed constant for all countries. The price of an SC diet is assumed to be the same as the average fodder price presented in Table 4.6. The cost increase from changing the diet per ton of methane reduced in country *i* is calculated as:

$$OM_{ton;i} = \left[\underbrace{0.25 * d * \left(p_{NSC} - \frac{p_{fodder;i}}{0.90} \right)}_{\substack{Cost\_increase \\ per\_animal}} * \underbrace{n_{animal;i} * (1 - r_{livestock})}_{\substack{Animal\_number \\ after\_option \\ implemented}} \right] * \left[\underbrace{r_{emission} * ef * n_{animal;i}}_{\substack{total \\ emission \\ reduction}} \right]^{-1},$$

Equation 4.3

where p_{NSC} price of NSC concentrate (=147 €/t dry matter),
p_{fodder} fodder price in €/t,
d annual consumption of feed in t dry matter per animal,
n_{animal} number of animals in country before option implemented,
$r_{livestock}$ livestock reduction from option implementation in %,
$r_{emission}$ emission reduction from option implementation in %, and
ef no control emission factor for enteric fermentation.

The cost-savings from this option are defined in the same way as for the previous option and are specified in Equation 4.2.

Just as for the previous option, the total cost of this option varies between countries and between dairy and non-dairy cattle. For dairy cows, the average total cost is calculated between -600 and +1,200 €/t CH_4 for Western Europe and +2,800 to +3,500 €/t CH_4 for Eastern Europe. For non-dairy cows, the average total cost is estimated at 300-5,200 €/t CH_4 for Western Europe and 4,500-4,700 €/t CH_4 for Eastern Europe. Main reasons for these differences are variations in fodder prices, productivity increases and attainable emission reductions. Without country-specific assumptions about prices and animal productivity and assuming the price of NSC to be the same as for SC concentrate, Gerbens (1998, p.24) found cost-savings of -269 €/t CH_4 for Eastern Europe and -308 €/t CH_4 for Western Europe.

The cost of replacing 0.5 kg dry matter of roughage per day with 1 kg dry matter of concentrate is measured as the sum of the cost of replacing the feed and the cost-saving of the resulting productivity increase. Gerbens (1998, p.23) uses a price of roughage, which is 63 percent of the concentrate price. Adopting this assumption and using the average fodder price in kg dry matter as the price of concentrates, the increase in the variable cost is defined as:

$$OM_{ton;i} = \left[\underbrace{(1-0.5*0.63)*\frac{p_{fodder;i}}{0.90}*F*365}_{Cost\_increase\ per\_animal} * \underbrace{n_{animal;i}*(1-r_{livestock})}_{Animal\_number\ after\_option\ implemented} \right] * \left[\underbrace{r_{emission}*ef*n_{animal}}_{total\ emission\ reduction} \right]^{-1}$$

Equation 4.1

where p_{fodder} fodder price in €/t,

F increase in fodder consumption in t dry matter/animal/day,

n_{animal} number of animals in country before option implemented,

$r_{livestock}$ livestock reduction from option implementation in %,

$r_{emission}$ emission reduction from option implementation in %, and

ef no control emission factor for enteric fermentation.

The cost-savings from this option are defined in the same way as for the two previous options and are specified in Equation 4.2.

The total cost of this option varies between countries and between dairy and non-dairy cattle. For dairy cows, the average total cost varies between -24,500 to -9,500 €/t CH_4 for Western Europe and between -13,100 and -1,900 €/t CH_4 for Eastern Europe. For non-dairy cows, the average total cost varies between -15,600 and -1,400 €/t CH_4 for Western Europe and between -2,200 and 7,400 €/t CH_4 for Eastern Europe. Main reasons for the fluctuations are variations in fodder prices, productivity increases and attainable emission reductions. Without country-specific assumptions about prices and animal productivity, Gerbens (1998, p.28) found total costs of -8,258 €/t CH_4 for Eastern Europe and -5,648 €/t CH_4 for Western Europe.

In Table 4.5, control costs are specified for the regions that are considered to have a potential to further implement the options increased feed intake, change to a NSC diet, and replacement of roughage for concentrate.

A third option, which is still at a research stage and not yet commercially available, is to introduce grass varieties with high levels of malate and fumarate, which rumen microbes use to produce propionate instead of methane (ECCP, 2003, Annex II). If found satisfactory, these propionate precursors have a potential for use in the European Union (ECCP, 2003), where the introduction of the CAP is expected to lead to an increased use of roughage feed. AEAT (2001a) estimates the removal efficiency at 25 percent of methane emissions from dairy cattle and 10 percent from non-dairy cattle when an 80g supplement is given per day and animal. Allowing for a reduction in other feed costs, the cost is estimated at 527 €/t CH_4 for dairy cattle and 1,100 €/t CH_4 for non-dairy cattle.

In the CLE case, no application of propionate precursors is assumed.

In the MFR case, propionate precursors are applied to all roughage/forage fed cattle in all regions from 2020 and onwards. The share of roughage/forage fed animals is assumed to correspond to the share of animals feeding outdoor, i.e., the average share of days in a year spent outdoor for cows and cattle given by the RAINS ammonia module (Klimont and Brink, 2003).

Table 4.4: Enteric fermentation: Control option applications and removal efficiencies.

Control option	GAINS technology abbreviation	Application CLE (%)	Application MFR	Removal efficiency (%)	
				W. Europe	E. Europe
Autonomous productivity increase	AUTONOM	Dairy: 0-47 Non-dairy: 0	No further implementation (replaced by implementation of options below)	100	100
Increased feed intake	INCRFEED	No further implemen-tation	Dairy: Stall fed cattle in countries with milk prod <4 tons/cow/year. Non-dairy: Stall fed cattle in all countries except EU-15, Norway, Switzerland, Malta and Cyprus.	8 dairy 10 non-dairy	13 dairy 5 non-dairy
Change to more NSC in diet	NSCDIET	No further implemen-tation	Dairy: Stall fed cattle in all countries. Non-dairy: Stall fed cattle in all countries.	13 dairy 8 non-dairy	11 dairy 8 non-dairy
Replacement of roughage for concentrate	CONCENTR	No further implemen-tation	Dairy and non-dairy: Stall fed cattle in all countries except EU-15, Norway, Switzerland, Malta and Cyprus.	6.2 dairy 8.2 non-dairy	12.4 dairy 5.4 non-dairy
Propionate precursors	PROPPREC	No implemen-tation	All roughage/forage fed cattle from 2010 onwards	25 dairy 10 non-dairy	25 dairy 10 non-dairy

Table 4.5: Enteric fermentation: Control option costs specified for regions where further implementation of options is assumed possible.

Control option		Regions with further implementation possible	Investm. cost €/t CH_4	O&M cost €/t CH_4	Cost-savings €/t CH_4	Total cost €/t CH_4
Autonomous productivity increase		No further implementation (replaced by implementation of options below)	0	0	0	0
Increased feed intake	Dairy	Stall fed animals in countries with milk prod <4 tons/cow/year.	0	3,132	-14,886 to -3,236	-11,754 to -104
	Non-dairy	Stall fed animals in all regions except EU-15, Norway, Switzerland, Malta, and Cyprus.	0	12,109	-11,958 to -1,136	151 to 10,972
Change to more NSC in diet	Dairy	Stall fed animals in all regions	0	621-3,725	-1,942 to -191	-599 to 3,534
	Non-dairy	Stall fed animals in all regions	0	1,452 to 5,808	-1,693 to -26	301 to 5,154
Replacem. roughage for concentr.	Dairy	Stall fed animals in all regions except EU-15, Norway, Switzerland, Malta, and Cyprus	0	1,257	-14,319 to -3,113	-13,061 to -1,856
	Non-dairy		0	8,385	-10,599 to -1,007	-2,214 to 7,378
Propionate precursors	Dairy	All regions	0	527	0	527
	Non-dairy	All regions	0	1,100	0	1,100

Table 4.6: Assumptions about milk and meat production per animal, producer prices of domestically produced meat and milk and consumer price of fodder.

Country	Milk production 2000	Beef production 2000	Milk price 2000	Beef price 2000	Fodder price
	t/cow/year	t/cattle/year	€/t	€/t	€/t
Albania	2.84	0.072	281	2,113	99
Austria	5.14	0.131	288	2,925	113
Belarus	2.14	0.097	140	1,370	99
Belgium	5.85	0.114	298	2,918	111
Bosnia-H..	1.42	0.041	281	2,113	99
Bulgaria	3.13	0.164	173	903	99
Croatia	1.59	0.127	281	2,113	99
Cyprus	6.11	0.144	305	2,437	99
Czech Rep.	4.35	0.057	204	2,045	99
Denmark	7.37	0.116	327	2,079	108
Estonia	2.72	0.044	170	888	99
Finland	6.71	0.129	340	4,392	104
France	4.17	0.113	286	5,841	117
Germany	4.88	0.117	314	2,162	111
Greece	4.26	0.173	338	3,550	135
Hungary	3.97	0.104	242	1,521	99
Ireland	4.26	0.103	269	3,030	119
Italy	6.17	0.231	358	3,928	126
Latvia	2.34	0.090	154	1,077	99
Lithuania	2.35	0.056	121	948	99
Luxembourg	5.63	0.084	319	2,918	116
Macedonia	3.15	0.029	281	2,113	99
Malta	4.80	0.179	338	3,550	99
Moldavia	1.38	0.032	140	1,370	99
Netherlands	7.11	0.149	320	2,841	115
Norway	4.43	0.240	357	2,233	116
Poland	2.97	0.071	195	1,442	99
Portugal	5.55	0.105	288	3,961	126
Romania	2.94	0.057	138	2,132	99
Russl. (KALI)	2.14	0.097	140	1,370	99
Russl.(KOLK)	2.14	0.097	140	1,370	99
Russl.(REMR)	2.14	0.097	140	1,370	99
Russl.(SPET)	2.14	0.097	140	1,370	99
Serbia-M.	1.78	0.199	281	2,113	99
Slovakia	3.15	0.086	198	1,881	99
Slovenia	3.23	0.137	244	2,324	99
Spain	4.70	0.139	272	3,357	124
Sweden	6.59	0.115	357	2,233	109
Switzerland	5.18	0.131	491	5,431	116
Turkey	1.63	0.032	381	6,527	99
Ukraine	1.66	0.063	140	1,370	99
UK	4.92	0.087	269	3,030	106

Sources: FAO (2004), European Commission (2004b).

4.2 Manure management

Methane emissions from manure can be reduced through anaerobic digestion (AD) of the manure in a closed vessel. The process generates methane, which can be utilized as energy. The removal efficiency is 95 percent of the generated methane (AEAT, 1998, p.33). However, the process itself produces more methane and therefore a lower removal efficiency of 80 percent of the original methane potential is assumed. Farm-scale AD plants have a minimum size of 100 dairy cows, 200 beef cattle or 1000 pigs. Centralized AD plants, serving many farms, are only feasible in areas with very intensive animal farming, since long distance transport is costly and increases emissions of both methane and carbon oxides. Farm-scale digesters do not have these limitations and are more generally applicable than centralized plants. The applicability and costs for the AD option assumed here are therefore based on farm-scale digesters.

Emissions per animal vary with temperature and manure management method (liquid or solid). The control cost per unit of reduced emissions will therefore vary with these parameters. AD is only considered to be feasible for liquid manure management, since emissions from solid manure management are much too low to justify the use of AD (AEAT, 1998, p.41).

In the CLE case, no adoption of farm-scale AD is assumed.

In the MFR case, AD is assumed to be applied to the share of farms above the minimum size for farm-scale AD (i.e., 100 dairy cattle, 200 beef cattle, or 1000 pigs per farm) as stated for the EU-15 by AEAT (1998, p.45). Due to a lack of data for Eastern Europe, this region is assumed to have the same farm size distribution as Greece, i.e., 15 percent of dairy cow farms have 100 animals or more and 24 percent of beef cattle farms have 200 animals or more and 71 percent of pig farms have 1000 animals or more.

Costs for installing AD are based on Italian cost data for the installation of a farm-scale AD plant (AEAT, 1998, p.37). The plant is designed to handle 22,000 t manure/year generating 180 MWh electricity and 440 MWh heat per year. The investment cost is estimated at 72,600 € or 5,344 €/year when annualized over a 20 years lifetime of the equipment. Operating and maintenance costs are estimated at 4,539 €/year, whereof 39 percent are labour costs. The utilized energy (i.e. electricity and heating) is regarded as a cost-saving.

Housing adaptation is an option to primarily reduce ammonia emissions from pig farms. This implies installing a manure slide and storage system or a manure rinsing system, which regularly empties the manure cellar or stable floor. As an additional effect, methanogenesis is retarded and 10 percent of methane emissions are removed (Hendriks *et al.*, 1998, p.36). The same reference gives the costs for housing adaptation options. Installing a manure slide and storage system requires an investment of 100-500 €/pig. A manure rinsing system needs an investment cost of 70-350 €/pig. With a lifetime of 20 years, the annualized investment cost is calculated to 5-37 €/pig/year. The emission factor for pigs is 5.5 kg CH_4/animal and the removal efficiency of this option is 10 percent. Thus, if housing adaptation is adopted exclusively as an option to control methane, the annualized investment cost is estimated in the range of 9,400-66,900 €/t CH_4 removed.

Table 4.7: Control options manure management

Option	GAINS technology abbreviation	Type of animal/ Climate/ Manure management	Application CLE (%)	Applic. MFR (%)	Removal efficiency (%)
Farm-scale anaerobic digestion plant	FARM_AD	Dairy cows/cool/liquid	0	0-84	80
		Dairy cows/temp/liquid	0	11-42	80
		Beef cattle/ cool/liquid	0	4-96	80
		Beef cattle/temp/liquid	0	0-54	80
		Pigs/cool/liquid	0	12-95	80
		Pigs/temperate/liquid	0	52-82	80
Housing adaptation	SA	Pigs/liquid	0	24-91	10

Source: AEAT (1998) and Hendriks *et al*. (1998)

Table 4.8: Costs for control options manure management

Option	GAINS technology abbreviation	Type of animal/ Climate/ Manure management	Annual. investm. cost €/t CH_4	O&M costs €/t CH_4	Cost-saving €/t CH_4	Total cost €/t CH_4
Farm-scale anaerobic digestion plant	FARM_AD	Dairy cows/cool/liquid	145	80-144	-200 to -14	74 to 223
		Dairy cows/temp/liquid	41	23-36	-53 to -18	20 to 58
		Beef cattle/ cool/liquid	191	106-191	-266 to -19	98 to 294
		Beef cattle/temp/liquid	54	30-48	-70 to -23	27 to 76
		Pigs/cool/liquid	84	46-84	-117 to -8	43 to 129
		Pigs/temperate/liquid	21	12-19	-27 to -9	10 to 30
Housing adaptation	SA	Pigs/liquid	9,400-66,900	0	0	9,400-66,900

Source: AEAT (1998) and Hendriks *et al*. (1998)

4.3 Rice cultivation

The literature lists low methane emitting rice strains as an option to reduce methane emissions from rice paddies (IEA, 1998). Methane emissions vary significantly between rice strains. A careful selection of strains is estimated to reduce emissions by 20-30 percent. No information has been found on current and expected implementations of this option. This option is therefore assumed not to be applied at all in the CLE case. In the MFR case, it is applied to all of the arable area cultivated by rice.

Table 4.9: Control option for rice cultivation

Option	Applic. CLE (%)	Applic. MFR (%)	Removal efficiency (%)	Investm. cost €/t CH_4	O&M costs €/t CH_4	Cost-savings €/t CH_4	Total cost €/t CH_4
Alternative rice strains	0	100	25	0	47	0	47

Source: IEA (1998)

4.4 Disposal of biodegradable solid waste

Methane emissions are generated when biodegradable waste is digested anaerobically in landfills. The biodegradable waste has here been divided into paper and organic waste. Emissions may be reduced either by diverting paper and organic waste away from landfills through paper recycling, composting, incineration, or biogasification, or by reducing emissions from landfills by applying various landfill control options. The options have been applied in two stages. First, waste diversion options are applied and in a second stage the landfill control options are applied on the residual biodegradable waste that is landfilled.

The EU-wide Landfill Directive (European Council Directive 99/31/EC of 26 April 1999) is considered in the current legislation case (CLE). This directive requires a reduction of biodegradable landfilled waste and control of landfill gas. The following amounts of biodegradable waste (expressed as percentage of 1995 volumes) are required to be diverted from landfills (Hogg *et al.,* 2002, p.35):

- 2006: -25 percent
- 2009: -50 percent
- 2016: -65 percent.

These targets also apply to New Member countries. For countries with a heavy reliance on landfill (Greece, Ireland, Italy, Portugal, Spain, UK, Cyprus, Estonia, Hungary, Poland and Slovenia), an additional compliance period of four years is foreseen (Hogg *et al.,* 2002; p. 9). In this report, it is assumed that the targets set in the directive will be achieved. In GAINS, the required reductions are assumed to apply to both paper and organic waste. For example, in 2006 a 25 percent reduction of landfilled paper waste is assumed to be attained in addition to a 25 percent reduction of landfilled organic waste.

The 1995 amounts of landfilled paper and organic waste were calculated applying 1995 levels of paper recycling and composting, based on the 1995 levels of paper consumption and generation of organic waste. The residual waste is either landfilled or incinerated in accordance with the current shares of municipal waste going to different waste management treatments in the EU-15, Norway and Switzerland (AEAT 2001b, p.1; Umwelt Schweiz, 2002; Statistics Norway, 2003). For all other countries a zero incineration and composting rate has been assumed for 1995. The Landfill Directive also requires that all new landfill sites must have gas recovery facilities. All existing sites must have installed these facilities by 2009.

4.4.1 Paper waste

Of all paper consumed in a country, 95 percent is assumed to end up in the municipal waste flow. The residual five percent is assumed to be scattered or burned without generating methane. The waste management options available to treat the paper in the waste flow are recycling, incineration, or landfilling. Landfills can be capped and the residual landfill emissions of methane can be recovered and either flared or utilized as energy. Figure 4.1 shows a flow-chart for paper waste treatment.

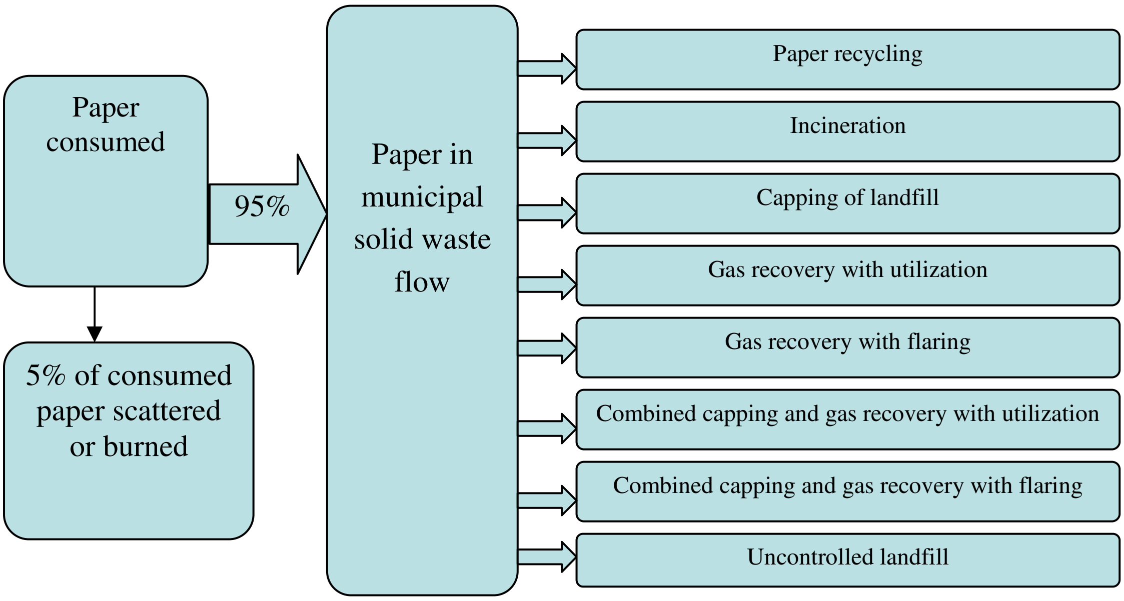

Figure 4.1: Paper waste flow with waste management options used in GAINS.

Removal efficiencies and application rates for control options to reduce emissions from paper waste are presented in Table 4.10. Diverting paper waste from landfills through collection and recycling of paper is assumed to remove 80 percent of the methane emissions generated by the paper if land filled (AEAT, 1998, p.63). This takes into consideration a 10 percent loss of the used paper during the de-inking process and an organic content of the resulting sludge amounting to at least 50 percent. The sludge is then assumed to be incinerated (Bresky, 2004), thereby removing 80 percent of the methane contained in the sludge. In addition, fugitive emissions during collection, transportation and storage are assumed to amount to 16 percent of methane generated. Fugitive emissions are also assumed to arise when paper is incinerated and the assumed removal efficiency is 80 percent of the methane emissions generated if the paper had been land filled. Paper waste that is not diverted away from the waste stream is assumed to be land filled. Methane emissions from landfills can be controlled by capping the landfill, recovering the gas, and flaring or utilizing it as energy. Capping of landfill is assumed to be a prerequisite for landfill gas recovery. Removal efficiencies for landfill capping and gas recovery were provided by AEAT (2001b) (1998, pp.85-86). Oxidation of methane from capping of the landfill varies with the type of capping between 10 to 50 percent (AEAT, 2001b, p.50). A mean oxidation rate of 30 percent is assumed. The maximum recovery rate of methane from landfills is 70 percent (AEAT, 2001b, p.19). The maximum removal efficiency from a capped landfill with gas recovery is accordingly 79 percent (i.e., 0.3+0.7*0.7).

In the CLE case, the current recycling and incineration levels, enforced by the legislation adopted by the EU countries in the Landfill Directive, are used. The paper waste that is not recycled is assumed to be either incinerated or land filled. Starting from the current shares of municipal waste going to different waste management treatments in EU-15, Norway and Switzerland (AEAT 2001b, p.1; Umwelt Schweiz, 2002; Statistics Norway, 2003), the shares will change as more paper is diverted away from landfills through increased recycling. All EU-15 countries, Norway and Switzerland are assumed to have capped landfills already in 1990. The requirements to equip all sites with gas recovery facilities set out in the Landfill Directive are assumed to be met in all EU-25 countries from 2009 and onwards. Country-specific shares of methane recovered from landfills in 1990 for the EU-15 (AEAT 1998, p.82) have been considered as well as a few national requirements on landfill gas recovery specified in AEAT (2001b, p.43). EU New Member countries have zero gas recovery in 1990-2005, but do fulfil the requirements set out in the Landfill Directive from 2009 onwards. For all other countries zero landfill capping and gas recovery is considered for the CLE case. The shares of recovered gas that is utilized or flared were calculated using information in AEAT (2001b, p.46) on the current and future capacity to utilize recovered landfill gas in EU-15, see Table 4.11. The amount of recovered and utilized methane was calculated assuming a 100 percent utilisation of the capacity and the energy content of methane to be 50 GJ/tonne. The resulting amount of utilized methane was divided by the estimated total amount of recovered gas in order to obtain the shares of utilized gas presented in Table 4.11 for EU-15. All countries outside EU-15 are assumed to have a zero utilization of energy from recovered landfill gas. Recovered gas that is not utilized as energy is assumed to be flared.

When applied separately, the MFR application rates are 100 percent for all options controlling methane emissions from paper waste, except for paper recycling. However, since the options are mutually exclusive and not possible to apply simultaneously to the same waste, it is necessary to make assumptions about the shares of the individual options in the MFR case. Recycling is in the MFR case applied to as much paper waste as possible because it is by far the cheapest option and also consistent with the EU waste hierarchy (see, e.g., European Communities, 2001, p.3), where recycling is preferred to incineration or landfill. All of the residual waste is incinerated, because incineration is a cheaper option with a higher removal efficiency than disposal on a landfill with gas recovery (which is required in the Landfill Directive from 2009). Thus, for the MFR case, a maximum collection rate of 75 percent of paper consumed (or 79 percent of paper waste) is assumed to be attainable in all countries. According to CEPI (2003), 19 percent of paper consumed is non-collectable and/or non-recyclable paper. In addition, some paper finds secondary uses or is simply not economically viable to collect. A maximum collection rate of 75 percent appears therefore feasible. Current collection rates exceed or are close to 70 percent in Finland, Germany, Netherlands, Sweden, Latvia, Norway and Switzerland. Less than 40 percent is collected in Cyprus, Greece, Ireland, Estonia, Lithuania, Poland, Bulgaria, and Romania (CEPI, 2003). Thus, there may be scope for increasing the collection rates further in many of the European countries. Paper that is not recycled (i.e., currently 21 percent of paper waste) is incinerated. No paper waste is assumed to be landfilled.

The cost of diverting paper waste away from landfills by increasing the collection and recycling of paper waste is assumed to be the sum of increased costs for collection including the time spent by individuals separating paper waste from other waste and increased transportation costs. Cost-savings arise from the revenues of using recovered pulp instead of virgin pulp in paper production and from the foregone cost of landfilling when less paper waste is land filled. AEAT (1998, p.75) presents costs for a UK de-inking plant producing 200 t/day of recovered pulp of a quality equal to virgin pulp. The investment cost is estimated at 35 €/t pulp produced or 171 €/t avoided CH_4 assuming paper would have generated 0.205 t CH_4/t paper if land filled. The O&M cost is estimated at 97 €/t pulp or 473 €/t CH_4 reduced.

The collection cost of recovered paper is estimated at 58 €/t assuming a 10 percent yield loss and the UK collection rate of 40 percent (AEAT, 1998, p.75). For EU-25 the marginal collection cost is assumed to increase according to the following equation: $MC=11.7e^{4s}$, where s is the collection rate. This implies that a 40 percent collection rate is reached at a marginal collection cost of 58 €/t paper collected (i.e., the UK collection cost). The marginal cost is then assumed to increase exponentially reaching 235 €/t paper collected at the maximum collection rate of 75 percent. With this collection cost relationship, the total cost of recycling paper turns positive at the maximum collection rate of 75 percent. Above this collection rate, the paper industry does not consider it economically viable to collect and recycle paper for use in paper production (CEPI, 2002). For countries outside the EU-25, collection costs are assumed to increase at a much faster rate. The marginal cost relationship is set to $MC=57.6e^{5s}$, which implies that a positive total cost of recycling is rendered for expected CLE collection rates of about 30 percent in 2020. Thus, at a collection rate of 40 percent, the marginal collection cost will be 426 €/t paper and at a 75 percent collection rate, the collection cost will be 2,449 €/t paper. There are two reasons for assuming a considerably higher collection cost in these countries. First, the current waste collection infrastructure is poorer and development is usually costly. Second, the collection cost in Western Europe is estimated assuming a zero cost to households for separating paper waste from other waste before disposal. The opportunity cost for the extra time households spend on paper waste separation is to spend the time on something else, e.g., work or leisure. Still, most households in Western Europe do this separation for free, which implies that they must receive some kind of benefit from it. The benefits are likely to be linked to environmental awareness, social acceptance, and to the benefit of contributing to environmental improvement relative spending the time on other issues of concern to the households. These benefits are likely to be lower in transitional and developing countries, where environmental education and awareness is lower, GDP/capita is lower and households need to spend their time on more immediate concerns. Paper waste may also be valuable to the households for secondary uses, e.g., as burning material. To attain paper collection rates in these countries that are comparable to the collection rates attainable in Western Europe, paper collectors may need to compensate the households for paper separation work. Such compensation is hardly economically viable when carried out on a larger scale.

The cost-saving of using recovered instead of virgin pulp in paper production is derived from the price of virgin pulp. Mean prices for virgin pulp for the UNECE area were calculated for the years 1990, 1995, and 1998-2002 using import and export quantities and values for virgin pulp from FAO (2004). Over these years the mean price for virgin pulp for the UNECE area was relatively stable, fluctuating between 433 and 645 €/t. Assuming the lower value of 433 €/t and a methane generation rate of landfilled paper of 0.205 t CH_4/t paper, the virgin pulp price corresponds to a cost-saving of 2,112 €/t CH_4 when recycled paper is used in paper production instead of virgin pulp. The cost-saving of avoided landfilling of paper is estimated at 98 €/t CH_4. The methane emission factor of paper is 0.205 t CH_4/t paper and the cost of landfilling is assumed to be 20 €/t waste (AEAT, 1998, p.76).

The cost of incinerating paper was calculated based on costs for a UK waste incineration plant reported by Patel and Higham (1996) and referred to by AEAT (1998, p.77). The plant is assumed to have a capacity to burn 200,000 t waste/year and to produce and sell 324 TJ electricity and 324 TJ heat per year. Investment costs are estimated at 51 M€ or 3.7 M€/year when annualized over an equipment lifetime of 20 years. Operating and maintenance costs are estimated at 3.8 M€/year. Cost-savings from electricity and heat generation were calculated assuming the same heat value of paper waste as of municipal solid waste. The electricity generated is valued using the power plant price of gas (see Section 2.4.2.3) for a corresponding amount of energy (assuming gas contains 50 GJ/t CH_4). The price of heat is assumed to be 25 percent of the price of electricity. The avoided cost of landfilling paper is also counted as a cost-saving and assumed to be 20 €/t paper.

The cost of landfill capping is based on data collected by AEAT (2001b, p.51) for a typical UK landfill of 62,500 m^2 (250x250m) with a capacity to landfill one million tonnes waste over a lifetime of 50 years. Over its entire lifetime, the landfill is assumed to generate 72,000 tonnes CH_4 or 1,440 t CH_4/year. The investment cost is estimated at 29 €/m^2 and the O&M cost to 2,433 €/year. Capping reduces fugitive emissions from the landfill by 30 percent. This corresponds to an annualized investment cost of 195 €/t CH_4 and an O&M cost of 5.63 €/t CH_4.

When the landfill is capped, the gas can be recovered to be flared or utilized as energy. The costs of installing a flaring facility or a boiler have been reported by AEAT (1998, p.78) based on UK data. The flaring facility is assumed to have a lifetime of 10 years and the capacity to burn 500 m^3 landfill gas/hour. With a 98 percent availability and for 0.727 kg CH_4/m^3 landfill gas, the facility will burn 1,073 t CH_4/year. Assuming a removal efficiency of 80 percent, the annualized investment cost amounts to 17 €/t CH_4 and the O&M cost to 8 €/t CH_4.

Instead of flaring, the recovered gas can be utilized as energy. The cost of installing a typical boiler for gas utilization in the UK was reported by AEAT (1998, p.78). The boiler has a capacity to burn 3.01 million m^3 CH_4/year or 2,139 t CH_4/year. This implies that one boiler would be enough for the typical landfill generating 1,440 t CH_4/year. The lifetime of the equipment is assumed to be 20 years. The investment cost amounts to 90,800 € or 3 €/t CH_4 when annualized. The O&M cost is estimated at 10,400 €/year or 5 €/t CH_4. 80 percent of the recovered gas can be utilized as energy. A lower and more variable quality of the recovered gas reduces its value in comparison with pure natural gas. The value of recovered methane is therefore assumed to correspond to 50 percent of the natural gas price.

Table 4.10: Waste diversion as control options to reduce methane emissions from paper waste.

Option	RAINS techn. abbrev.	Applic rate CLE[a] (%)	MFR applic. rates, max. (assumed)[d] (%)	Removal effic.(%)	Annual investm. cost €/t CH_4	O&M cost €/t CH_4	Cost-savings €/t CH_4	Total cost €/t CH_4
Paper recycling	PAP_REC	5-79	79 (79)	80	171	394-4318[b]	-2210	-1645 to 2279
Incineration	PAP_INC	0-53	100 (21)	80	91	53-132	-168 to -102	2 to 95
Capping of landfill	PAP_CAP	0-91	100 (0)	30	195	3-8	0	198-203
Gas recovery with utilization[c]	PAP_USE1	0	100 (0)	70	3	3-7	-142 to -10	-133 to -4
Gas recovery with flaring[c]	PAP_FLA1	0	100 (0)	70	17	5-11	0	22-28
Combined capping and gas recovery with utilization	PAP_USE2	0-10	100 (0)	79	198	6-15	-142 to -10	69-194
Combined capping and gas recovery with flaring	PAP_FLA2	0-54	100 (0)	79	212	8-18	0	220-231

[a] Country and year specific. [b] Includes O&M and collection costs. [c] Only applicable to capped landfills. [d] Assumed maximum application rate when options are mutually exclusive. Sources: AEAT (1998, 2001b)

4.4.2 Organic waste

Organic waste considered in GAINS is the organic matter from food and garden waste that ends up in the municipal solid waste flow. Some organic waste never reaches the municipal waste flow because it is treated in domestic composts. Home composts are assumed to be too small to generate any methane emissions. The options available for controlling methane, which is generated when organic waste is disposed of to an uncontrolled landfill, are large-scale composting, incineration, biogasification, capping of landfill, and landfilling with or without utilization of recovered gas. These options are displayed in Figure 4.2.

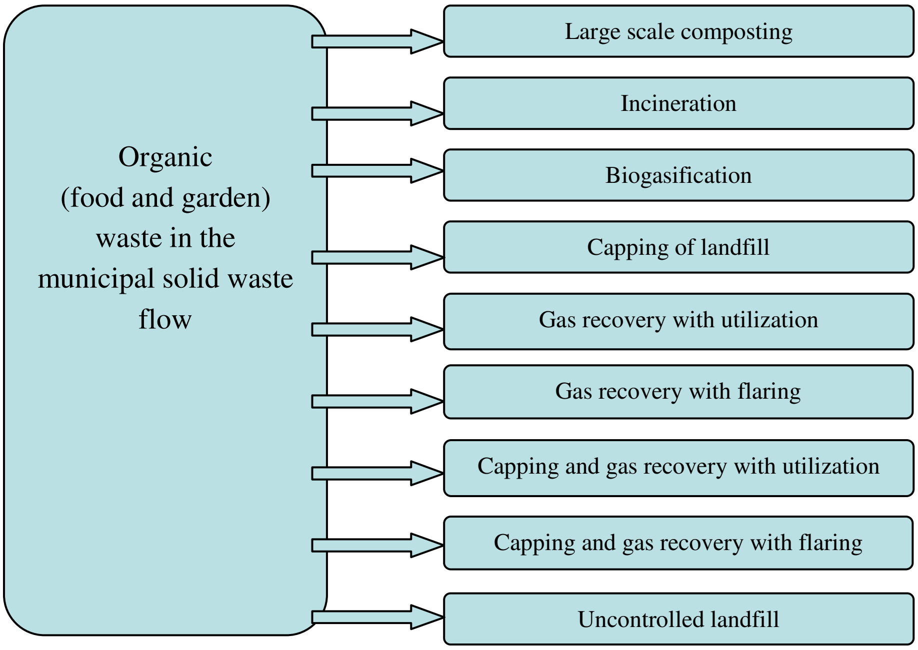

Figure 4.2: Organic waste flow with waste treatment options used in GAINS.

Removal efficiencies and application rates of the options for reducing emissions from organic municipal waste are presented in Table 4.12. Composting considered as a control option refers to large scale composts diverting organic matter that else would end up in the municipal solid waste disposal. These composts are assumed to remove 80 percent of the methane emissions that would have occurred if the same waste had been landfilled. For incineration and biogasification, the assumed removal efficiencies are also 80 percent of methane emissions generated (AEAT, 1998, p.69). Organic waste that is not diverted away from the waste stream is assumed to be landfilled. Methane emissions from landfills can be controlled by capping the landfill, recovering the gas, and flaring or utilizing it as energy. Landfill capping can be a control option of its own, but is also assumed to be a prerequisite for gas recovery. Removal efficiencies for landfill capping and gas recovery were provided by AEAT (1998, pp.85-86).

In the CLE case, current levels of composting and incineration of municipal organic waste have been considered as well as the legislation adopted by the EU countries in the Landfill Directive. Current shares of municipal solid waste composted in the EU-15, Switzerland and Norway (AEAT, 2001b, p.1; Umwelt Schweiz, 2002; Statistics Norway, 2003) were used as estimates of the current levels of composting. Other countries are assumed not to have any current composting of municipal solid waste. The calculated current levels of landfilled organic waste in 1995 have been used as a baseline for the reduction targets set out in the Landfill Directive. Organic waste that is not composted is assumed to be either incinerated or landfilled. The proportions of incinerated to landfilled waste have been calculated using shares of waste treatment routes for municipal solid waste presented in AEAT (2001b, p.1); Umwelt Schweiz (2002); and Statistics Norway (2003). Just like for landfilled paper waste, application rates for landfill control options were adopted assuming that the requirements to equip all landfill sites with gas recovery facilities set out in the Landfill Directive are met. In addition, country-specific shares of methane recovered from landfills in 1990 for the EU-15 (AEAT 1998, p.82) have been considered as well as a few national requirements on landfill gas recovery specified in AEAT (2001b, p.43). The New Member States fo the EU have zero gas recovery in 1990-2005, but need to fulfil the requirements set out in the Landfill Directive in 2009. All other countries have zero gas recovery in the CLE case. The shares of recovered gas that is utilized or flared were calculated using the same assumptions as for paper waste in the previous section.

When applied separately, the MFR application rates are 100 percent for all options controlling methane emissions from organic waste, except for large-scale composting. Because of the mutually exclusiveness of the control options, it is necessary to make assumptions about the application shares for the different control options in the MFR scenario. Composting has the highest removal efficiency and is therefore applied to the maximum extent. According to AEAT (1998, p.9), the potential maximum production of compost from organic waste is estimated for the EU-15 to vary between 49 and 124 kg per person and year, with a mean of 80 kg per person and year. It is therefore assumed that the maximum amount of organic waste that can be composted is 80 kg per person and year in all countries. Organic waste that is not composted is assumed to be treated through biogasification. Biogasification has higher removal efficiency and is cheaper than incineration or landfilling.

Cost data for composting were adopted from AEAT (1998, p.66). Cost estimates are given for a large tunnel composting plant located in the Netherlands and composting 25,000 t/ year. The plant has a capital investment cost of 2.98 M€ and an expected lifetime of the equipment of 15 years. The O&M cost is estimated at 25 €/t waste composted and the cost of source separating the waste is estimated at 8.2 €/t waste. The process is assumed to produce 7,000 t of poor quality material and 10,000 t of compost. 50 percent of the poor quality material will have to be landfilled at an assumed cost of 20 €/t waste (AEAT, 1998, p.76). 50 percent of the compost produced is assumed to be of a quality high enough to be sold at the market at a price of 4 €/t. The residual compost is of a poorer quality, which is given away for free. Cost-savings also arise from avoided costs of landfill disposal calculated to 500,000 €/year. Costs and cost-savings per unit of methane reduced are measured assuming the alternative would be disposal at a no control landfill with a methane generation rate of 0.082 t CH_4/t organic waste.

The cost of incinerating organic waste was calculated based on the same data as used for calculating the cost for incinerating paper. The only difference in the calculation is that organic waste is assumed to generate 0.082 ton CH_4 per ton organic waste when landfilled instead of 0.205 t CH_4 generated per ton paper waste. It should be pointed out that the costs for waste incineration used here are based on data from 1996 and may underestimate the current cost for the EU because of the introduction of stricter environmental regulations for waste incineration in 2000. The New Directive (2000/76/EC) on waste incineration published on 28 December 2000 implies considerably stricter limits on emissions of various pollutants from waste incineration plants in the EU.

The cost of biogasification reported by AEAT (1998, p.77) is based on the costs for a UK plant processing 50,000 t waste/year and producing 8,000 MWh/year of electricity. The investment cost is estimated at 7.1 M€ or 641,000 €/year assuming a 15 years lifetime of the equipment. The O&M cost is estimated at 1.07 M€/year. The cost for source-separated collection is estimated at 8.2 €/ton or 410,000 €/year. The process generates 5,000 t of poor quality material, which is assumed to be landfilled at a cost of 20 €/t waste. It also generates 3,000 t of liquor. It is assumed that it is possible to find a secondary use for 50 percent of the liquor at a zero disposal cost, while the residual 50 percent is disposed of to a landfill. The process is assumed to produce 34,500 t compost/year. 50 percent of the compost is assumed to be of a high quality and sold at a price of 4 €/t. It is assumed to be possible to find secondary use at no cost for the residual 50 percent of low quality compost. The avoided cost of not having to landfill the waste (while it is biogasified instead) is estimated at 20 €/t waste. The power plant price of gas was used as a measure of the cost-savings from selling the electricity generated during the process.

The cost of landfill control options are calculated in the same way for landfilled organic waste as presented for landfilled paper waste in the previous section. In Table 4.12, the total costs are presented for capping and gas recovery options separately as well as for the combined options “capping with gas recovered and utilized” and “capping with gas recovered and flared”.

Table 4.11: Share of recovered methane gas utilized. Assumptions based on capacity rates specified in AEAT (2001b, p.46).

Country	Utilization capacity of recovered gas (MW)		Assumed share of recovered gas utilized (%)	
	1996	2010	1995	2010
Austria	10	2	5.9	2.3
Belgium	2	27	0.5	13.9
Denmark	10	23	0.21	0.94
Finland	0	11	0	4.9
France	20	69	1.7	11.2
Germany	170	286	8.3	27.9
Greece	0	12	0	3.9
Ireland	12	11	7.3	8.5
Italy	10	160	0.4	8.4
Luxembourg	0	1	0	12.4
Netherlands	120	100	48.3	77.2
Portugal	0	2	0	0.8
Spain	5	27	0.3	2.3
Sweden	49	20	26.7	21.6
United Kingdom	145	589	4.8	25.4

Table 4.12: Waste diversion as control options to reduce methane emissions from organic waste.

Option	GAINS technology abbrev.	CLE applic. rate[a] (%)	MFR applic. rate, max (assumed)[b] (%)	Rem. effic. (%)	Ann. inv. cost €/t CH_4	O&M cost €/t CH_4	Cost-savings €/t CH_4	Total cost €/t CH_4
Large scale composting	ORG_COMP	0-81	19-65 (19-65)	80	131	258-520	-254	135-397
Incineration	ORG_INC	0-55	100 (0)	80	228	131-330	-175 to -12	248-481
Biogasification	ORG_BIO	0	100 (35-81)	80	156	236-544	-311 to -264	100-399
Capping of landfill	ORG_CAP	0-91	100 (0)	30	195	3-8	0	198-203
Gas recovery with utilization[c]	ORG_USE1	0	100 (0)	70	3	3-7	-142 to -10	-133 to -4
Gas recovery with flaring[c]	ORG_FLA1	0	100 (0)	70	17	5-11	0	22-28
Combined capping and gas recovery with utilization	ORG_USE2	0-17	100 (0)	79	198	6-15	-142 to -10	69-194
Combined capping and gas recovery with flaring	ORG_FLA2	0-100	100 (0)	79	212	8-19	0	220-231

[a] Country and year specific. [b] Assumed max application rate when options are mutually exclusive. [c] Only applicable to capped landfills. Sources: AEAT (1998, 2001b)

4.5 Wastewater treatment

Wastewater treatment has primarily been introduced for public health concerns and for reducing emissions causing eutrophication to water. Treatment implies that large amounts of sewage is collected and treated. If the treatment takes place under anaerobic conditions, methane is generated. In developed countries treatment is usually undertaken in open lagoons under aerobic conditions and methane generation is minimal. An end-product of the treatment process is sludge, which will have to be disposed of either through composting, aerobic or anaerobic digestion, incineration or landfilling. Depending on the method chosen for the disposal of the sludge, methane emissions might be generated. In economies in transition and developing countries, the types of integrated systems used in developed countries are uncommon and urban areas often rely on cess pits and septic tanks, which are likely to generate methane emissions. These emissions can be recovered and used, e.g., for electricity and heating in households, which would simultaneously reduce methane emissions (IEA-GHG, 1998).

The two control options considered here are to introduce an integrated treatment system in regions where this is not already adopted and to install facilities for methane recovery and utilization wherever the treatment involves anaerobic digestion of sewage. The introduction of integrated systems in Eastern Europe is assumed to reduce methane emissions from wastewater by 85 percent. This removal efficiency corresponds to the difference in IPCC emission factors for wastewater in Western and Eastern Europe (see Section 3.3.4). Installing a gas recovery and utilization facility is assumed to remove 70 percent of the methane emissions (IEA_GHG, 2003, p.B-39).

In the CLE case, EU-15 countries are already assumed to have installed integrated sewage treatment with aerobic treatment. This is reflected in lower IPCC emission factors for Western Europe. For EU New Member and Candidate countries, data provided by Eurostat (2003) on the share of the residential population connected to public wastewater treatment system in 2000 were used as a measure of how extensive the current treatment is (see Table 4.13). For Latvia and Lithuania, the same fraction is assumed as for Estonia, i.e., 69 percent. Albania, Belarus, Russia, Romania, the former Yugoslav Republics, Moldavia, and Ukraine were assumed to have the same fraction of the urban population connected to a public wastewater treatment scheme as Bulgaria, i.e., 37 percent.

The existing legislation in the EU was accounted for in the CLE case. Wastewater treatment is regulated within the EU primarily through the adoption of the Council Directive (91/271/EEC) of 21 May 1991 and the amendment by the Commission Directive (98/15/EC) of 27 February 1998. These directives require from 1999 all Member States to have wastewater facilities available for all urban areas with a population over 10,000 people and where the effluents are discharged into sensitive areas. The directives also stipulate that by the end of 2000, wastewater treatment facilities are required for all urban areas with a population over 15,000 people. Finally, the directives state that by the end of 2005, a collection and treatment system must be provided in all urban areas with a population between 2,000 and 15,000 people (European Commission, 2004). The regulation also applies to the New Member states. No further application of integrated wastewater treatment systems is assumed to be applicable in the EU-15. New Member countries are assumed to fulfil the requirements set out in the Wastewater Directives, i.e., application of integrated systems in urban areas will increase to 100 percent by 2005. In the CLE case, no further application of integrated systems is assumed to be applied outside the EU-25, and no application of gas recovery and utilization from wastewater handling is assumed.

In the MFR case, gas recovery and utilization facilities can be applied to all remaining emissions from the treatment of residential wastewater. In the EU-25, the remaining emissions are mainly emissions from anaerobic handling of the sludge. For the non-EU-25 countries, it is assumed that integrated systems can be applied to 100 percent of wastewater in residential areas. The methane generated from cess pits, septic tanks and other anaerobic collection and storage of wastewater, is assumed to be recovered. 50 percent of the recovered gas is assumed to be utilized as energy and the rest is flared.

Because of the high cost for integrated wastewater treatment systems, it is hardly a feasible option when the objective is exclusively to reduce methane emissions. For example, Renzetti and Kushner (2004) estimate for Canada the annual operating expenditure for sewage treatment (including costs for labour, material, energy, debt charges and capital reserve funds) to 100

\$/person/year (i.e., 72 €/person/year). With an emission factor for Eastern Europe of 0.0056 kt CH_4/million people and a removal efficiency of 85 percent, the corresponding cost would be about 15 million €/t CH_4 reduced. Still, if the costs are balanced with the benefits of improved public health and reduced eutrophication, the option is most likely welfare enhancing. We therefore conclude that as an option to reduce methane emissions, the control cost is extremely high. When the option is undertaken for other reasons, the methane emission reductions attained should be treated as an external benefit, which then comes at no additional cost.

Costs for installing gas recovery and utilization facilities in the wastewater sector were provided by IEA-GHG (2003, p.B-39) for North American conditions. These costs have been used here with adjustments for differences in labour costs and gas prices. The lifetime of the equipment is assumed to be 30 years.

Table 4.13: Share of the residential population connected to a public wastewater treatment system in 2000 in EU Candidate countries.

Country	Percent of residential population connected to public wastewater treatment in 2000
Bulgaria	37
Cyprus	35
Czech Rep.	64
Estonia	69
Hungary	32
Latvia	n.a. (69)
Lithuania	n.a. (69)
Malta	13
Poland	53
Romania	n.a.
Slovak Rep.	49 (1998)
Slovenia	30 (1999)
Turkey	17 (1998)

Source: Eurostat (2003, p.199)

Table 4.14: Control options for wastewater handling

Option	GAINS technology abbrev.	Rem. effic. (%)	Appl. rate CLE (%)	Applic. MFR (%)	Annual. investm. cost €/t CH_4	O&M cost €/t CH_4	Cost-savings €/t CH_4	Total cost €/t CH_4
Integrated sewage system	INT_SYS	85	0-87	0-87	n.a.	n.a.	n.a.	>1 M
Gas recovery and utilization	GAS_USE	70	0	100 (13-100)[a]	284	4-13	-155 to -11	140-277

Sources: IEA-GHG (1998, 2003), Eurostat (2003), European Commission (2004c)

[a] Application due to mutually exclusive control options.

4.6 Coal mining

Methane emissions from coal mines can be reduced by upgrading the gas recovery of existing mines or by installing more efficient methane recovery in new mines. The recovered gas can then be utilized for energy purposes. Current recovery and utilization rates for methane emissions from coal mines are presented in Table 4.15 for the Former Soviet Union, Germany, Poland and the UK (AEAT, 2001c, p.38). Based on this information, recovery and utilization rates for other EU and non-EU countries were assumed. For EU countries, the gas recovery rate is assumed to be 50 percent of total emissions, whereof 25 percent is utilized as energy. For non-EU countries, the gas recovery and utilization rates of the former Soviet Union are assumed, i.e., 28 percent recovered, whereof 14 percent is utilized. The control option considered in GAINS is an upgrade of the current capture and utilization rates. It is assumed that it is technically possible to extend the recovery and utilization rate to on average 70 percent of total emissions from coal mines (AEAT, 2001c, p.44). The removal efficiency of the recovered gas is assumed to be 90 percent taking into account that some fugitive emissions will take place during the utilization of the recovered gas.

In the CLE case, current capture and utilization rates are assumed and no further upgrade is applied.

In the MFR case, an upgrade of the gas recovery and utilization rates from the current levels to 70 percent of total emissions is assumed for all countries.

The cost of increased gas recovery and utilization from 30 percent to 70 percent of total emissions is estimated assuming a typical mine producing 1.7 Mt coal/year and emitting 20 kt CH_4/year, i.e., emitting 0.012 t CH_4/t coal (AEAT, 1998, p.101). The recovery upgrade implies that emission recovery is increased from 6 to 10 kt CH_4/year reducing emissions by 4 kt CH_4/year. Costs are based on the installation of a reciprocal engine, which according to AEAT (1998, p.101) is the most cost-effective measure. The lifetime of the equipment installed is 10 years. The additional investment cost of upgrading the gas recovery from 30 to 70 percent is assumed to be 3.8 M€ or 0.28 M€/year when annualized (AEAT, 1998 p.102). With an additional emission reduction of 4 kt CH_4/year, the investment cost amounts to 70 €/t CH_4 reduced. The additional O&M cost are 0.222 M€/year or 43 €/t CH_4 reduced, assuming UK labour costs. When gas utilization increases from 30 to 70 percent, the cost-saving per unit of CH_4 reduced is set at 80 percent of the gas price, assuming that 80 percent of the gas made available for utilization can be used in the vicinity of the coal mine.

Table 4.15: Methane captured and proportion utilized of mine gas.

Country-region	Methane captured (% of total emitted)	Proportion utilized (% of total captured)	Source:
Former USSR	28	14	AEAT (2001c, p.38)
Germany	63	40	AEAT (2001c, p.38)
Poland	49	29	AEAT (2001c, p.38)
UK	18	20	AEAT (2001c, p.38)
Other EU	50	25	Assumed here
Other Non-EU	28	14	Assumed here

Source: AEAT (2001c, p.38)

Table 4.16: Control option for coal mining

Option	GAINS techn. abbrev.	Appl. CLE (%)	Appl. MFR (%)	Rem. effic. (%)	Annual. inv. cost €/t CH_4	O&M costs €/t CH_4	Cost-saving €/t CH_4	Total cost €/t CH_4
Upgraded recovery and utilization of gas from current level to 70%	CH4_REC	18-63	70	100	118	13 to 72	-284 to 20	- -107 to 112

Source: AEAT (1998, 2001c)

4.7 Gas and oil production and processes

Emissions of methane occur during oil and gas production and during the associated refining of oil. These emissions can be controlled either by flaring (instead of venting) or by recovering the gas in order to use it for heat or electricity. Apart from limited on-site use, it may be difficult to find use for the recovered energy in the vicinity of the gas or oil field. Oil refineries are usually located in the outskirts of urban areas and may also have problems finding use for the recovered gas in the close vicinity. Utilization of recovered gas from these activities is therefore not considered to be a feasible option. Flaring is the only option considered here for reducing emissions from oil and gas production and processes. Flaring is also a more emission effective measure than gas recovery and utilization. According to AEAT (1998, p.121), the removal efficiency of a flaring facility is 97 percent compared with 80 percent for a gas recovery and utilization installation. AEAT (1998, p.30) assumes that under a business-as-usual scenario, flaring is undertaken on a voluntary basis and will be fully implemented by 2010 in the EU-15. This assumption is based on information about the situation in the two major oil and gas producing countries in the EU-15, the Netherlands and the UK. In these countries, oil and gas producing companies have undertaken various measures to recover and utilize methane emissions. In the Netherlands, such measures are estimated to reduce methane emissions from on- and off-shore oil and gas production by 30 percent in the year 2000 compared with the 1990 level.

In the CLE case, no control measures are assumed to be applied in the gas and oil production sectors for non-EU-15 countries. For EU-15, a 30 percent reduction from the 1990 level is assumed to take place between 1990 and 2000 and to continue to 100 percent in 2010 without any introduction of legal requirements. These reductions are assumed to be inherent in the lower emission factor used to estimate emissions for Western Europe (see Section 3.3.6). No further implementation is assumed to take place in response to legislation, since no current or future legislation is known.

In the MFR case, flaring is assumed to be applied to 100 percent of the production and processing of oil and gas.

AEAT (1998, p.124) provides cost data for flaring based on Dutch off-shore installations. Woodhill (1994) estimates the capital costs of an on-shore installation at 40 percent of the capital cost of an off-shore installation. GAINS applies the Dutch cost data for installations made in oil and gas production in the Netherlands, the UK, Norway and Denmark and assumes that all other countries need mainly on-shore installations. The cost of on-shore installations is assumed to be 40 percent of the Dutch cost estimates. Installations in oil refineries are always assumed to be on-shore. Gas prices are country-specific.

Table 4.17: Control options for oil and gas production and processes. Source: AEAT (1998)

Option	GAINS techn. abbrev.		Appl. CLE (%)	Potential application MFR (%)	Rem. effic. (%)	Annual. invest. cost €/t CH_4	O&M costs €/t CH_4	Cost-saving €/t CH_4	Total cost €/t CH_4
Flaring instead of venting of gas - oil/gas production	FLA_PROD	Off-shore	0	100	97	162	58-79	0	220-241
		On-shore	0	100	97	65	8-38	0	73-103
Flaring instead of venting of gas - oil/gas refinery	FLA_REF	On-shore	0	100	97	65	8-38	0	73-103

4.8 Gas transmission and distribution

Emissions from gas leakages during pipeline transmission and consumer distribution networks are extensive, especially in Eastern Europe.

For Western Europe, emission estimates are based on the amount of gas consumed. They primarily arise from leakages in the distribution to the consumers. Following Houghton et al. (1997, p.1.30), no emissions from leakages in the industrial, power plants and residential sectors are assumed. Fugitive emissions from old consumer distribution networks make up the majority (79 percent) of emissions from gas distribution in Western Europe (AEAT, 1998, p.123). Emissions from this source can be reduced by replacing grey cast iron networks (built when town gas was used instead of methane) by polyethylene (PE) or polyvinylchloride (PVC) networks. This control option is expected to remove 97 percent of this type of fugitive emissions (AEAT, 1998, p.132). Investments have a lifetime of 20 years.

An alternative option is to increase the frequency of inspections and maintenance to improve leakage detection and repair. A doubling of the control frequency (from every fourth year to every second year) of gas networks in the Netherlands reduced emissions by 50 percent (AEAT, 1998, p.123). Cost estimates for a doubling of the leak control frequency of the distribution network for the Netherlands were given by AEAT (1998, p.125). These estimates were adopted for Western Europe adjusting for differences in labour costs. The annualized investment cost is estimated at 2036 €/t CH_4 abated. Cost-savings from reduced gas losses correspond to the gas price.

In the CLE case, no options are assumed to have been implemented in 1990. For subsequent years, AEAT (1998, p.131) reports that measures are being undertaken to reduce emissions from distribution networks in Austria, France, Germany, Ireland, Italy, Netherlands, and the UK. Assuming a replacement rate of the old networks of three percent per year (the current replacement rate in Ireland) in these countries and starting from 1995, emissions from this source are assumed to be successively reduced until the network is fully replaced by 2030. For 50 percent of non-replaced networks, the control frequency is assumed to be doubled in these countries.

In the MFR case, all grey cast iron pipe networks can be replaced, thereby removing 76 percent of emissions from gas distribution in Western Europe. Residual emissions are reduced by 50 percent through increased control frequency of all distribution networks. The resulting application rates, removal efficiencies and costs for the control options applied for Western Europe are presented in Table 4.18.

For Eastern Europe, IPCC emission factors and emission estimates are based on the amount of gas *produced.* Emissions arise from leakages of gas transmission pipelines and distribution networks. In Russia, emissions during gas transmission are the most important source of methane emissions and emissions from gas compression and control systems are the major contributors to emissions during transmission (IEA Greenhouse Gas R&D Programme, June 1998). Methane emissions arise for several reasons, e.g., compressor seals are not gas-tight, valves are poorly controlled and maintained, and due to flushing with natural gas during start-ups.

Hendriks *et al*. (1998, pp.19-20) calculates for EU-15 the costs for a set of measures reducing up to 90 percent of emissions at compressors. The measures include no flushing at start-up, electrical start-up, and inspection and maintenance programs. The removal efficiency is 80 percent. The cost estimates for Western Europe have been applied to Eastern Europe with adjustments for different labour costs and gas prices. Cost-savings from this set of measures arise due to reduced gas losses and to an efficiency increase of the equipment of 10 percent (Hendriks *et al*., 1998, p.20). For all countries except Russia, the cost of gas losses are measured as the export price of gas from Russia to the European market. Export prices for gas in 2002 from Gazprom (2002) were used as starting values. These were 60 €/t gas for the CIS member states Ukraine, Belarus, Moldavia and the Baltic states. For all other countries, the price was 116 €/t gas. The price is assumed to increase linearly by 1.8 €/year until 2020 following Kononov (2003) and assuming 0.9 t CH_4 per thousand m^3 CH_4. After 2020, the producer price is assumed constant. Thus, the price in 2000 is assumed to be 56.4 €/t rising to 92.4 €/t gas in 2020 in CIS member countries. For all other countries the price is assumed to increase from 112 to 148 €/t gas in 2000 to 2020. For Russia, the producer price of gas is used as a measure of the benefit of reduced gas losses during transmission. Producer prices for gas in Russia were assumed to be 36 €/t CH_4 in 2000 rising to 45 €/t CH_4 in 2020 (Makarov and Likhachev, 2002). For a valuation of the reduced gas losses in Russia, 75 percent of gas is assumed to be sold in the internal market and 25 percent to be exported to Europe (Gazprom Annual Report 2002). All other costs (investment and material costs) are assumed to be the same in Eastern Europe as in Western Europe.

In the CLE case, pipelines in the Former Soviet Union are assumed to be refurbished at a rate of one percent per year starting from year 2000. This corresponds to the share of pipeline length refurbished in Russia in the year 2002 (Gazprom Annual Report, 2002). No control of leakages of emissions from residential and industrial consumer networks is assumed in the CLE case.

In the MFR case, all compressor stations can be subject to the control option package described above. Emissions from residential and industrial sources in Eastern Europe are controlled through replacement of grey cast iron networks and increased leak control frequency.

Table 4.18: Control options to reduce emissions from gas distribution in Western Europe.

Option	GAINS techn. abbrev.	Applic. CLE (%)	Applic. MFR (%)	Rem. effic. (%)	Annual. inv. cost €/t CH_4	O&M cost €/t CH_4	Cost-savings €/t CH_4	Total cost €/t CH_4
Replacement of grey cast iron networks	REPL_NET	0-71	79	97	2,036	0	-280 to -66	1,756 to 1,970
Doubling of leak control frequency of network	CONT_NET	0-25	21 (residual emissions)	50	0	538-1,630	-355 to -84	338 to 1,394

Source: AEAT (1998, p.126), Hendriks *et al*. (1998, p.20-21)

Table 4.19: Control options to reduce emissions from gas transmission and distribution in Eastern Europe.

Option	GAINS techn. Abbrev.	Appl. CLE (%)	Applic. MFR	Rem. effic. (%)	Annual invest. cost €/t CH_4	O&M cost €/t CH_4	Cost-savings €/t CH_4	Total cost €/t CH_4
Reduction at compressor stations	COMPRESS	0	100% of transmission pipelines in FSU	80	75	5-16	-83 to -32	0-48
Replacement of grey cast iron networks	REPL_NET	0	79% of leakage in domestic and industrial sectors	97	2,036	0	-245 to -20	1,791 to 2,016
Doubling of leak control frequency of network	CONT_NET	0	21% of residual emissions from leakage in domestic and industrial sectors	50	0	349-1,310	-248 to -20	169-1,078

Source: Hendriks *et al*. (1998, p.19-20), AEAT (1998, p.122)

4.9 Agricultural waste burning

A control option for agricultural waste burning already considered in the RAINS VOC module (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/) is the ban on open burning of agricultural waste (Klimont *et al.,* 2000). A ban on burning of agricultural waste has already been implemented in national legislation in several countries. For the CLE case, we use information on the implementation of a ban collected through national communications for the VOC module in the RAINS database. A ban is assumed to be present from 1990 or 1995 in the Czech Republic, Denmark, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, Spain, Sweden and the UK. The cost for a ban was calculated in the VOC module to 60 €/t VOC. With emission factors of 8-10 t VOC/Mt waste and 1.2 t CH_4/Mt waste, the corresponding cost for using this option to reduce methane emissions is about 500 €/t CH_4. In the CLE case, a ban on agricultural waste burning is not applied in any further country. In the MFR case, it is applied in all countries.

Table 4.20: Control options for agricultural waste burning

Option	GAINS techn. abbrev.	Applic. CLE (%)	Applic. MFR (%)	Rem. effic. (%)	Annual. inv. cost €/t CH_4	Annual O&M costs €/t CH_4	Cost-saving €/t CH_4	Total cost €/t CH_4
Ban on agricultural waste burning	BAN	0-100	0-100	100	n.a.	n.a.	n.a.	500

Source: Klimont *et al.* (2000)

4.10 Summary

In Table 4.21, the control options have been ordered by the average cost for emission reduction.

Five control measures are estimated to involve negative costs for emission reduction. These are the increased feed intake or a replacement of roughage for concentrates for dairy cows in Eastern Europe, paper recycling, upgrade of the recovery and utilization of gas from coal mines, and recovery and utilization of gas from landfills that are already capped. All other options come at a positive cost.

All cost estimates involve uncertainties. Most often, the estimates are based on a single or a couple of estimates of the costs for an actual implementation of the option in a European country. To consider differences in, e.g., prices and wages between countries, the actual implementation costs have been adjusted accordingly. Still, large uncertainties remain, e.g., due to the small number of case studies upon which the estimates are based and due to other country-specific factors that have not been controlled for in the estimations. For some options, no case study exists and estimates are instead based on references from the literature. These options have no cost range specified in Table 4.21 and are subject to high uncertainty.

Table 4.21: Marginal costs for implementing control options (mean of all countries and years 1990-2030).

Control option	GAINS technology abbrev.	Cost €/t CH_4 Mean	Range
Ent. ferm: Repl. roughage for concentrates –dairy cows E.Europe	CONCENTR	-6,194	-13,061 to -1,856
Ent. ferm: Increased feed intake –dairy cows E.Europe	INCRFEED	-4,615	-11,754 to -104
Waste: Paper recycling	PAP_REC	-445	-1,645 to 2,280
Waste: utilization of gas from paper waste deposited on capped landfill	PAP_USE1	-70	-133 to -4
Waste: utilization of gas from organic waste deposited on capped landfill	ORG_USE1	-70	-133 to -4
Coal mining: Upgraded gas recovery and utilization	CH4_REC	-5	-115 to 111
Ent. ferm: Autonomous efficiency increase in milk and meat prod.	AUTONOM	0	no range
Manure management: Farm-scale AD –pigs/temperate	FARM_AD	17	8 to 30
Waste: flaring of gas from paper waste deposited on capped landfill	PAP_FLA1	23	22 to 28
Waste: flaring of gas from organic waste deposited on capped landfill	ORG_FLA1	23	22 to 28
Gas transmission –Reduction at compressor stations in FSU	COMPRESS	27	-3 to 48
Waste: Paper incineration	PAP_INC	31	-11 to 95
Manure management: Farm-scale AD –dairy cows/temperate	FARM_AD	33	16 to 58
Manure management: Farm-scale AD –beef cattle/temperate	FARM_AD	43	21 to 76
Rice cultivation: Alternative rice strains	ALT_RICE	47	No range
Manure management: Farm-scale AD –pigs/cool	FARM_AD	81	33 to 129
Oil and gas: Flaring instead of venting –onshore refinery	FLA_REF	81	73 to 100
Oil and gas: Flaring instead of venting –onshore production	FLA_PROD	81	73 to 100
Waste: capping of landfill *and* utilization of gas from paper waste	PAP_USE2	130	68 to 194
Waste: capping of landfill *and* utilization of gas from organic waste	ORG_USE2	130	68 to 194
Manure management: Farm-scale AD –dairy cows/cool	FARM_AD	139	57 to 223
Manure management: Farm-scale AD –beef cattle/cool	FARM_AD	184	76 to 294
Waste: biogasification of organic waste	ORG_BIO	193	91 to 395
Waste: landfill capping of paper waste	PAP_CAP	200	198 to 203
Waste: landfill capping of organic waste	ORG_CAP	200	198 to 203
Wastewater: Gas recovery and utilization	GAS_USE	207	139 to 277
Waste: composting of organic waste	ORG_COMP	210	135 to 372
Waste: capping of landfill *and* flaring of gas from paper waste	PAP_FLA2	223	220 to 230
Waste: capping of landfill *and* flaring of gas from organic waste	ORG_FLA2	223	220 to 230
Oil and gas: Flaring instead of venting –offshore production	FLA_PROD	232	220 to 241
Gas distribution: Doubling leak control frequency E. Europe	CONT_NET	258	117 to 679
Waste: Organic waste incineration	ORG_INC	322	216 to 481
Agricultural waste burning: Ban	BAN	500	No range
Enteric fermentation: Propionate precursors –dairy cows	PROPPREC	527	No range
Gas distribution: Doubling leak control frequency W. Europe	CONT_NET	891	248 to 1,394
Enteric fermentation: Propionate precursors –beef cattle	PROPPREC	1,100	No range
Gas distribution: Replacement grey cast iron networks W. Europe	REPL_NET	1,869	1,756 to 1,970
Gas distribution: Replacement grey cast iron networks E. Europe	REPL_NET	1,897	1,791 to 2,016
Enteric ferm.: Change to NSC diet –dairy cows E. and W. Europe	NSCDIET	1,945	1,607 to 2,293
Enteric ferm: Change to NSC diet –beef cattle E. and W. Europe	NSCDIET	3,963	301 to 5,154
Enteric ferm: Repl. roughage for concentr. –beef cattle E. Europe	CONCENTR	4,475	-2,214 to 7,378
Enteric ferm: Increased feed intake –beef cattle E. Europe	INCRFEED	7,698	151 to 10,972
Manure management: Housing adaptation –pigs/liquid manure	HO_ADAP	38,150	9,400 to 66,900
Wastewater: Integrated sewage system	INT_SYS	> 1M	No range

5 Results

5.1 Emissions in the base year

For the 42 Eureopan regions analysed in GAINS, the aggregate methane emissions for 1990 amount to 64,200 kt (see Table 5.1). EU-25 emissions are estimated at 24,900 kt (or 39 percent), for the European part of Russia at 25,200 kt (with 13,100 kt or 20 percent of total European emissions alone form gas transportation.

Figure 5.1 provides a sectoral analysis of the 1990 emissions for the 42 regions, highlighting the gas and agricultural sectors as the main sources of methane emissions. They both emit just over 30 percent each of total emissions, followed by waste and coal mining sectors with 17 and 13 percent, respectively. Other sectors contributeminor shares. A separate sector analysis for EU-25 (Figure 5.2) shows a slightly different picture. Agriculture, waste and coal mining are the dominating contributors and only eight percent of total emissions emerge from the gas sector.

The UNFCCC (2004) and EDGAR (2004) inventories do not cover the full GAINS domain. However, comparisons of the emissions for EU-25 show similar emission levels for most countries (see Table 5.1). For seven countries (Bulgaria, Czech Republic, Estonia, the Netherlands, Portugal, Slovenia, and Ukraine), the GAINS estimates for 1990 deviate by more than 30 percent from the figures reported by countries to UNFCCC (2004). Table 5.2 shows a sectoral comparison of emissions between the GAINS and the UNFCCC estimates. Large discrepancies in emission estimates appear for the waste sector and from coal mining, but not in the agricultural sector. For the Czech Republic, the UNFCCC data seem to report considerably lower emissions from coal mining. For all countries, the UNFCCC emissions for the waste sector are estimated based on the amounts of municipal solid waste. In GAINS, emissions from the waste sector are based on estimations of the amount of consumed paper and generated food and garden waste, which end up in the municipal solid waste. This implies, e.g., that countries with high paper consumption and relatively limited recycling and incineration of paper in 1990 (like Italy and Spain) will have higher emissions from the waste sector in GAINS than in UNFCCC.

Table 5.1: CH_4 baseline emission estimates for 1990 and 2000 (kilotons CH_4)

	1990				2000		
	GAINS	UNFCCC	EDGAR	ECOFYS	GAINS	UNFCCC	ECOFYS
Albania	159	n.a.	105	n.a.	168	n.a.	n.a.
Austria	418	538	391	587	328	448	600
Belarus	937	n.a.	914	n.a.	685	n.a.	n.a.
Belgium	527	550	488	634	470	524	537
Bosnia-H..	159	n.a.	95	n.a.	134	n.a.	n.a.
Bulgaria	471	1,334	457	n.a.	323	n.a.	n.a.
Croatia	190	182	190	n.a.	217	n.a.	n.a.
Cyprus	23	n.a.	n.a.	n.a.	28	n.a.	n.a.
Czech Rep.	1,245	798	1,059	n.a.	1,021	510	n.a.
Denmark	313	278	269	421	334	274	409
Estonia	129	208	124	n.a.	88	118	n.a.
Finland	326	292	353	246	291	187	226
France	2,857	3,169	2,701	3,017	2,578	2,871	2,820
Germany	4,310	5,273	5,232	5,682	3,428	2,885	3,892
Greece	412	416	305	443	454	518	n.a.
Hungary	703	664	677	n.a.	612	553	n.a.
Ireland	636	612	551	811	601	610	837
Italy	2,159	1,876	2,015	2,329	1,617	1,801	2,455
Latvia	197	196	206	n.a.	100	121	n.a.
Lithuania	310	378	369	n.a.	246	n.a.	n.a.
Luxembourg	28	24	12	24	30	23	22
Macedonia	92	n.a.	57	n.a.	89	n.a.	n.a.
Malta	9	n.a.	5	n.a.	10	n.a.	n.a.
Moldavia	228	n.a.	229	n.a.	207	n.a.	n.a.
Netherlands	983	1,292	922	1,290	890	983	971
Norway	259	307	362	n.a.	286	324	n.a.
Poland	2,613	3,141	4,286	n.a.	2,405	2,183	n.a.
Portugal	392	614	355	806	389	625	714
Romania	2,253	2,357	2,014	n.a.	1,563	n.a.	n.a.
Russl. (KALI)	74	n.a.	n.a.	n.a.	57	n.a.	n.a.
Russl.(KOLK)	157	n.a.	n.a.	n.a.	155	n.a.	n.a.
Russl.(REMR)	24,554	n.a.	n.a.	n.a.	21,421	n.a.	n.a.
Russl.(SPET)	398	n.a.	n.a.	n.a.	299	n.a.	n.a.
Serbia-M.	485	n.a.	614	n.a.	459	n.a.	n.a.
Slovakia	313	323	355	n.a.	251	215	n.a.
Slovenia	120	176	83	n.a.	101	n.a.	n.a.
Spain	1,950	1,412	1,508	2,181	2,081	1,827	2,356
Sweden	396	324	365	324	319	280	284
Switzerland	300	242	229	n.a.	297	216	n.a.
Turkey	2,701	n.a.	n.a.	n.a.	2,758	n.a.	n.a.
Ukraine	5,835	9,402	6,971	n.a.	4,861	n.a.	n.a.
UK	3,550	3,645	3,227	4,409	2,803	2,427	3,361
Total (42 reg.)	64,172	n.a.	n.a.	n.a.	55,452	n.a.	n.a.
CO_2-eq, Mton	1,476	n.a.	n.a.	n.a.	1,275	n.a.	n.a.
EU-25	24,919	26,199	n.a.	n.a.	21,473	20,307[a]	n.a.
CO_2-eq, Mton	573	603	n.a.	n.a.	494	467[a]	n.a.

Sources: GAINS, UNFCCC (2004), EDGAR (2004) and Hendriks *et al*. (1998)

[a] EU-25 excluding Cyprus, Lithuania, Malta, and Slovenia.

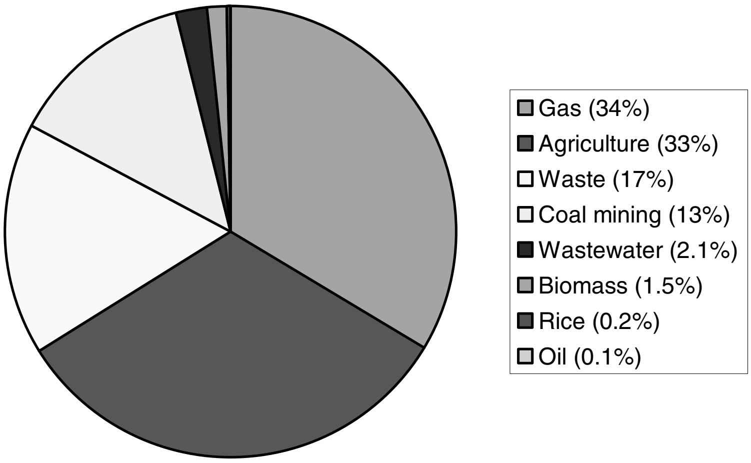

Figure 5.1: Methane emissions by sectir estimated for the year 1990 for the 42 regions analysed in GAINS.

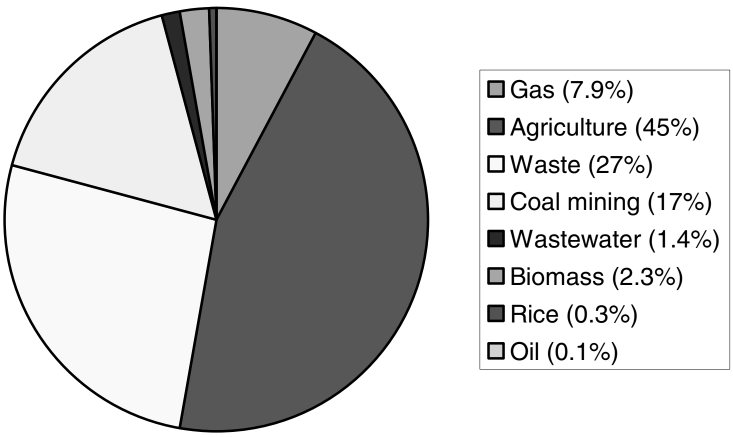

Figure 5.2: Methane emissions by sectir estimated for the year 1990 for the EU-25 as estimated by GAINS

Table 5.2: Sector analysis by country for 1990 in GAINS in comparison with UNFCCC (2004). Values in kt/year.

Country	Data source	CH_4 emissions (kt/year)				
		Fuels and industrial processes[a] (whereof coal mining)	Agri-culture	Waste (whereof wastewater)	Other	Total
Albania	GAINS	14 (0)	95	50 (7)	0	159
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Austria	GAINS	88 (17)	226	104 (6)	0	418
	UNFCCC	*26 (0)*	*218*	*295 (14)*	*0*	*538*
Belarus	GAINS	200 (0)	562	175 (38)	0	937
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Belgium	GAINS	70 (17)	276	181 (8)	0	527
	UNFCCC	*49(1)*	*314*	*155(0)*	*5*	*550*
Bosnia-Herc.	GAINS	11 (3)	90	58 (1)	0	159
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Bulgaria	GAINS	91 (23)	225	155 (32)	0	471
	UNFCCC	*270 (92)*	*273*	*791 (148)*	*0*	*1334*
Croatia	GAINS	34 (1)	84	72 (14)	0	190
	UNFCCC	*69 (2)*	*75*	*38 (n.a.)*	*0*	*182*
Cyprus	GAINS	0 (0)	16	8 (0)	0	23
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Czech Rep.	GAINS	794 (700)	281	170 (6)	0	1245
	UNFCCC	*459 (362)*	*204*	*133 (39)*	*3*	*798*
Denmark	GAINS	25 (0)	227	61 (4)	0	313
	UNFCCC	*23 (3)*	*193*	*62 (n.a.)*	*0*	*278*
Estonia	GAINS	36 (12)	68	25 (1)	0	129
	UNFCCC	*61 (19)*	*70*	*77 (9)*	*0*	*208*
Finland	GAINS	35 (0)	110	181 (4)	0	326
	UNFCCC	*20 (1)*	*96*	*175 (2)*	*1*	*292*
France	GAINS	335 (112)	1,846	656 (48)	0	2857
	UNFCCC	*519 (206)*	*1,667*	*887 (12)*	*97*	*3169*
Germany	GAINS	1304 (953)	1,744	1262 (66)	0	4310
	UNFCCC	*1775 (1227)*	*1,605*	*1894 (52)*	*0*	*5273*
Greece	GAINS	39 (27)	214	159 (8)	0	412
	UNFCCC	*59 (44)*	*173*	*179 (45)*	*6*	*416*
Hungary	GAINS	353 (130)	182	168 (5)	0	703
	UNFCCC	*456 (223)*	*208*	*n.a.*	*0*	*664*
Ireland	GAINS	13 (0)	558	65 (3)	0	636
	UNFCCC	*13 (0)*	*514*	*85 (n.a.)*	*0*	*612*
Italy	GAINS	228 (1)	998	933 (47)	0	2159
	UNFCCC	*403 (6)*	*913*	*559 (98)*	*1*	*1876*
Latvia	GAINS	38 (0)	121	38 (2)	0	197
	UNFCCC	*63 (0)*	*111*	*19 (0)*	*2*	*196*
Lithuania	GAINS	64 (0)	197	49 (2)	0	310
	UNFCCC	*31 (0)*	*181*	*166 (4)*	*0*	*378*
Luxembourg	GAINS	5 (0)	16	7 (0)	0	28
	UNFCCC	*2 (0)*	*18*	*4 (0)*	*0*	*24*
Macedonia	GAINS	14 (5)	47	31 (6)	0	92
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Malta	GAINS	0 (0)	5	4 (0)	0	9
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*

Table 5.2 (continued): Sector analysis by country for 1990 in GAINS in comparison with UNFCCC (2004). Values in kt/year.

Country	Data source	CH_4 emissions (kt/year)				
		Fuels and industrial processes[a] (whereof coal mining)	Agri-culture	Waste (whereof wastewater)	Other	Total
Moldavia	GAINS	49 (0)	109	70 (11)	0	228
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Netherlands	GAINS	213 (0)	531	239 (12)	0	983
	UNFCCC	*216 (0)*	*505*	*569 (7)*	*2*	*1292*
Norway	GAINS	70 (3)	105	84 (4)	0	259
	UNFCCC	*28 (0)*	*98*	*182 (0)*	*0*	*307*
Poland	GAINS	1302 (1049)	813	498 (19)	0	2613
	UNFCCC	*1311 (1043)*	*863*	*966 (131)*	*1*	*3141*
Portugal	GAINS	35 (0)	218	139 (8)	0	392
	UNFCCC	*29 (3)*	*302*	*283 (19)*	*0*	*614*
Romania	GAINS	1204 (46)	682	367 (70)	0	2253
	UNFCCC	*1482 (367)*	*635*	*241 (18)*	*0*	*2357*
Russl. (KALI)	GAINS	20 (0)	37	17 (4)	0	74
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Russl. (KOLK)	GAINS	25 (0)	15	117 (25)	0	157
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Russl. (REMR)	GAINS	19241 (3036)	3,558	1755 (379)	0	24554
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Russl. (SPET)	GAINS	206 (0)	129	63 (14)	0	398
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Serbia-M.	GAINS	122 (82)	220	143 (4)	0	485
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Slovakia	GAINS	99 (12)	133	81 (2)	0	313
	UNFCCC	*86 (33)*	*135*	*98 (48)*	*3*	*323*
Slovenia	GAINS	27 (12)	46	47 (1)	0	120
	UNFCCC	*58 (47)*	*44*	*76 (26)*	*1*	*176*
Spain	GAINS	217 (136)	1,052	681 (32)	0	1950
	UNFCCC	*170 (85)*	*886*	*356 (72)*	*0*	*1412*
Sweden	GAINS	117 (0)	150	129 (7)	0	396
	UNFCCC	*37 (0)*	*165*	*122 (0)*	*0*	*324*
Switzerland	GAINS	25 (0)	172	103 (6)	0	300
	UNFCCC	*22 (0)*	*151*	*69 (1)*	*0*	*242*
Turkey	GAINS	269 (118)	1,594	838 (192)	0	2701
	UNFCCC	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
Ukraine	GAINS	2875 (1180)	2,074	886 (194)	0	5835
	UNFCCC	*6256 (n.a.)*	*2,254*	*892 (n.a.)*	*0*	*9402*
UK	GAINS	1267 (958)	1,209	1074 (48)	0	3550
	UNFCCC	*1462 (819)*	*1,032*	*1150 (33)*	*0*	*3645*

[a] Includes emissions from fuel combustion, fugitive emissions from fuels, and emissions from industrial processes including emissions from coal mining.

5.2 Emission projections

GAINS emission projections for the 42 analysed regions suggest that, with current legislation, methane emissions will be 18 percent lower in 2020 than in 1990. With maximum application of the presently available technical control measures, methane emissions could be reduced in 2020 by 56 percent below 1990 emission level (see Table 5.3). These reductions are technically achievable mainly in the gas and waste sectors (see Figures 5.3 and 5.4 and Table 5.4). Important control options include measures to reduce leakages from gas pipelines (mainly in Russia) and to increase the diversion of biodegradable waste from landfills. There is only little potential for further emission reductions in the agricultural sector.

For the EU-25, the total emission reduction in 2020 calculated for the current legislation case is 27 percent of the 1990 emission level, while the maximum technically feasible reduction (MFR) potential over the same period is estimated at 43 percent. Limited further emission reductions are technically feasible in the gas sector (see Table 5.5).

The GAINS emission estimates have also been compared with the assessments performed in 1998 by ECOFYS (Hendriks et al., 1998) and AEAT (1998). Since these estimates are not available for all countries, only the estimates for the EU-15 are compared here. Table 5.7 shows higher reductions estimated by GAINS both for the current legislation and maximum feasible reduction cases than calculated in the AEAT study. The higher estimates in GAINS are due to the implications of the Landfill Directive, which is considered by GAINS, but was not included in the assessment of AEAT (1998, p.156). At that time, the AEAT study assumed no changes in landfilling practices, so that the fraction of waste that is disposed of to landfills in 1990 remains the same until 2010. In GAINS, the total expected emission reduction under current legislation during this period is 4,810 kt/year in EU-15. These reductions emerge primarily in the agricultural sector from the autonomous productivity increases, from the decreasing amount of coal mining, and from waste disposal due to the requirements of the Landfill Directive. Without these emission reductions in the solid waste sector, the GAINS estimates a 15 percent reduction from the other sources, which is more comparable to the decline estimated by ECOFYS (26 percent) and AEAT (9 percent).

Table 5.3: GAINS estimates of methane emission calculation for 1990 and 2020 for the "Current Legislation" (CLE) and "Maximum Technically Feasible Reduction" (MFR) cases (in kt CH_4).

Country	1990	2020 CLE	2020 MFR
Albania	159	195	120
Austria	418	336	303
Belarus	937	750	381
Belgium	527	526	376
Bosnia-H.	159	154	78
Bulgaria	471	349	179
Croatia	190	257	121
Cyprus	23	25	20
Czech Rep.	1,245	694	470
Denmark	313	317	225
Estonia	129	73	51
Finland	326	215	182
France	2,857	2,264	1,941
Germany	4,310	2,592	2,188
Greece	412	382	310
Hungary	703	454	285
Ireland	636	586	501
Italy	2,159	1,655	1,334
Latvia	197	87	63
Lithuania	310	212	157
Luxembourg	28	39	29
Macedonia	92	98	55
Malta	9	6	5
Moldavia	228	209	104
Netherlands	983	772	558
Norway	259	255	138
Poland	2,613	2,158	1,545
Portugal	392	347	278
Romania	2,253	1,879	1,210
Russl. (KALI)	74	60	27
Russl.(KOLK)	157	151	39
Russl.(REMR)	24,554	20,288	6,785
Russl.(SPET)	398	306	120
Serbia-M.	485	526	282
Slovakia	313	197	112
Slovenia	120	75	48
Spain	1,950	1,908	1,382
Sweden	396	321	275
Switzerland	300	308	214
Turkey	2,701	3,470	1,905
Ukraine	5,835	4,919	2,420
UK	3,550	2,019	1,579
Total UNECE	64,172	52,435	28,397
CO_2-eq, Mton	1,476	1,206	653
EU-25	24,919	18,260	14,206
CO_2-eq, Mton	573	420	327

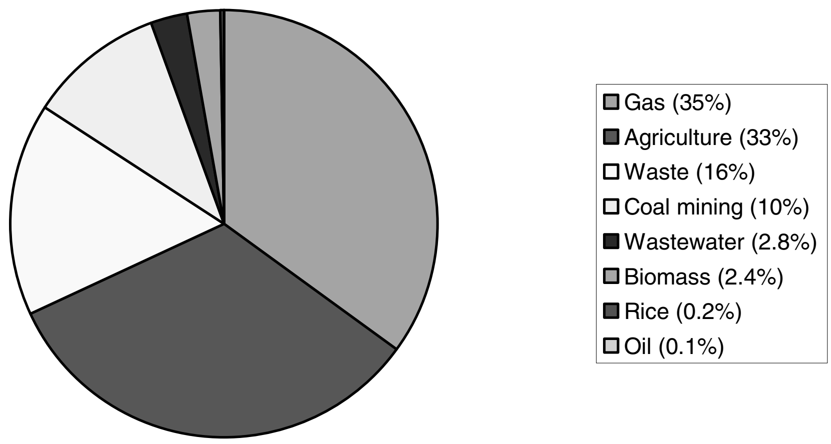

Figure 5.3: Contribution to methane emissions estimated by GAINS for the Current Legislation case for the year 2020, for the 42 European regions considered in GAINS

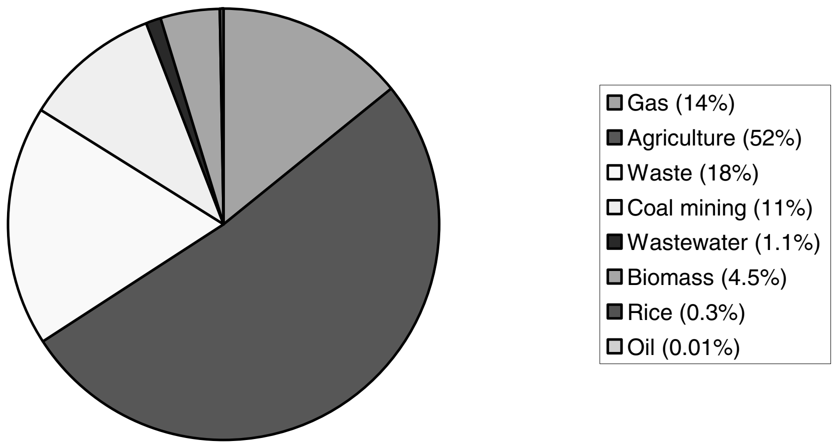

Figure 5.4: Contribution to methane emissions estimated by GAINS for the “Maximum Technically Feasible Reduction” case for the year 2020, for the 42 European regions considered in GAINS

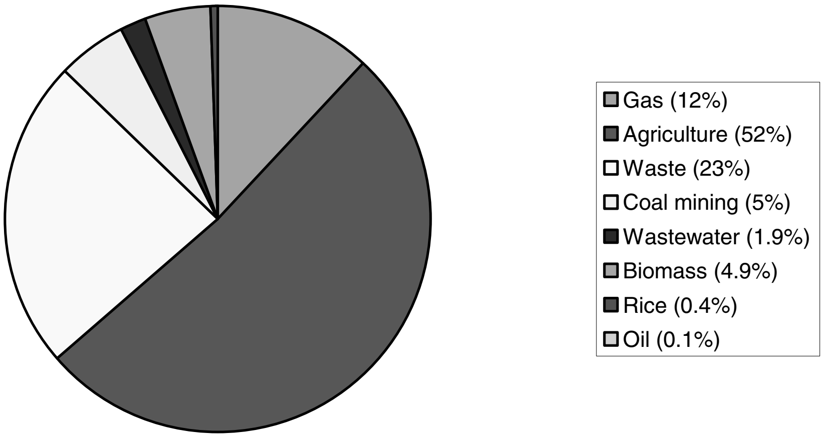

Figure 5.5: Contribution to methane emissions estimated by GAINS for the "Current Legislation" case for the year 2020, for the EU-25

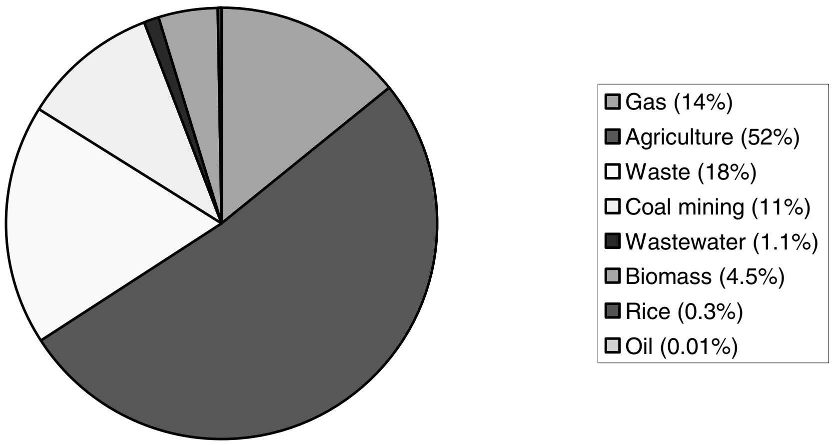

Figure 5.6: Contribution to methane emissions estimated by GAINS for the "Maximum Feasible Reduction" case for the year 2020, for the EU-25

Table 5.4: Sectoral changes in methane emissions of the 42 European regions (a) between 1990 and the "Current Legislation" case in 2020, and (b) the technical potential for further reductions beyond "Current Legislation"

Sector	Emission change between 1990 and CLE [kt CH_4/year]	Additional technically feasible reductions beyond CLE [kt CH_4/year]
Agriculture	-3562	-2699
Biomass	+290	0
Gas	-3186	-14304
Coal mining	-3177	-2578
Oil	+2	-62
Rice cultivation	+10	-29
Biodegradable solid waste	-2226	-3236
Wastewater	+110	-1130
Total change	-11738	-24038

Table 5.5: Sectoral changes in methane emissions of the EU-25 (a) between 1990 and the "Current Legislation" case in 2020, and (b) the technical potential for further reductions beyond "Current Legislation"

Sector	Emission change between 1990 and CLE [kt CH_4/year]	Additional technically feasible reductions beyond CLE [kt CH_4/year]
Agriculture	-1674	-1688
Biomass	+309	0
Gas	+179	-1636
Coal mining	-3138	-325
Oil	+3	-20
Rice cultivation	0	-21
Biodegradable solid waste	-2337	-111
Wastewater	+6	-242
Total change	-6659	-4043

Table 5.6: Sectoral changes in methane emissions of the EU-25 (a) between 1990 and the "Current Legislation" case in 2020, and (b) the technical potential for further reductions beyond "Current Legislation"

Sector	Emission change between 1990 and CLE [kt CH_4/year]	Additional technically feasible reductions beyond CLE [kt CH_4/year]
Agriculture	-1569	-1451
Biomass	+290	0
Gas	-34	-931
Coal mining	-1980	-72
Oil	-3	-20
Rice cultivation	0	-20
Biodegradable solid waste	-1703	-97
Wastewater	+20	-227
Total change	-4979	-2817

Table 5.7: Changes in methane emissions in 2010 in EU-15 compared to 1990 emissions (kt CH_4).

Emissions kt/year	GAINS		ECOFYS		AEAT	
	CLE	MFR	CLE	MFR	CLE	MFR
1990 baseline	19,257		23,742		23,349	
2010	14,447	11,420	17,338	11,386	21,348	16,153
Reduction 1990-2010	-25 %	-41 %	-26 %	-50%	-9 %	-31 %

Table 5.8: Sectoral changes in methane emissions of the EU-25 (a) between 1990 and the "Current Legislation" case in 2010, and (b) the technical potential for further reductions beyond "Current Legislation"

Sector	Emission change between 1990 and CLE [kt CH_4/year]	Additional technically feasible reductions beyond CLE [kt CH_4/year]
Agriculture	-1436	-1170
Biomass	+90	0
Gas	+144	-1246
Coal mining	-1728	-160
Oil	+3	-25
Rice cultivation	0	-20
Biodegradable solid waste	-1900	-181
Wastewater	+18	-225
Total change	-4810	-3027

5.3 Estimates of emission control costs

In Table 4.21, the different control options were ranked by the average cost expressed as the mean over all years and all countries. In Table 5.9, the ranking of the options has been repeated, but now accompanied by the maximum feasible emission reductions (MFR) achievable by the control measures in 2020 when these are applied on top of the measures required under current legislation (CLE). The result shows that maximum technically feasible application of the presently available control measures would reduce CH_4 emissions by 24,000 kt in the year 2020, i.e., by 46 percent below CLE.

GAINS estimates that about 18,400 kt CH_4/year can be reduced at an annual total cost of 1.7 billion € or less than 1150 €/t CH_4 (i.e. 50 €/t CO_2-equiv.). An additional reduction of 5,000 kt CH_4/year can be achieved at a total cost of 12 billion €/year.

Table 5.9: Maximum feasible emission reduction (on top of CLE reduction) and associated costs for 2020 for the whole of the analyzed area of 42 regions.

Control option	GAINS technology abbreviation	Marginal cost (mean) [€/t CH_4]	MFR 2020 [kt CH_4]r	Costs for MFR 2020 M€/year
Baseline (CLE) emissions 1990			64,172	
Current legislation emission level (CLE) in 2020			52,435	0
Enteric ferm: Repl. roughage for concentrates –dairy cows E.Europe	CONCENTR	-6,194	65.1	-316.4
Enteric ferm: Increased feed intake –dairy cows E.Europe	INCRFEED	-4,615	68.7	-217.5
Waste: Paper recycling	PAP_REC	-445	537.6	-33.9
Waste: utilization of gas from paper waste deposited on capped landfill	PAP_USE1	-70	0	0
Waste: utilization of gas from organic waste deposited on capped landfill	ORG_USE1	-70	0	0
Coal mining: Upgraded gas recovery and utilization	CH4_REC	-5	2577.8	70.4
Enteric ferm: Autonomous efficiency increase in milk and meat prod.	AUTONOM	0	0	0
Manure management: Farm-scale AD –pigs/temperate	FARM_AD	17	418.2	31.2
Waste: flaring of gas from paper waste deposited on capped landfill	PAP_FLA1	23	0	0
Waste: flaring of gas from organic waste deposited on capped landfill	ORG_FLA1	23	0	0
Gas transmission –Reduction at compressor stations in FSU	COMPRESS	27	7934.8	307.6
Waste: Paper incineration	PAP_INC	31	1433.9	54.1
Manure management: Farm-scale AD –dairy cows/temperate	FARM_AD	33	157.6	21.0
Manure management: Farm-scale AD –beef cattle/temperate	FARM_AD	43	211.7	35.4
Rice cultivation: Alternative rice strains	ALT_RICE	47	29.4	1.4
Manure management: Farm-scale AD –pigs/cool	FARM_AD	81	305.1	4.7
Oil: Flaring instead of venting –onshore refinery	FLA_REF	81	1.7	0.1
Oil and gas: Flaring instead of venting –onshore production	FLA_PROD	81	1167.6	85.7
Waste: capping of landfill *and* utilization of gas from paper waste	PAP_USE2	130	-266.1[a]	0
Waste: capping of landfill *and* utilization of gas from organic waste	ORG_USE2	130	-364.1[a]	0
Manure management: Farm-scale AD –dairy cows/cool	FARM_AD	139	55.3	1.6
Manure management: Farm-scale AD –beef cattle/cool	FARM_AD	184	74.4	3.0
Waste: biogasification of organic waste	ORG_BIO	193	2416.5	515.3
Waste: landfill capping of paper waste	PAP_CAP	200	-12.5[a]	0
Waste: landfill capping of organic waste	ORG_CAP	200	-2.1[a]	0
Wastewater: Gas recovery and utilization	GAS_USE	207	484.8	96.6
Waste: composting of organic waste	ORG_COMP	210	1733.9	269.8
Waste: capping of landfill *and* flaring of gas from paper waste	PAP_FLA2	223	789.4[a]	0
Waste: capping of landfill *and* flaring of gas from organic waste	ORG_FLA2	223	799.7[a]	0
Oil and gas: Flaring instead of venting –offshore production	FLA_PROD	232	196.0	44.6
Gas distribution: Doubling leak control frequency E. Europe	CONT_NET	258	507.1	123.7
Waste: Organic waste incineration	ORG_INC	322	-652.1[a]	0
Agricultural waste burning: Ban	BAN	500	0.05	0.02
Enteric fermentation: Propionate precursors –dairy cows	PROPPREC	527	547.5	288.5
Gas distribution: Doubling leak control frequency W. Europe	CONT_NET	891	63.5	53.0
Enteric fermentation: Propionate precursors –beef cattle	PROPPREC	1,100	271.8	299.0
Gas distribution: Replacement grey cast iron networks W. Europe	REPL_NET	1,869	794.3	1456.9
Gas distribution: Replacement grey cast iron networks E. Europe	REPL_NET	1,897	3700.8	7094.3
Enteric ferm.: Change to NSC diet –dairy cows E. and W. Europe	NSCDIET	1,945	201.4	244.6
Enteric ferm: Change to NSC diet –beef cattle E. and W. Europe	NSCDIET	3,963	198.3	677.7
Enteric ferm: Repl. roughage for concentr. –beef cattle E. Europe	CONCENTR	4,475	32.9	148.8
Enteric ferm: Increased feed intake –beef cattle E. Europe	INCRFEED	7,698	32.9	254.9
Manure management: Housing adaptation –pigs/liquid manure	HO_ADAP	38,150	58.3	2224.25
Wastewater: Integrated sewage system	INT_SYS	> 1M	645.0	645048.7
Sum of emission reduction and costs			24038	657542

[a] Additional emissions reductions are negative, because the application of these control options in the current legislation case (CLE) are substituted for other options in order to attain the maximum feasible reduction case (MFR).

5.4 Interactions with other emissions.

A number of cases have been identified where emissions of methane and related emission control options influence emissions of other greenhouse gases and air pollutants, and vice versa. During treatment of manure, N_2O and NH_3 are emitted together with methane. When wastewater is discharged, methane and nitrous oxide (N_2O) emissions are released. Waste disposal, gas production, distribution and consumption, and oil production and refining are processes during which both methane and volatile organic compounds (VOC) are emitted. Agricultural waste burning causes emissions of methane, particulate matter (PM), nitrogen oxides (NO_x) and VOC. It will be important to capture these interactions when the findings of this study are implemented together with the other pollutants in the GAINS optimization model.

Table 5.10: Methane emitting sectors and major interactions with emissions of other air pollutants

Sector		Interactions with other gases
Agriculture	Enteric fermentation	
	Manure management	NH_3, N_2O
	Rice cultivation	
Waste	Solid waste	VOC
	Wastewater	N_2O
Fugitive emissions in energy sector	Gas production, processing and distribution	VOC, CO_2
	Coal mining	CO_2
	Oil production and refinery	VOC, CO_2
Biomass burning	Field burning of agricultural residues	PM, NO_x, VOC
	Residential bio-fuel combustion	CO_2

6 Conclusions

This report estimates the current and future emissions of methane in 42 regions in Europe, whereof 38 are countries and four are regions in the European part of Russia. The possibilities to reduce emissions are investigated by examining applicability, removal efficiency and costs of the available control options. 28 measures for reducing CH_4 emissions have been identified, ranging from animal feed changes and waste management options to gas recovery and utilization.

For 1990 emissions are estimated at 64,200 kt/year (i.e., 1476 Mt CO_2-equiv.) for the total area of the 39 countries analyzed. For the EU-25, emissions are estimated at 24,900 kt/year (i.e., 573 Mt CO_2-equiv.), and for EU-15 at 19,300 kt/year (i.e., 443 Mt CO_2-equiv.).

Assuming implementation of the current legislation on emission controls, by the year 2020 CH_4 emissions are estimated to decline by 11,700 kt (or 18 percent) in the total area, by 6,700 kt (or 27 percent) in the EU-25, and by 5,000 kt (or 26 percent) in the EU-15. The higher reductions in the EU are primarily caused by the implementation of the Landfill Directive, which requires increased diversion of waste away from landfills and extended recovery of gas from landfills.

With maximum application of the currently available control technologies, methane emissions in 2020 could be reduced by an additional 24,000 kt/year. A reduction of about 18,000 kt/year can be achieved at a cost of 1.7 billion €/year or less than 50 €/t CO_2-equiv. An additional 5,000 kt/year can be reduced at a total cost of 12 billion €/year. Thus, large emission reductions are identified at relatively low cost. However, once these low-cost options have been exhausted, costs increase at a fast rate.

In 1990, four sectors make dominant contributions to European methane emissions: gas (34 percent), agriculture (33 percent), solid waste (17 percent) and coal mining (13 percent). Minor contributors are biomass burning, wastewater treatment, rice cultivation and oil production and refining. In the EU-25, largest emissions come from agriculture, waste and coal mining, while emissions from gas distribution are less important with only eight percent of total emissions.

Present legislation will reduce CH_4 emissions in 2020 by 11,700 kt CH_4/year (i.e., by 18 percent). Major reductions stem from autonomous productivity increases coupled with livestock reductions in milk production, improved distribution nets for gas in Western Europe, the phase-out of coal mining in Western Europe, and the Landfill Directive in the EU countries. Further emission reductions would be technically feasible through, in particular, reduced gas leakages from gas transmission pipelines and distribution networks, extended waste diversion and higher landfill standards in non-EU countries. There is only little potential for further reductions in emissions from enteric fermentation and manure management in the agricultural sector.

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APPENDIX: DRAFT Minutes from the GAINS review meeting on CH_4

September 30, 2004, Laxenburg

Present: Martha van Eerdt (RIVM) - ME, Chris Hendriks (Ecofys) - CH, Martin Adams (AEAT) - MA, Ger Klaassen - GK (IIASA), Lena Höglund - LH (IIASA), Wilfried Winiwarter (IIASA) - WW

Opening

Meeting opens at 9:00 a.m. GK presents the concept and the background of RAINS/GAINS. The original RAINS has been developed and is operative as a model to cover air pollution. GAINS adds to this model to also include greenhouse gases. An important focus therefore is the interaction between gases, rather than the perfect implementation of algorithms describing just one gas.

Presentation of report on CH_4 and simultaneous discussion

ME: Nitrates directive will affect the number of animals, at least in NL

LH will check with Zig Klimont (ammonia module), how much this has been taken into account in the RAINS animal number forecast. At least the national projections (after consultation) should have this considered.

ME: The report discriminates between "uncontrolled", "CLE" and "MFR" scenario – it is not really clear what actually is uncontrolled, and also the definition of baseline is not clear.

MA: it is also not important – suppress the mention of "NOC", and use CLE as baseline consistently. Only the difference CLE – MFR counts in the end.

Focus on CLE and MFR in the report, avoid if possible mentioning an uncontrolled (NOC) option.

Presentation and discussion on enteric fermentation

ME: options currently discussed: the replacement of roughage by concentrate and efficient, genetically improved animals. Both will come as an autonomous development. She will provide detailed forecast numbers on milk production.

Economic requirements imply that feed intake increases causing increasing CH_4 emissions per cow, while simultaneously decreasing the number of cows since productivity increases.

CH: The situation in Eastern Europe may be different, as benefits of development are smaller and thus options may require additional costs (non-autonomous).

IIASA will check numbers and try to accommodate these. Additionally, we will explain why we do not use meat or milk production as activity number (linkage to NH3 module, in order to cover interdependence).

Detailed comments

- ME: in NL cows are stall fed even if outside during day
- IIASA will check actual RAINS definition of "housing days".
- ME: All cattle / even stall fed / will be fed some roughage for physiological reasons. Also, 5 kg dry matter concentrates / cow / day seem too much.
- ME will provides figures to LH
- ME: Nomenclature in RAINS / GAINS should consistently refer to "dairy cows" (not "dairy cattle")
- LH to check with Zig
- MA: propionate precursors will be available in 2020 only, not in 2010.
- CH will provide workshop report to IIASA, to check this information
- ME: Some of the options presented can not be reflected in a national inventory when using the IPCC methodology (as simply the parameters will not feed in any of the equations given for emission assessment).IIASA will flag this problem in the text.

Some more detailed comments:

CH

- page 31. Explanation for CH_4 reduction is too simplistic.The text "higher emission factor per animal" does not seem logical in this context (even if the fact as such is correct)
- page 33. F is in dry matter/animal/DAY The autonomous productivity increase is 1-2%/yr in NL → changes will have an effect on CLE
- page 34 NSC price is NOT country specific: needs to be made clear!

MA

- section 4.9: Ban of agricultural waste burning is not sufficiently accounted for in CLE. IIASA will explain assumptions in RAINS (check with Zig!) on not-enforced regulations

ME

- EF's for sheep and goats may not be cited correctly, or not derive from the latest available IPCC emission factors. IIASA will Check IPCC guidelines and Good Practice Guidelines (2001)

Manure management

- ME: p. 39 (Tab. 4.7) cost savings should be explained. Mention also risk of anaerobic digester (possible leakages should be considered, as the total amount of CH_4 produced in a system is of course much higher than the emissions without digester are)
- CH: use the phrase "avoidance" rather than "removal" of emissions (CH_4 is not removed, but specifically formed in the process. IIASA is to carefully rephrase – without proof of leakages no firm statement should be made.

- CH: 95% removal efficiency is too high – refers to CH_4 production in the total system, which however (see above) is much higher than CH_4 emissions without digestion. In relation to CH_4 emissions, removal efficiency will be closer to 50-70%.
- CH will send references to IIASA for an update of factors.
- ME:p. 38. Add option "combined waste plants" (Waste and manure plants decentralized) – much cheaper than anaerobic digesters: 70€/t CO2 eq.(See Kuikman, P.J.; Buiter, M.; Dolfing, J.; Perspectieven van co-vergisting voor beperking van emissies van broeikasgassen uit de landbouw in Nederland. Alterra-rapport, 210, Wageningen, 2000. 115 p [HAAFF 32/476(210) 2 ex.]).
- CH: In general a comparison to "sectoral objectives" study is missing – costs and also order of measures are different. IIASA agrees to compare with "sectoral objectives" – adapt data or explain differences
- ME: low nitrogen feed and NSC may be independent, no side effects between NH3 and CH_4 abatement measures are expected.

Reporting and discussion on biodegradable organic waste

- MA: organic waste per capita possibly increases over time, does not remain constant. IIASA tries to find reference
- LH: Paper recycling – how to assess costs at different level of abatement? Can the cost function as taken over from Swedish data be applied?
- CH: cost function may also consider economy of scale, i.e. cost decrease with increasing application at least in some part of the total range. IIASA to collect more empirical data to confirm the shape of the function. MA will contact AEAT waste unit.
- CH: removal efficiencies are too large (see also manure anaerobic digestion).IIASA will check for numbers in sectoral objectives study
- CH: p. 47 (middle of page): statement unclear, misleading. IIASA checks options and express more carefully – possibly check with Judith Bates and MA, possibly use an example. Or simply state "we have used emission factors as given in …" without presenting confusing details.
- CH: p.48 Tab. 4.10. IIASA to check the order of measures

General comments on other parts of the report:

- MA: report nice to read. Use "new member states instead of accession countries". p.15 update UNFCCC data for 2004
- MA: data on coal production (fraction of surface mining etc.) is outdated
- MA: treatment of leakage from gas networks is unsatisfactory, improvement is not possible however.
- A: comment on this in the text
- MA: data on country level would be useful. IIASA will add information on a country level, for 1990, 2000, 2010 and 2020: emissions by country/sector+costs of CLE, MFR
- MA: Table 5.2, details per sector for some countries, shows large differences between national submissions and GAINS. IIASA to explain (and where necessary correct) differences occurring in coal mining and in waste paper; allocation of coal mining in GAINS needs to be corrected.

CH: some corrections/inconsistencies:

- p. 15 – graphics is somewhat misleading (pie chart, or bars for EU vs. non-EU?)
- p. 26 – venting and flaring occurs in oil, not gas production
- p. 51 – numbers to be adjusted/compared to sectoral objectives study

- p. 51 – recovery in coal mines for security purposes: this does not necessarily mean that CH_4 is abated, as the gas collected might likewise be vented!
- p. 53 – emissions for gas and oil production are low, based on a lower EF in Eastern Europe (Russia) than Western Europe – is this realistic? IIASA to check and correct when applicable.
- flaring produces CO2 which is to be added in the interrelation table (section 5.4)

Closing

The meeting closes at 16.00 hours