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# **GAINS Documentation Hub**

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**Aug 19, 2024**



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These pages document the Greenhouse Gas and Air Pollution INteractions and Synergies (GAINS) model hosted in IIASA. Launched since 2006, GAINS has been developed as a tool to identify emission control strategies that achieve given targets on air quality and greenhouse gas emissions at least costs. GAINS considers measures for the full range of precursor emissions that cause negative effects on human health via the exposure of fine particles and ground-level ozone, damage to vegetation via excess deposition of acidifying and eutrophying compounds, as well as ten air pollutants and six of the seven greenhouse gases included in the Kyoto Protocol's Annex A. In addition, GAINS includes an *optimization framework* allowing the identification of the least-cost combination of abatement measures for air pollutants and/or greenhouse gases that meet user-specified environmental or health policy targets for each of the above-mentioned endpoints.

## Greenhouse gas–Air pollution Interactions and Synergies: The GAINS tool

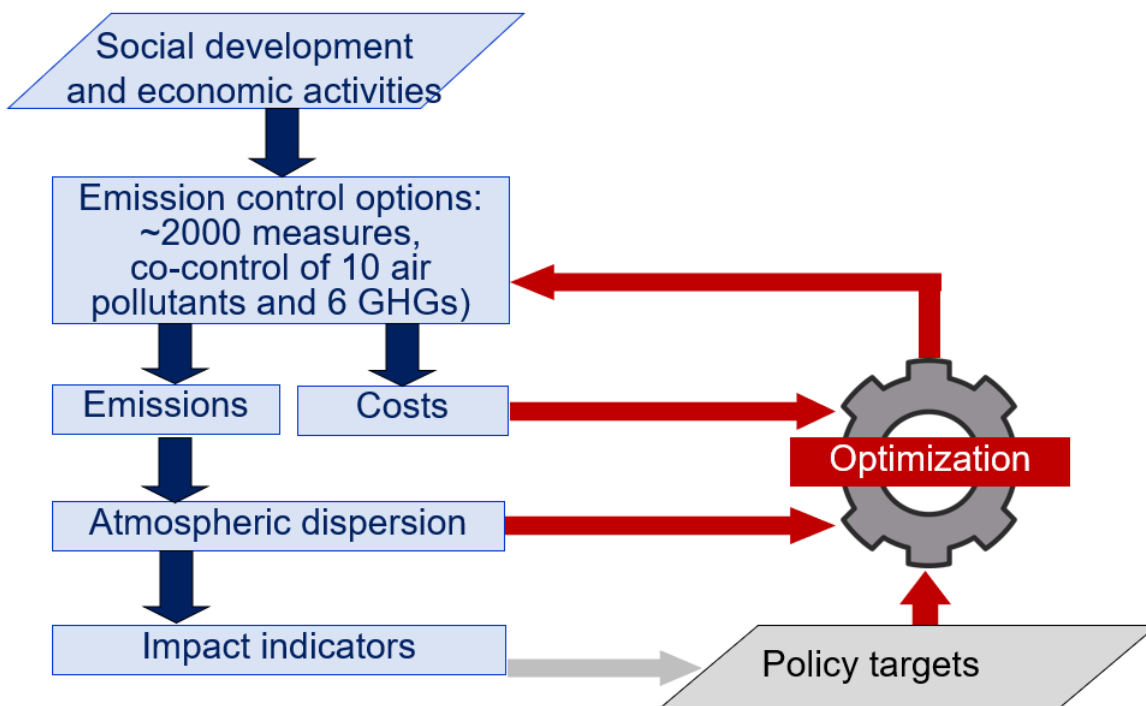


Fig. 1: GAINS model overall workflow

This Integrated Assessment Model is extensively used for policy analyses under the Convention on Long-range Transboundary Air Pollution (CLRTAP), e.g., for the revision of the Gothenburg Protocol, and by the European Commission for the EU Thematic Strategy on Air Pollution and the air policy review.

**This documentation is under constant development and is being expanded with additional information to reflect the latest changes in the modeling framework. The latest version of GAINS is the version 4.03 and has been released in October 2023. The “Release notes” summarizing such changes with respect to the previous versions of GAINS can be accessed [here](#).**



## GETTING STARTED

The present Section describes the first steps needed to get started with the GAINS model, including:

- *Overview*: Provides a high-level overview of the policy work that was, or is currently, carried out using the GAINS as well as more detailed explanations of the model capabilities.
- *Target audience*: Describes main user categories as well as prerequisites to access/use the GAINS model.
- *Access rights/Installation*: Details the various types of rights inherent to each given user category and the steps needed to be granted these rights and start using the model.
- *Choose your regional domain*: Lists the various model instances, including the regional and local ones.

### 1.1 Overview

The [Greenhouse Gas and Air Pollution Interactions and Synergies \(GAINS\) model](#) is an Integrated Assessment Model (IAM) allowing the identification of emission control strategies achieving given targets on air quality and greenhouse gas emissions at least costs, thereby revealing important synergies and trade-offs between these policy areas.

In its function as the Centre for Integrated Assessment Modelling (CIAM), IIASA has extensively been using the GAINS model to inform the negotiations under the Convention on Long-range Transboundary Air Pollution (CLRTAP) for e.g. the revision of the Gothenburg Protocol. Other relevant policy applications include the EU Thematic Strategy on Air Pollution and the Air Policy review as well as negotiations under the United Nations Framework Convention on Climate Change (UNFCCC), for which a special version of GAINS has been developed to compare greenhouse gas mitigation efforts among the Annex-I countries.

In practice, GAINS quantifies the technical and economic interactions between mitigation measures for ten air pollutants and six GHGs based on data from international energy and industrial statistics, emission inventories and on data supplied by countries themselves. Such an approach allows analyzing different air pollution policy packages, including the estimation of emissions, costs for air pollution control measures as well as the health or environmental impacts from various endpoints.

To that extent, the GAINS model also features an *optimization* routine deriving the most cost-effective combination of mitigation measures or the one minimizing emissions following given policy targets (e.g., current legislation, maximum feasible reduction).

## 1.2 Target audience

The GAINS model is targeting two main user categories at various degree of intensities:

- **Experts** (e.g. from ministries): This largest target audience concerns experts willing to use scientific information related to high-level air quality assessment.
- **(Academic) researchers**: This second target audience is using GAINS for its own research purposes, to e.g. enhance its own mitigation scenarios or directly collect data.

### 1.2.1 Prerequisites

GAINS is an online model directly accessible through a [web interface](#). Hence, no other hardware/software requirements than having one of the latest browsers (e.g. Google Chrome, Mozilla Firefox, Opera, Microsoft Edge) installed on one's personal laptop/desktop computer is required for using it.

For the more advanced users willing to benefit from the various functionalities of GAINS' *Extensions*, the following prerequisites are relevant:

- *PyGAINS*: Basic data post-processing skills in Python language;
- *The GAINS optimization module*: Knowledge of the GAMS language and of mathematical optimization.

## 1.3 Access rights/Installation

The [GAINS landing page](#) provides access to the online implementations of the GAINS model at the global, regional (e.g. Europe), national and sub-national scale, as well as to supporting documentation material, such as the [release notes](#) or [user guide](#) (see also the *Library* Section for more details). Further information on such separate model instances can be found in the *Regional domains and time coverage* Section.

The use of the GAINS model is free of charge and only necessitates an up-to-date web browser (see also the *Target audience* Section). A one-time registration is required for technical reasons before having access to the model. Please consult the Section 1.2 of the [user guide](#) for detailed explanations of the procedure.

### 1.3.1 VIEWER rights (Basic mode)

The *VIEWER* status is automatically granted upon registering (subject to acceptance of the disclaimer and licensing conditions), allowing the user to view input data and calculate results for scenarios prepared by IIASA. Printing, exporting and downloading various tables and maps with input data and results are also possible in this Basic mode.

Among other things, the Basic mode allows rapid exploration of the following key features:

- Macro-economic assumptions
- Projected future energy use
- Agricultural activities
- Transport volumes and industrial production
- Assumed emission controls,
- Costs of these measures,

- Resulting air pollutant and greenhouse gas emissions,
- Ambient air quality, and
- Health and ecosystems impact indicators.

### 1.3.2 USER rights (Advanced mode)

Upon request ([gains.dev@iiasa.ac.at](mailto:gains.dev@iiasa.ac.at)), IIASA collaborators can obtain the user status, which grants them permission to carry out a.o. the following advanced tasks:

- Advanced data management and upload functions
- Create personalised scenarios within the GAINS framework
- Advanced editor functions, such as:
  - Creation of new input data
  - Organization of new data sets into an emission scenario.

## 1.4 Regional domains and time coverage

### 1.4.1 Regional domains

The GAINS model comprises several online interfaces with distinct regional domains, which can be accessed by clicking [here](#). Some interface versions are publicly available, while others are research versions restricted to collaborators. The model resolution varies across different geographic scales, ranging from national to subnational and regional levels. *Emission calculations* are performed on various grid levels, with the smallest grid resolution being 0.1 degrees. The most comprehensive domain within the GAINS model is the global version, which covers 183 regions worldwide, which are countries (Europe, parts of Asia, North and South America, single countries in Africa), subnational entities such as provinces or states (China, India, several other Asian countries), or aggregates of countries (in Africa, Central America, Caribbean). Beyond the online interfaces, some elements of GAINS are offline and their use is restricted to collaborators in dedicated projects.

To determine the regions included in each specific model instance, consult the *Region glossary* and select the corresponding model.

### 1.4.2 Time coverage

Data in GAINS are displayed in 5-year intervals and cover the years from 1990 to 2050, with some scenarios extending up to 2070. The years until 2020 are considered statistical years. GAINS calibrates future data relative to a specific base year, depending on the project.



## HOW DOES THE MODEL WORK?

The **GAINS model** offers a powerful tool for evaluating various scenarios and assessing the potential impact of policy interventions on greenhouse gas emissions and air pollution. Those impacts include the shortening of statistical life expectancy due to the human exposure to PM<sub>2.5</sub>, premature mortality related to ground-level ozone, protection of vegetation against harmful effects of acidification and terrestrial eutrophication through excess sulfur and nitrogen deposition, as well as metrics like global warming potentials. For given predefined scenarios, users can analyze the economic and environmental consequences of exogenous patterns of technology-related emission controls. Additionally, the *optimization* mode of the **GAINS model** can be operated outside the online interface to identify cost-minimal combinations of abatement measures of multiple pollutants over the various economic sectors in all regions that simultaneously achieve user-specified targets for the above mentioned impact endpoints.

While **GAINS** models the impacts of emission control measures on multiple pollutants, it does not include the simulation of behavioural changes of consumers that influence demand for energy, transport and agriculture. Similarly, responses of the energy and agricultural markets towards higher emission control costs, or effects that higher pollution control costs might have on the transfer of production to third countries are not taken into account into the model's dynamics.

Further information on the way *scenarios* are defined in **GAINS**, as well as on the various assumptions underpinning the methodology of the model's *core calculations* can be find under the pages below. Additional description of the optimization module can be found *here*.

### 2.1 Scenarios

**GAINS** enables researchers, policymakers, and relevant stakeholders to (i) explore pre-defined scenarios or (ii) evaluate user-defined scenarios in order to gain valuable insights into storylines of human activities and emissions of air pollutants and greenhouse gases under certain assumptions on macroeconomic drivers, emission factors, and emission control legislation:

- **Evaluating Given Scenarios:** By utilizing the online version of the **GAINS model**, you can explore pre-defined scenarios and obtain comprehensive evaluations. Whether you are interested in understanding the consequences of different energy or agricultural policies, analyzing the effects of technological advancements, or assessing the implications of regulatory measures, **GAINS** allows to simulate and assess the outcomes with precision.
- **Creating Custom Scenarios:** One of the standout features of the **GAINS model** is its flexibility to accommodate the evaluation of user-defined scenarios. By leveraging the model's customizable framework, new scenarios can be tailored to suit the user's specific needs and evaluate the potential impact of targeted policy interventions. Doing so, the potential benefits and trade-offs associated with different policy options can be analyzed, thereby empowering policy experts to make informed decisions and drive meaningful change.

Data in **GAINS** are organized into scenarios, which consist of individual combinations of activity data, emission factors, unit costs, and emission control technologies. For more information about the components of a scenario refer to the *Components* page. To learn more about the data categories considered in **GAINS** and the underlying assumptions,

visit the [Data categories](#) page. Finally, some of the most commonly used scenarios can be explored under the page [Commonly used scenarios](#).

Scenarios in GAINS are typically grouped by projects. As a result, most users can only access publicly available scenarios and the ones they have created and own themselves.

### 2.1.1 Components

An emission scenario in GAINS is created through a combination of region-specific activity data, emission vectors, and control strategies. Each combination determines the level of actual emissions. While an emission scenario is generally specific to each GAINS region, some components, such as emission vectors, can be common across a few of them. In addition to region-specific parameters, there are also general (global) parameters that need to be defined, known as *scenario metadata*. The latter encompass for instance the *scenario ID*, which is unique to each created scenario and is valid for one or several years.

#### Activity data

The activity data represent the magnitude of a specific *activity-sector*-combination in GAINS. They are organized into activity pathways, which describe the time-dependent evolution of economic activities causing emissions, such as energy production & consumption, passenger & freight transport, industrial and agricultural activities, waste, etc. By creating/assigning a pathway for your scenario, you design the way your activities will evolve in the future.

#### Control strategy

The implementation of emission mitigation *technologies* for each activity is specified in control strategies. More precisely, a control strategy is a dataset that contains assumptions on the penetration of emission control technologies for each GAINS source category (e.g. coal use in the power sector) and in a given emission scenario. The complete control strategy includes information on controls applied in all sectors for all pollutants. Control strategies are independent of country and activity projections. They can be seen as legislative packages for emission controls that specify, for each type of emission source, the type and percentage of implementation of control technologies required to comply with a given pollution control legislation (emission standards, sectoral emission ceilings, etc.), regardless of the extent to which such emission sources exist in a particular country at a given time. This approach facilitates the analysis of the implications of different activity projections under a constant set of emission control requirements.

#### Emission vector

The sets of emission factors and unit costs of control technologies, along with all background information, form the so-called *emission vectors*.

### 2.1.2 Data categories

The GAINS model encompasses various data categories that play a fundamental role in simulating and analyzing emissions and their mitigation strategies, as well as in creating custom scenarios. These data categories include:

1. *Activity* Activities in GAINS represent source categories of socio-economic activities, such as the use of coal or the number of electric vehicles. These activities are linked to specific sectors, such as energy, macroeconomics, or agriculture, to determine meaningful emission drivers.
2. *Sector* GAINS covers all sectors of the economy, including Power Plants, Industry, Household, Waste, Transport, and Agriculture. Each sector may be associated with different activities, and some activities can be attributed to multiple sectors.

3. *Technology* Technologies in GAINS describe measures designed to control or abate emissions. These technologies play a crucial role in calculating emissions by specifying the level of technology implementation for each activity.
4. *Pollutant* GAINS covers a wide range of pollutants, including greenhouse gases (GHGs) and air pollutants.

By combining and analyzing data from these categories, the GAINS model facilitates the development of informed policies and measures for sustainable environmental management. You can learn more about each of the data categories below.

## Activity

Activities in GAINS represent various source categories of socio-economic activities. They can correspond to fuel combustion (e.g. coal combustion) or non-combustion categories (e.g., number of electric vehicles or animals in agricultural sectors). These activities can be related to multiple sectors (cross-reference), such as energy, macroeconomics, or agriculture, and need to be combined with a sector build a meaningful emission driver. In practice, this means that every of the 842 legitimate sector-activity combinations of the model is associated with its specific emission factor and responsible for the emissions of one or several pollutants.

For example, the activity *hard coal grade 1* (HC1) can be used in the *power plants* sector but also in the *domestic* or the *industrial* one. Similarly, the sector of *chemical industrial boilers* (IN\_BO\_CHEM) can be related to various activities that are the fuels used in those boilers, i.e., gaseous fuels (GAS), hard coal grade 1 (HC1), heavy fuel oil(HF), etc. In road transport sectors, activities exist both in terms of combustion of different fuels as well as vehicle mileage. The former is associated with exhaust emissions while the latter drives the non-exhaust emissions (road abrasion, brake and tyre wear). Activities may be further subdivided; for instance, coal can be divided into hard coal (grade 1), hard coal (grade 2), etc.

For a comprehensive list of the 147 activities used in the model, please visit the [activity glossary](#) page.

## Sectors

GAINS covers all sectors of the economy, including Power Plants, Industry, Household, Waste, Transport, and Agriculture, encompassing 364 sectors/subsectors. For a complete list of the sectors, refer to the [sector glossary](#) page.

Each sector may be associated with a number of *activities*, and some activities can be attributed to multiple sectors, forming a total of 842 legitimate sector-activity combinations in the model. The structure of the sectors in GAINS follows the SNAP (Standard Nomenclature for Air Pollution) classification system. That structure is detailed below for some of the most important sectors, along with the abbreviations used in the model.

## Power Plants

GAINS differentiates between existing and new power plants. Existing plants PP\_EX are defined as all capacities put into operation on or before December 31, 1995. They include small and large coal-fired (PP\_EX\_S and PP\_EX\_L, respectively) and other non-coal-fired existing power plants PP\_EX\_OTH, such as industrial power plants, Combined Heat and Power (CHP) plants, and public district heating plants. Similarly, new plants include small and large coal-fired (PP\_NEW\_S and PP\_NEW\_L, respectively) and other non-coal-fired new power plants PP\_NEW. Furthermore, GAINS covers (i) Integrated Gasification Combined Cycle (IGCC) power plants with and without carbon capture technology (PP\_IGCC and PP\_IGCC\_CCS), and (ii) modern power plants, which are ultra and supercritical coal power plants or combined cycle gas turbines CCGT gas plants, with and without carbon capture technology (PP\_MOD and PP\_MOD\_CCS). Diesel generator sets are denoted as PP\_ENG. The total inputs into power plants, including electricity generation, are represented by PP\_TOTAL, which may result in negative values.

### Conversion Sector CON

The conversion sector includes on-site consumption of fuel and energy in coal mines, refineries, coke and briquette plants, gasification plants, etc. It also includes own use of electricity and heat in the power and district heating sector, as well as transmission and distribution losses for electricity, heat, and gas. The sector CON is further divided into fuel used in combustion processes (CON\_COMB) and own use and losses that occur without combustion (CON\_LOSS). This distinction is necessary to account for different emission factors in combustion and non-combustion processes.

GAINS treats fuel combustion in boilers and furnaces separately due to differences in operating conditions, emission factors, and emission control technologies for these two types of combustors. The sector CON\_COMB covers fuel combustion in furnaces used in the energy sector. Examples include combustion in crude oil distillation furnaces and catalytic cracking installations in oil refineries, or coking gas use for heating coke batteries in coke plants. Fuel combusted in heat only boilers (in oil refineries, coke plants, coalmines, coal gasification plants etc.) should be reported in the sector called *Combustion in industrial boilers* (IN\_BO). Should it not be possible to distinguish between combustion in boilers and combustion in furnaces, it is recommended to report all fuel combustion in energy industries belonging to the CON sector under CON\_COMB.

#### The sector CON\_LOSS includes the following items:

- Losses of fuels, electricity and district heat in transmission and distribution to final consumer
- Own use of electricity and heat in the power sector, representing the difference between gross electricity/heat output and the energy supplied to the grid. It also includes electricity use in pumped storage hydro plants.
- Use of electricity, heat and fuels in other plants belonging to the energy sector (coalmines, oil refineries, coke plants, gasification and liquefaction plants etc.)
- Difference between total fuel inputs and outputs from the conversion processes.

#### The latter bullet includes:

- For coke plants a difference between input of coal and gross output of coke and coke oven gas. The fuel lost is coal (HC).
- For oil refineries, it accounts for the difference between crude oil and other feedstocks input and gross output of petroleum products (residual oil, gasoline, medium distillates, refinery gas, other). Since GAINS does not include crude oil in the energy balance, it assumes that the fuel lost is heavy fuel oil (HF).
- For biomass liquefaction and gasification plants, it accounts for the difference between biomass input and gross output of products (liquid fuels, biogas). The fuel lost is biomass.

IN\_BO\_CON covers fuel combustion in industrial boilers, while CON\_COMB covers fuel combustion in furnaces.

### Industry (IN)

Energy consumption in the Industry sector is divided into combustion in (heat only) boilers (IN\_BO) and other industrial combustion (IN\_OC\_TOT). Boiler fuel consumption is further divided into consumption in the conversion sector (IN\_BO\_CON), chemical industry (IN\_BO\_CHEM), pulp and paper industry (IN\_BO\_PAP), small coal boilers (<50 MWth) in other industries (IN\_BO\_OTH\_S), large coal boilers (>50 MWth) in other industry (IN\_BO\_OTH\_L), and non-coal boilers in other industry (IN\_BO\_OTH). Should the detailed split by sub-sectors not be known for a given energy pathway, it is recommended to report the total boiler fuel consumption under IN\_BO\_OTH. Other industrial combustion (IN\_OC\_TOT) is divided into iron and steel (IN\_OC\_ISTE), chemical (IN\_OC\_CHEM), non-ferrous metals (IN\_OC\_NFME), non-metallic minerals (IN\_OC\_NMMI), paper, pulp, and printing (IN\_OC\_PAP), and other manufacturing industries (IN\_OC\_OTH). Should the detailed split by sub-sectors not be known for a given energy pathway, it is recommended to report the total fuel consumption under *other industrial combustion* (IN\_OC\_TOT). Should the detailed split of fuel consumption between boilers and other combustion not be known, it is recommended to report the total fuel consumption under *other industrial combustion* (IN\_OC\_TOT).

For the *other industrial combustion* (IN\_OC\_TOT) sector, GAINS calculates emissions based on activity data reported under IN\_OC. This column is internally calculated by the GAINS model during data initialization by subtracting energy use reported for cement and lime production from the total energy use in industry (IN\_OC\_TOT). Thereby, the model takes into account the high retention of the sulfur during cement and lime production and calculates emissions from these activities under *industrial process emissions*. These measures are taken to avoid double counting of emissions.

## Domestic Sector (DOM)

The Domestic sector includes the subsectors urban residential (DOM\_URB) and rural residential (DOM\_RUR), residential kerosene lamps (DOM\_LIGHT), commercial and public services (DOM\_COM), and other services, agriculture, forestry, fishing, and non-specific sub-sectors (DOM\_OTH).

## Transport Sector (TRA)

In the Transport sector, we distinguish between road and rail transport. The road transport is further divided into motorcycles, mopeds and cars with 2-stroke engines (TRA\_RD\_LD2), motorcycles and mopeds with 4-stroke engines (TRA\_RD\_M4), cars and small buses with 4-stroke engines (TRA\_RD\_LD4C), light commercial trucks with 4-stroke engines (TRA\_RD\_LD4T), heavy duty buses (TRA\_RD\_HDB), and heavy duty trucks (TRA\_RD\_HDT). For each vehicle type GAINS requires information on total annual fuel consumption by fuel type (in PJ), total annual vehicle-kilometers driven (Gveh-km), and vehicle numbers (1000 vehicles).

The following tree presents the structure of the transport sectors to visualize the how main sectors and subsectors are generally linked in GAINS:

## Transport Sector

### Technology

Technologies in GAINS represent applications designed to control or reduce emissions of air pollutants and short-lived greenhouse gases. The implementation rate of specific end-of-pipe technologies multiplied with activity data and the corresponding emission factor leads to the computation of emission levels of the relevant pollutants, as detailed under the page *Emissions*.

Those abatement measures encompass filters, scrubbers, various types of installations such as stove types, various standards of exhaust cleaning such as the Euro standards for vehicles, as well as improved ways of handling manure, or best practice controls on process emissions. Some relate uniquely to one particular type of equipment while others represent rather categories of installations. For instance, selective catalytic reduction for power plants, or high efficiency dedusters and stage 3 process emission controls for SO<sub>2</sub> and NO<sub>x</sub> in the industrial sector are GAINS technologies.

In the GAINS framework, technologies influence emissions but they do not alter the activity level so that the energy balance stays unchanged. Technologies can influence emissions of one or more pollutants as not every technology controls every pollutant. In some cases, the application of a control technology which is mainly designed to reduce emissions of one pollutant can lead to small increases of emissions of another pollutant. For instance, the selective catalytic reduction of NO<sub>x</sub> leads to slightly increased NH<sub>3</sub> emissions. Such effects, both in terms of co-control or trade-offs across several pollutants are represented accurately in GAINS.

The level of technology implementation for each activity is specified in *control strategies* (see also the *Scenario components* section), whereas the complete strategy includes information on controls applied in all sectors for all pollutants. In the absence of any policy, the default technology is an uncontrolled one, whose emission factor is unmitigated. In addition to their physical properties, such as their efficiency in emission reduction, technologies in GAINS are further described by their costs. This includes the investment costs per unit of activity and total cost per unit of activity. The cost for an *uncontrolled* situation, that is, the absence of a specific emission control technology, is characterized by zero costs.

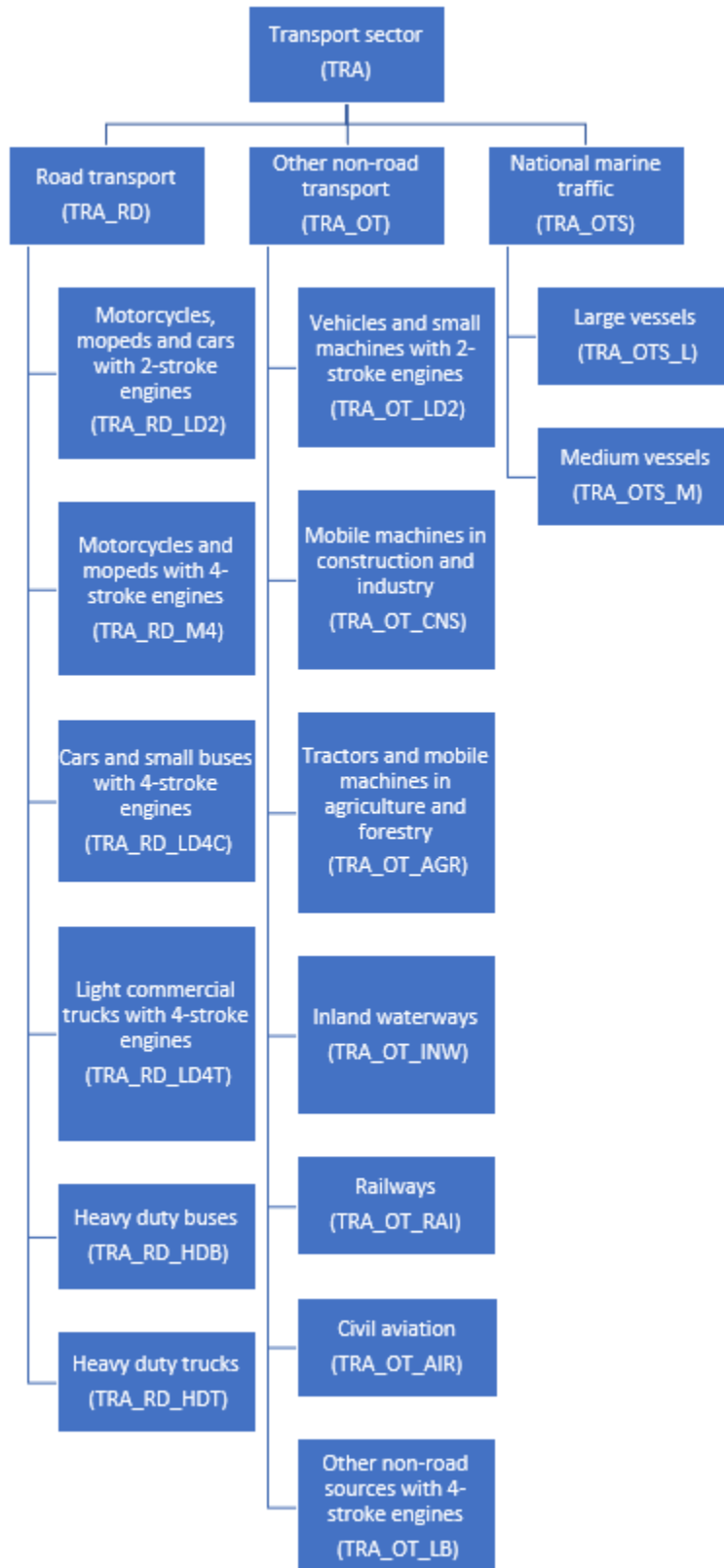


Fig. 2.1: Structure of the transport sector in GAINS.

A comprehensive list of the 522 technologies used in GAINS can be found under the *Technology* page of the *Glossary*.

## Pollutant

The GAINS model is designed to analyze interactions and synergies between various air pollutants and greenhouse gases, their sources, and their impacts on air quality, climate change, terrestrial ecosystems, and human health. The model covers a wide range of pollutants, including 4 greenhouse gases and 7 air pollutants:

### Greenhouse Gases (GHGs):

- Carbon dioxide (CO<sub>2</sub>)
- Methane (CH<sub>4</sub>)
- Nitrous oxide (N<sub>2</sub>O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF<sub>6</sub>)

### Air Pollutants:

- Particulate matter (PM)
- Nitrogen oxides (NO<sub>x</sub>)
- Sulfur dioxide (SO<sub>2</sub>)
- Carbon monoxide (CO)
- Ammonia (NH<sub>3</sub>)
- Volatile organic compounds (VOCs)
- Mercury (Hg)

A few pollutants and greenhouse gases have been temporarily suspended from the online GAINS calculations:

- The F-gases HFC, PFC, SF<sub>6</sub> were operational in GAINS version 3 and will be included again in the near future. Offline calculations are possible for selected scenarios.
- Mercury (Hg) has been taken out of the list of active pollutants but is in the process of being re-introduced with updated methodology.
- Particle numbers (PN) emissions were calculated as part of the particulate matter emissions but are currently not supported.

The full list of (sub-)pollutants covered by the model can be consulted under the *pollutant glossary* page.

### 2.1.3 Commonly used scenarios

In the GAINS model, different scenarios are used to explore and analyze various potential futures based on different assumptions and policy measures. Here are some commonly used scenarios:

#### Current Legislation (CLE) Scenario

The CLE scenario is the GAINS representation of the existing air pollution control legislation in a given region. It assumes the continued enforcement of those regulations and does not consider any additional policies beyond the current legal requirements. The implementation of the latter results in baseline emission levels reflecting the environmental performance if current policies remain unchanged over the simulation period.

#### Custom Policy Scenario

Custom policy scenarios allow users to design and implement their own policy assumptions, targets, and implementation timelines to explore the potential impacts of customized emission control strategies within the GAINS framework.

#### Maximum Technically Feasible Reductions (MTFR)

The MTFR scenario in the GAINS model focuses on achieving the maximum feasible emission reductions based on existing and potential technological advancements. Assuming the widespread implementation of current technical capabilities to their limits, it represents a hypothetical ambitious pathway providing valuable insights into the upper bounds of emission reductions that could be achieved solely through technological improvements without considering cost constraints or policy implementation.

## 2.2 Core calculations

The following pages detail some of the core calculations performed in the model, such as emissions, costs and impacts calculations.

### 2.2.1 Emissions

The GAINS model estimates the emissions of air pollutants and greenhouse gases (see also *Pollutant*) that exert radiative forcing and contribute to global warming. Specifically, GAINS estimates emissions of sulphur dioxide ( $SO_2$ ), nitrogen oxides ( $NO_x$ ), ammonia ( $NH_3$ ), non-methane volatile organic compounds (VOC), mercury (Hg)<sup>1</sup>, and primary emissions of particulate matter (PM), including fine ( $PM_{2.5}$ ) and coarse ( $PM_{10}$ ) PM as well as carbonaceous particles (BC, OC). In addition to these 5 air pollutants, GAINS also tracks emissions of some of the most potent greenhouse gases included in the Kyoto protocol: carbon dioxide ( $CO_2$ ), methane ( $CH_4$ ), and nitrous oxide ( $N_2O$ ), as well as the three F-gases Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur hexafluoride (SF6)<sup>1</sup>.

GAINS quantifies the technical and economic interactions between mitigation measures for the above considered air pollutants and greenhouse gases. For each of the above pollutants, GAINS estimates emissions based on activity data levels (see also *Activity data*), uncontrolled emission factors, the removal efficiency of emission control measures and the extent to which such measures are applied (see also *Control strategy*):

$$E_{i,p} = \sum_k \sum_m A_{i,k} ef_{i,k,m,p} x_{i,k,m,p} \quad (1)$$

where:

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<sup>1</sup> Note that the estimation of mercury and F-gases emissions is currently not supported on the online web interface.

$i, k, m, p$	Region, activity type, abatement measure, pollutant, respectively
$E_{i,p}$	Emissions of pollutant $p$ (for SO <sub>2</sub> , NO <sub>x</sub> , VOC, NH <sub>3</sub> , PM <sub>2.5</sub> , CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O, etc.) in country $i$
$A_{i,k}$	Activity data level of type $k$ (e.g., coal consumption in power plants) in country $i$
$e_{i,k,m,p}$	Emission factor of pollutant $p$ for activity $k$ in country $i$ after application of control measure $m$
$x_{i,k,m,p}$	Share of total activity of type $k$ in country $i$ to which a control measure $m$ for pollutant $p$ is applied

GAINS estimates future emissions according to Equation (1) by varying the activity levels along exogenous projections of anthropogenic driving forces and by adjusting the implementation rates of emission control measures.

Such approach allows capturing critical differences across economic sectors and countries that could justify differentiated emission reduction requirements in a cost-effective strategy. Both the country-specific activity levels and source-specific emission factors reflect the major structural differences in emission induced by specific sources and fuels, thereby accounting for the level at which emission abatement measures are applied. Additional information on the estimations of emissions per pollutant can be found under the page [Technical reports](#).

## 2.2.2 Costs

This Section details the cost calculation in GAINS and the various assumptions underlying such computations.

The cost evaluation in GAINS attempts to quantify the values to society of diverting resources to reduce emissions in Europe. In practice, these values are approximated by estimating costs at the production level rather than at the consumption one. Therefore, any mark-ups charged over production costs by manufacturers or dealers do not represent actual resource uses and are ignored. Any taxes added to production costs are similarly ignored as subsidies as they are transfers and not resource costs.

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

Some of the parameters are considered common to all countries. These include technology specific data, such as removal efficiencies, unit investment costs, and non-labor operating and maintenance costs. However, local circumstances lead to justifiable differences in the actual costs at which a given technology removes pollution at different sources. Country-specific parameters considered in the cost calculation routine include, inter alia, labor costs, energy prices, size distributions of plants, plant utilization, fuel quality, animal fodder prices, paper collection rates, composting rates, the state of technological development, and the extent to which emission control measures are already applied.

Overall net expenditures for emission controls can be divided into **Investments**; **Operating and Maintenance costs (OM)**; and **Cost-savings**. Out of these three components presented next, the annual costs per unit of activity level can finally be derived.

### Investments

The investments include the fixed capital costs associated with the control option.

Such capital investments are annualized according to the following equation:

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

where:

$I^{an}$	Annual capital investment
$lt$	Technology-specific lifetime of the installation
$q$	Discount rate

The discount rate  $q$  depends on the considered application: whereas a rate of 4%/year would be used for cost-effectiveness analyses from a social planners perspective, rates typically ranging between 10-20%/year would rather be used when exploring the perspectives of profit-oriented private investors.

### Operating and Maintenance costs (OM)

OM costs include all variable costs associated with a control measure. These are typically composed of material, energy and labor costs for operation of the pollution control equipment, as well as costs for operating installations for recovery and utilization or flaring of gas, or for separating and collecting waste.

The annual OM costs are derived as follows:

$$OM = L + M = a_L \cdot OM + a_M \cdot OM \quad (2)$$

where:

$L$	Annual labor costs
$M$	Annual material and energy costs
$a_L$	Share of annual labor costs in the total OM costs
$a_M$	Share of annual material and energy costs in the total OM costs

While material costs are not assumed to vary between countries, labor costs are country-specific.

### Cost-savings

Cost-savings primarily emerge from the sale of by-products (e.g. gypsum, compost), reduced energy demand (e.g. with more efficient appliances), reduced losses (e.g. from leakages) and other productivity increases. Avoided costs for waste disposal when waste is recycled or composted are also included as cost-savings.

Using these 3 elements constituting the overall net expenditures, the annual costs per unit of activity level, i.e. the so-called **unit costs of abatement** ( $ca$ ) can be computed:

$$ca_{i,k,m} = \frac{I_{i,k,m}^{an} + OM_{i,k,m}^{fix}}{A_{i,k}} + OM_{i,k,m}^{var} - S_{i,k,m} \quad (3)$$

where:

$i, k, m$	Region, activity type, abatement measure, respectively
$OM^{fix}$	Fixed operating and maintenance costs
$OM^{var}$	Variable operating and maintenance costs
$S_{i,k,m}$	Cost-savings for activity $k$ in country $i$ after application of control measure $m$
$A_{i,k}$	Activity level of type $k$ (e.g., coal consumption in power plants) in country $i$

## 2.2.3 Impacts

This Section describes the qualitative and quantitative framework surrounding the various types of impacts calculated in GAINS.

The calculation of ambient pollution concentrations and associated health and environmental impacts in GAINS relies on linearized approximations of atmospheric Chemistry-Transport Models (CTMs) based on sensitivity simulations. Specific established methodologies are followed to calculate the respective environmental and health indicators from gridded concentrations and deposition rates.

Contrary to emission calculations, the calculations of impacts do not follow one unified methodology globally but rather use different versions of CTMs which are region-dependent. Furthermore, not all endpoints are calculated in all regions.

### Ambient air pollution concentrations

The resulting emissions of all precursor emissions of PM<sub>2.5</sub> in ambient air, such as primary PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub> and volatile organic compounds (VOCs), are input into an atmospheric dispersion model to compute annual mean concentrations of PM<sub>2.5</sub> across the globe. GAINS employs reduced-form source-receptor relationships derived from the EMEP atmospheric CTM (see Simpson et al., 2012 [11]) hosted by the Norwegian Meteorological Institute since the beginning of the EMEP Programme in 1979. Resulting concentration fields distinguishing about 6000 individual cities with more than 100, 000 inhabitants, are then compared with air quality standards, and the corresponding population exposure is computed for the population distribution assumed in the socio-economic projection. In national and local versions of GAINS, different atmospheric models have been used, such as the Flexible Air quality Regional Model (FARM) in GAINS-Italy, AERMOD model in GAINS-Vietnam, or the Comprehensive Air Quality Model with extensions (CAMx) in GAINS-JET for South-Africa.

The atmospheric transfer coefficients used in GAINS are usually based on full year simulations of the EMEP CTM. Those coefficients describe the relationship between one unit of emissions of a given pollutant emitted in one source region (and possibly one source sector) and the related change in ambient concentrations of pollution (e.g.,  $PM_{2.5}$  or  $O_3$ ) on a receptor grid, taking into account the dispersion of emissions and all relevant chemistry in ambient air:

$$q_j = \delta_j + \sum_r \sum_p E_{i,p} \cdot T_{i,p,j} \quad (1)$$

where:

$i, p,$	Region, pollutant, receptor grid cell respectively
$j$	
$E_{i,p}$	Emissions of pollutant $p$ in region $i$
$T_{i,p,j}$	Transfer coefficient for region $i$ , pollutant $p$ , and receptor grid cell $j$
$\delta_j$	Grid-specific constant arising from natural background concentrations, inflow from outside the domain, and linearization effects due to the non-linear atmospheric chemistry
$q_j$	Concentrations $q$ in receptor grid cell $j$

Transfer coefficients are typically derived from perturbation simulations of atmospheric models, where a base case (*base*) is run, and then reduction runs (*red*) are performed, reducing emissions of one pollutant from one source region at a time. The response in terms of ambient concentration (or deposition) changes are recorded and used for a linear approximation as follows:

$$T_{i,p,j} = \frac{q_{base}(j) - q_{red}(j)}{E_{base}(r,p) - E_{red}(r,p)} \quad (2)$$

The receptor grid  $j$  is typically a regular Eulerian grid defined by the respective atmospheric model. Its spatial resolution must be suitable for calculating the impact indicators such as population exposure for calculating human health impacts or deposition for calculating ecosystem impacts. However, the suitable resolution depends on the pollutant and the indicator being considered. In GAINS, we follow the approach that the spatial resolution of the underlying atmospheric calculations should be detailed enough so that the population exposure calculated by GAINS within one region is similar to that calculated with a high-resolution atmospheric model:

$$\sum_j c_{p,j} \cdot pop_j \approx \sum_{jfine} c_{p,jfine} \cdot pop_{jfine} \quad (3)$$

where:

$p, j, j_{fine}$	Pollutant, receptor grid cell, and receptor grid cell of a high-resolution atmospheric CTM respectively
$c_{p,j}$	Concentration of a pollutant $p$ in the receptor grid cell $j$
$pop_j$	Population in receptor grid cell $j$

The details of the atmospheric model version and setups for deriving the atmospheric coefficients differ between individual model interfaces and domains. More information can be found on the [GAINS](#) model directly.

## Human health impacts

The [GAINS](#) model quantifies human health impacts from three different routes:

- Exposure to ambient fine particulate matter ( $PM_{2.5}$ )
- Exposure to ground-level ozone
- Exposure to nitrogen dioxide ( $NO_2$ )

The following pages detail the impact methodology for each of those impact endpoints.

### Fine particulate matter ( $PM_{2.5}$ )

For a specific scenario and year, the GAINS model computes mortality related indicators attributed to chronic exposure to ambient  $PM_{2.5}$  for five major diseases: Ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), lung cancer, and acute lower respiratory infections (ALRI). The three mortality metrics considered in [GAINS](#) are:

- The number of premature (attributable) deaths
- The shortening of life expectancy
- The number of life years lost

### Premature (attributable) deaths

Similarly to the Global Burden of Disease (GBD) project, estimations of excess number of deaths associated with ambient fine particulate matter ( $PM_{2.5}$ ) in GAINS are based on a *Comparative Risk Assessment* (CRA) methodology. Within the CRA, the change in population health outcomes are estimated under alternative scenarios based on a counterfactual distribution of exposure to a risk factor over time and using Population Attributable Fractions (PAFs). The CRA of the mortality burden from ambient  $PM_{2.5}$  can be divided into the 5 following components:

1. **Baseline ambient fine particulate matter concentrations:** The pollutant concentrations are estimated in [GAINS](#) and validated against monitoring data for background concentrations.
2. **Estimates of the distribution of population exposure to ambient fine particulate matter:** Population weighted exposure is ascertained by superimposing ambient  $PM_{2.5}$  concentration levels with gridded and total projected population data for each country/region on the same grid. These projections rely on finely gridded population data sourced from the University of Southampton's [WorldPop](#) dataset. To align with scenario years, these projections incorporate trends in both urban and rural population changes from the [UN World Urbanization Prospects](#) (2018 revision).
3. **Baseline death rates and population size by cause, age and potentially sex:** Baseline age-specific total mortality data in [GAINS](#) are derived from the [UN World Population Prospects 2017](#). For regions outside Europe, data on cause-specific shares of disease contributions to total baseline mortality are derived from the GBD 2021 database.

4. **Exposure-Response Functions (ERFs):** GAINS uses two different ERFs depending on the region of analysis in Europe and outside Europe. As the latter require regular evaluation and update to incorporate new scientific evidence, ERFs in GAINS have been changing over time following the latest World Health Organization (WHO) or GBD methodology. Typically based on data from pooled cohorts or meta-analyses from cohorts and case-control studies from multiple epidemiological studies in different populations, ERFs are represented by Relative Risk (RR) functions, which show the ratio of the probability of death at a certain age given a specific exposure to the probability of death at that age assuming a counterfactual exposure:

$$D_{BL,d,a}(PM_{2.5}) = D_0 \cdot RR(PM_{2.5}) \quad (1)$$

where:

$BL, d, a$	Baseline, disease, age, respectively
$D_{BL,d,a}(PM_{2.5})$	Number of deaths under elevated $PM_{2.5}$ concentrations (baseline total deaths) at age $a$ and disease $d$
$D_0$	Hypothetical number of deaths under a counterfactual level (“clean” level)
$RR_{d,a}(PM_{2.5})$	Relative risk for a given level of $PM_{2.5}$ at age $a$ and disease $d$

5. **Reference (counterfactual) exposure level:** GAINS uses distinct counterfactuals for regions in and outside Europe. Outside Europe, GAINS uses the Theoretical Minimum Risk Exposure Level (TMREL) as the counterfactual. The TMREL is the level of ambient  $PM_{2.5}$  exposure below which its relationship with a disease outcome is not supported by the available evidence, irrespective of whether it is currently attainable in practice. At the TMREL the risk of the exposed population is minimised, and hence maximum population-attributable burden is captured. In Europe, GAINS uses the sum of all natural contributions (dust and sea salt) as counterfactual for ambient  $PM_{2.5}$ .

The actual number of additional deaths (“premature” or attributable deaths) caused by  $PM_{2.5}$  exposure is obtained using Population Attributable Fraction (PAF), directly derived from RR functions:

$$D_{PM,d,a} = D_{BL,d,a} - D_0 \quad (2.1)$$

$$= D_{BL,d,a} \cdot \frac{RR_{d,a} - 1}{RR_{d,a}} \quad (2.2)$$

$$= D_{BL,d,a} \cdot PAF_{d,a} \quad (2)$$

where:

$D_{PM,d,a}$	Number of deaths attributable to $PM_{2.5}$ concentrations (“premature deaths”) at age $a$ and disease $d$
$PAF_{d,a}$	Population attributable fraction for a given disease $d$ and age $a$

## Years of Life Lost (YLLs)

The YLL metric is a measure for the total loss of human life span in a given region due to the exposure to  $PM_{2.5}$  in a given year. YLLs are calculated by multiplying age-specific attributable deaths with the remaining life expectancy at this age and summing over all ages:

$$YLL_i = \sum_a pd_{i,a} \cdot lex_{i,a} \quad (3)$$

where:

$i, a$	Region, age respectively
$YLL_i$	Years of life lost in region $i$
$pd_{i,a}$	Premature deaths attributable to $PM_{2.5}$ at age $a$ in region $i$
$lex_{i,a}$	Remaining life expectancy at age $a$ in region $i$

The remaining life expectancy is retrieved from life tables from the [UN World Population Prospects 2017](#).

### Loss of life expectancy

Loss of life expectancy is calculated from exposure to ambient PM<sub>2.5</sub> using a Cox proportional hazards model. [5] Assuming that air pollution only affects natural mortality (about 95% of deaths excluding accidents and suicides) and cohort exposure is being kept constant for the whole lifetime, the age-specific relative risk of dying for adults is expressed as follows using a first-order Taylor expansion with  $\beta \ll 1$ :

$$RR_{PM} = \exp(\beta \cdot [PM]) \approx 1 + \beta \cdot [PM] \quad (4)$$

where:

$\beta$	Coefficient $\ll 1$ expressed in $\mu g/m^3$
$RR_{PM}$	Relative risk function related to the level of $PM_{2.5}$

Cohort- and country-specific mortality data extracted from life table statistics from the [UN World Population Prospects 2017](#) are used to calculate for each cohort the baseline survival function over time. When modified by the exposure to ambient  $PM_{2.5}$ , the latter can be expressed as follows:

$$l_c(t) = \exp\left(-\sum_{z=c}^t \mu_{z,z-c+w_0}\right) \quad (5)$$

$$\bar{l}_c(t) = \exp\left(-(1 + \beta[PM]) \sum_{z=c}^t \mu_{z,z-c+w_0}\right) \quad (6)$$

where:

$t, c,$	Time, age of cohort, starting age (30 years) respectively
$w_0$	
$l_c(t)$	Baseline survival function indicating the percentage of a cohort aged $c$ alive after time $t$ elapsed since starting time $w_0$
$\bar{l}_c(t)$	Baseline survival function modified by the exposure to $PM_{2.5}$
$\mu_{a,b}$	Mortality rates derived from each country from life tables with $a$ as age and $b$ as calendar time

Following a methodology introduced by Pope et al. [10], it is assumed in [GAINS](#) that an increased risk applies only to people older than  $w_0 = 30$  years. The life expectancy  $e_c$  is then calculated as the integral over the remaining life time of the baseline survival function modified by the exposure to  $PM_{2.5}$ :

$$e_c(t) = \int_c^{w_1} \bar{l}_c(t) dt \quad (7)$$

where:

$w_1$	The maximum age considered (100 years)
$e_c$	Life expectancy of a cohort $c$

The change in life expectancy  $\Delta e_c$  in a cohort aged  $c$  due to  $PM_{2.5}$  is then calculated as follows:

$$\Delta e_c \approx \beta[PM] \int_c^{w_1} l_c(t) \cdot \log l_c(t) dt \quad (8)$$

where:

$\Delta e_c$	Change in life expectancy of a cohort c
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For all cohorts in a GAINS region  $i$ , the change in life expectancy  $\Delta e_i$  is eventually calculated as the averages of the change in life expectancy for the cohorts living in the  $7 \times 7 \text{ km}^2$  grid cells  $k$  of that region  $i$ :

$$\Delta e_i = \sum_{c=w_0}^{w_1} \frac{Pop_{c,i}}{Pop_{k,i}} \Delta e_{c,k} \quad (9)$$

where:

$\Delta e_i$	Change in life expectancy for all cohorts in region $i$
$\Delta e_{c,k}$	Change in life expectancy in cohorts aged $c$ living in grid cell $k$ of region $i$
$Pop_{c,i}$	Population in cohorts aged $c$ in region $i$
$Pop_{k,i}$	Total population in grid cell $k$ in region $i$

## Ground-level ozone

The UNECE/WHO Task Force on Health recommended the use of the SOMO35 as a relevant ozone indicator for health impact assessments (UNECE/WHO 2003). SOMO35 is calculated as the sum over the year of the daily 8-h maximum ozone concentrations in excess of a 35 ppb threshold. Based on a comprehensive meta-analysis of time series studies conducted for the World Health Organization [4] and on advices received from the UNECE/WHO Task Force on Health, the GAINS model quantifies premature mortality through an association with the SOMO35 indicator. Contrary to  $PM_{2.5}$  GAINS does not quantify the loss of life expectancy or Years of Life Lost from exposure to ground-level ozone but only mortality impacts.

The GAINS calculation estimates the full-year daily changes in mortality as a function of daily 8-h maximum ozone concentrations, employing the concentration-response curves derived in the above-mentioned meta-analysis. The annual cases of premature mortality attributable to ozone in receptor region  $k$  are then calculated as follows:

$$pd(k) = \frac{1}{365} d_{BL}(k) \cdot (RR_{O_3}(k) - 1) = \frac{1}{365} d_{BL}(k) \cdot SOMO35(k) \cdot \beta_{O_3} \quad (2.3)$$

where:

$d_{BL}(k)$	Natural-cause baseline annual total deaths in region $k$
$SOMO35(k)$	Population-weighted mean SOMO35 exposure in region $k$ expressed in $\mu g^{-3} \cdot d$
$\beta_{O_3}$	Risk coefficient corresponding to changes in relative risk for 1 $\mu g^{-3} \cdot d$ increase in exposure

Note that, in GAINS v4.0.3, the relative risk devised by Orellano et al. [9] has been implemented and will be updated pending advice from the World Health Organization in the upcoming HRAPIE2 assessment.

## Nitrogen dioxide ( $NO_2$ )

Beyond its contribution to secondary  $PM_{2.5}$  formation and the associated health impacts, recent epidemiological evidence has shown that there are health impacts of exposure to  $NO_2$  itself. [6] The recently revised GAINS-Europe transfer coefficients from 2022 have allowed the calculation of exposure to  $NO_2$  well enough to attempt a quantification of  $NO_2$ -related mortality in GAINS. These impact assessments have been included in the Clean Air Outlook 3 [8] but are not yet operational in the GAINS model.

## Ecosystems impacts

Within the European domain and East Asia domains, GAINS quantifies the deposition of total nitrogen (N) as the sum of oxidized ( $NO_x$ ) and reduced ( $NH_y$ ) nitrogen compounds, as well as deposition of sulfur, using linear transfer coefficients from the EMEP CTM. For quantifying ecosystems risks from acidification and eutrophication, the GAINS models employ the critical loads approach, with Critical Loads (CL) being defined to characterise the vulnerability of (parts of) an ecosystem in terms of deposition. If the CL of pollutant X at a given location is smaller than the deposition of X at that location, it is said that the CL is *exceeded* and the difference is called *exceedance*.

## Eutrophication

For a critical load of eutrophication  $CL_{eut}N$  (also called CL of nutrient N), the exceedance  $Ex_{eut}N$  for a deposition  $N_{dep}$  is calculated as:

$$Ex_{eut}(N_{dep}) = \max\{0, N_{dep} - CL_{eut}N\} = \begin{cases} N_{dep} - CL_{eut}N & \text{if } N_{dep} > CL_{eut}N \\ 0 & \text{if } N_{dep} \leq CL_{eut}N \end{cases} \quad (1)$$

where:

$N_{dep}, CL_{eut}N$	N deposition and Critical Load of N for eutrophication respectively
$Ex_{eut}(N_{dep})$	Exceedance of N eutrophication Critical Load for a given N deposition $N_{dep}$

In case exceedances are negative, they are simply set to zero.

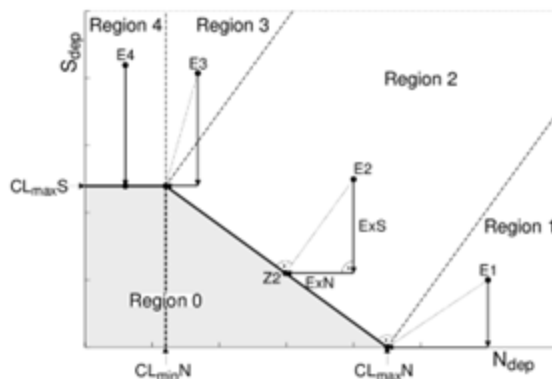
## Acidification

For acidification impacts, there is no unique critical load of S and N acidity. Instead, acidity CL are defined by a trapezoidal-shaped critical load function (CLF), defined by the quantities  $CL_{max}S$ ,  $CL_{min}N$ , and  $CL_{max}N$ . Thus, the exceedance is defined as the sum of the N- and S-deposition reductions needed to reach the closest point on the CLF, with zero exceedance for deposition pairs  $(N_{dep}, S_{dep})$  lying below the CLF (see below Figure 1).

**Figure 1** Critical Load Function (CLF) for acidifying Sulfur and Nitrogen defined by  $CL_{max}S$ ,  $CL_{min}N$ , and  $CL_{max}N$  (thick black line). The grey-shaded area below the CLF (region 0) defines deposition pairs  $(N_{dep}, S_{dep})$  for which there is non-exceedance. The points *E1* to *E4* refer to deposition pairs in four different regions and the way the exceedance  $(N_{ex}, S_{ex})$  is computed for a point in Region 2.

Given the above Figure 1, the exceedance of N and S acidity CLs is obtained as follows:

$$Ex_{ac}(N_{dep}, S_{dep}) = \begin{cases} 0 & \text{if } (N_{dep}, S_{dep}) \in \text{Region 0} \\ N_{dep} - CL_{max}N + S_{dep} & \text{if } (N_{dep}, S_{dep}) \in \text{Region 1} \\ N_{dep} - N_0 + S_{dep} - S_0 = (N_{ex}, S_{ex}) & \text{if } (N_{dep}, S_{dep}) \in \text{Region 2} \\ N_{dep} - CL_{min}N + S_{dep} - CL_{max}S & \text{if } (N_{dep}, S_{dep}) \in \text{Region 3} \\ S_{dep} - CL_{max}S & \text{if } (N_{dep}, S_{dep}) \in \text{Region 4} \end{cases} \quad (2)$$



where:

$N_0, S_0, N_{dep}, S_{dep}, CL_{max}S, CL_{min}N$	$N$ and $S$ deposition for point $Z_2$ , $N$ and $S$ deposition, maximum Critical Load of $S$ , and minimum and maximum Critical Load of $N$ respectively
$Ex_{ac}(N_{dep}, S_{dep})$	Exceedance of $N$ and $S$ acidity Critical Load for a given deposition pair $(N_{dep}, S_{dep})$

To obtain a single exceedance value for a given grid cell or an entire region, GAINS computes the *Average Accumulated Exceedance* (AAE), defined as follows:

$$AAE = \frac{\sum_{j=1}^n A_j Ex_j}{\sum_{j=1}^n A_j} \quad (3)$$

where:

$j, n$	Ecosystem, number of ecosystems respectively
$A_j$	Area of ecosystem $j$
$Ex_j$	Exceedance of $N$ or $S$ Critical Load for ecosystem $A_j$
AAE	Average Accumulated Exceedance of $N$ or $S$ Critical Load

The AAE is thus expressed as the area-weighted exceedance of the CLs for the individual ecosystems. To remain consistent with the latter definition,  $Ex_j$  needs to be set to zero if the CL is not exceeded.



## EXTENSIONS

The **GAINS model** offers several extension modules that provide additional functionalities and tools for enhanced analysis and optimization. These extensions can be utilized to customize and extend the capabilities of the **GAINS model** to suit specific research and policy needs. We encourage users to explore these extensions and leverage their functionalities to conduct in-depth analyses, optimize emission scenarios, and gain deeper insights into the interactions between energy systems, emissions, and policy interventions using the **GAINS model**.

### 3.1 PyGAINS

PyGAINS is a new project designed to enhance the accessibility and usefulness of the **GAINS model**. Its primary objective is to offer a Python implementation of the standard **GAINS** functionality, empowering **GAINS** users to work with specific datasets while enjoying complete flexibility to modify, aggregate, and visualize both model inputs and outputs.

PyGAINS is currently under development and not yet publicly available.

### 3.2 The **GAINS** optimization module

The **GAINS** model can also be used to identify cost-effective scenarios that meet predefined environmental or health objectives. For example, it can answer questions like:

- How much would it cost to reduce the number of premature deaths linked to fine particles by half in 2030 relative to 2010?
- Which measures in which sectors are the most cost-effective ones to reduce NO<sub>x</sub> emissions by 20%?

Such cost-effective solutions are identified using a mathematical procedure called optimization. The **GAINS** optimization is a separate module from the online model and can be used to explore the effects of different target setting options on the distribution of costs and benefits throughout the modeling domain. It can aid policy makers in exploring cost-effective policy options and address issues of economic efficiency and equity considerations as well. The optimization module is written in the GAMS programming language. Full operation of the module also requires **GAINS** database access and is currently only accessible internally.



## HELP AND RESOURCES

### 4.1 Library

This Section includes various additional resources relevant to the understanding of the GAINS model or some of its important policy applications.

#### 4.1.1 Training material

This Section will list future training materials developed to enhance capacity and expand the GAINS knowledge. Below are two hyperlinks to capacity-building websites created within the framework of specific projects: (i) the GAINS Strategic Partnerships for the Implementation of the Paris Agreement (SPIPA) project, and (ii) the GAINS Indo-Gangetic Plain (IGP) project.

##### Capacity building websites

- [SPIPA Workshop](#) (March 2021)
- [IGP Workshop](#) (October 2020)

#### 4.1.2 Technical Reports

This page presents a compilation of key technical reports that have been produced over time in the context of the GAINS model. These reports cover a range of topics related to emissions, abatement technologies, methodologies, and estimates generated by the GAINS model. Below is a selection of notable technical reports categorized by emission types for both air pollutants and greenhouse gases.

##### Air pollutants

##### NH<sub>3</sub> Emissions

The methodology for calculating NH<sub>3</sub> emissions is described in [Klimont Z. and Winiwarter W., \(2011\)](#). Integrated Ammonia Abatement - Modelling of Emission Control Potentials and Costs in GAINS. Additional information can be found in [Asman W.A.H, Klimont Z., and Winiwarter W., \(2011\)](#). A simplified model of nitrogen flows from manure management.

### NOx Emissions

The methodology for calculating NOx emissions is described in [Cofala J., and Syri S., \(1998\)](#). Nitrogen Oxides Emissions, Abatement Technologies and Related Costs for Europe in the RAINS Model Database.

### PM Emissions

Since incorporating the Particulate Matter (PM) component into the GAINS model, an array of reports and papers has emerged, documenting distinct facets of the model and its ongoing enhancements.

The latest comprehensive publication, which encompasses a global viewpoint, delves into the methods for estimating PM and associated emission factors, encompassing black carbon (BC) and organic carbon (OC). This paper also outlines the evolution of emissions between 1990 and 2010: [Klimont et al.,\(2017\)](#). Global anthropogenic emissions of particulate matter including black carbon.

The initial methodology for calculating PM emissions, encompassing cost estimation techniques, is meticulously expounded upon in the following IIASA report: [Klimont et al., \(2002\)](#). Modelling Particulate Emissions in Europe A Framework to Estimate Reduction Potential and Control Costs.

Moreover, the foundational methodology for computing primary black carbon (BC) and organic carbon (OC) emissions, complete with a comprehensive compendium of available measurement data and emission factors of that period, is encapsulated in the following IIASA report: [Kupiainen K. and Klimont Z., \(2004\)](#). Primary Emissions of Submicron and Carbonaceous Particles in Europe and the Potential for their Control. This endeavor culminated in the publication of the following pioneering paper presenting one of the initial assessments of European BC emissions: [Kupiainen K. and Klimont Z.,\(2007\)](#). Primary emissions of fine carbonaceous particles in Europe.

It is important to acknowledge that the emission factor values delineated in the aforementioned reports may not precisely mirror those in the current iteration of the model. This discrepancy arises from the continual evolution of the model's architecture and methodologies.

### SO2 Emissions

The methodology for calculating SO2 emissions in GAINS is described in [Cofala et al., \(1998\)](#). Sulfur Emissions, Abatement Technologies and Related Costs for Europe in the RAINS Model Database.

### VOC Emissions

The methodology for calculating Volatile Organic Compounds emissions is described in [Klimont, Z., Cofala J., and Amann M., \(2000\)](#). Estimating Costs for Controlling Emissions of Volatile Organic Compounds (VOC) from Stationary Sources in Europe.

Furthermore, recent information on emission controls in sectors regulated within the EU Solvent Directive has been incorporated into GAINS in collaboration with the [Task Force on Techno-Economic Issues \(TFTEI\)](#).

## Hg Emissions

The initial methodology for calculating Hg emissions in GAINS is described in Rafaj P., Bertok I., Cofala, J., and Schopp W., (2013). Scenarios of global mercury emissions from anthropogenic sources.

It is noteworthy that the mercury module of the GAINS model is presently undergoing enhancements to refine its accuracy and capabilities, aligning with the model's ongoing evolution.

## Greenhouse gases

### CO2 Emissions

The methodology for calculating CO2 emissions in GAINS is described in Klaassen G., Berglund C., Wagner F. (2005). The GAINS Model for Greenhouse Gases - Version 1.0: Carbon Dioxide (CO2).

### CH4 Emissions

Technical reports related to methane emissions are divided into the following:

- **Methodologies for calculating bottom-up inventory of CH4 between 1990-2020 & future projections to 2050:**
  1. Höglund-Isaksson et al., 2020. Technical potentials and costs for reducing global anthropogenic methane emissions in a 2050 timeframe.
  2. Höglund-Isaksson, 2012. Global anthropogenic methane emissions 2005-2030: Technical mitigation potentials and costs.
- **Methodology focused on European CH4 with technical mitigation potentials and costs:**
  1. Höglund-Isaksson et al., 2018. Non-CO2 greenhouse gas emissions in the EU-28 from 2005 to 2070 with mitigation potentials and costs –GAINS model methodology.
- **Methodology for CH4 emission factors for the oil and gas sector:**
  1. Höglund Isaksson, 2017. Bottom-up simulations of methane and ethane emissions from global oil and gas systems 1980 to 2012.
- **Other selected publications with GAINS estimates of CH4 emissions:**
  1. Saunio et al., 2020. The Global Methane Budget 2000-2017.
  2. Harmsen et al., 2019. Long-term marginal abatement cost curves of non-CO2 greenhouse gases.
  3. Gomez Sanabria et al., 2018. Carbon in global waste and wastewater flows – its potential as energy source under alternative future waste management regimes.

## Fluorinated Gases Emissions

The latest comprehensive publications addressing the incorporation of F-Gases into GAINS, also including global perspective and cost estimation methods, are the following:

- Purohit, P., and Höglund Isaksson L., (2017). Global emissions of fluorinated greenhouse gases 2005–2050 with abatement potentials and costs.
- Purohit P. et al., (2020). Electricity savings and greenhouse gas emission reductions from global phase-down of hydrofluorocarbons.

The initial methodology for calculating Fluorinated Gases emissions is meticulously expounded upon in the following IASA report: [Tohka A., \(2005\)](#). The GAINS Model for Greenhouse Gases – Version 1.0: HFC, PFC and SF6.

## **N2O Emissions**

Methodology of calculating N2O emissions has been initially described in [Winiwarter W., \(2005\)](#). The GAINS Model for Greenhouse Gases - Version 1.0: Nitrous Oxide (N2O).

Subsequent improvements have been documented, specifically in the Supplementary Material of [Winiwarter et al., \(2018\)](#). Technical opportunities to reduce global anthropogenic emissions of nitrous oxide.

### **4.1.3 Peer-reviewed papers**

This page presents a compilation of key selected peer-review documentation that have been produced over time in the context of the **GAINS** model. These papers cover a range of topics related to emissions, abatement technologies, methodologies, and estimates generated by the GAINS model. The list below is up-to-date as of November 20, 2023.

Davidson, E. A. & Winiwarter, W. (2023). Urgent abatement of industrial sources of nitrous oxide. *Nature Climate Change* **13**, 599–601 (2023) (In Press). <https://doi.org/10.1038/s41558-023-01723-3>

Harmsen, M., C. Tabak, L. Höglund-Isaksson, F. Humpenöder, P. Purohit, and D. van Vuuren, 2023. Uncertainty in non-CO2 greenhouse gas mitigation contributes to ambiguity in global climate policy feasibility. *Nature Communications* **14**, 2949 (2023). <https://doi.org/10.1038/s41467-023-38577-4>

Liu, Z., Rieder, H.E., Schmidt, C., Mayer, M., Guo, Y., Winiwarter, W., & Zhang, L. (2023). Optimal reactive nitrogen control pathways identified for cost-effective PM2.5 mitigation in Europe. *Nature Communications* **14** (1) e4246. <https://doi.org/10.1038/s41467-023-39900-9>

Mohajeri, N., Hsu, S.-C., Milner, J., Taylor, J., Kiesewetter, G., Gudmundsson, A., Kennard, H., Hamilton, I., et al. (2023). Urban–rural disparity in global estimation of PM2.5 household air pollution and its attributable health burden. *The Lancet Planetary Health* **7** (8) 660-672. [https://doi.org/10.1016/S2542-5196\(23\)00133-X](https://doi.org/10.1016/S2542-5196(23)00133-X)

Ru, M., Shindell, D., Spadaro, J., Lamarque, J.-F., Challapalli, A., Wagner, F., & Kiesewetter, G. (2023). New concentration-response functions for seven morbidity endpoints associated with short-term PM2.5 exposure and their implications for health impact assessment. *Environment International* **179** e108122. <https://doi.org/10.1016/j.envint.2023.108122>

Rychła, A., Amon, B., Hassouna, M., van der Weerden, T.J., & Winiwarter, W. (2023). Costs and effects of measures to reduce ammonia emissions from dairy cattle and pig production: A comparison of country-specific estimations and model calculations. *Journal of Environmental Management* **344** e118678. <https://doi.org/10.1016/j.jenvman.2023.118678>

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[Contributing author from GAINS: L. Höglund-Isaksson] Chapter 12: Cross-sectoral perspectives. IPCC Sixth Assessment Report Working Group III, Climate change 2022: Mitigation of Climate Change.

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Del Grosso, S.J., Ogle, S.M., Nevison, C., Gurung, R., Parton, W.J., Wagner-Riddle, C., Smith, W., Winiwarter, W., et al. (2022). A gap in nitrous oxide emission reporting complicates long-term climate mitigation. *Proceedings of the National Academy of Sciences* **119** (31) e2200354119. <https://doi.org/10.1073/pnas.2200354119>

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Shindell, D., L. Höglund-Isaksson, A.R. Ravishankara, B. Poulter, M. Saunio, S. Ragnauth, et al., 2022. Global Methane Assessment: 2030 Baseline Report. Climate and Clean Air Coalition (CCAC) by the United Nations Environment Programme (UNEP). <https://www.unep.org/resources/report/global-methane-assessment-2030-baseline-report>

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## 4.1.4 User Guide

The motivated users desiring to get hands-on experience with the model can explore the following [User Guide Tutorial](#). The [GAINS User Guide](#) is thoughtfully structured to cater to users with varying levels of familiarity and access to the model. The guide is divided into two main distinct parts, each respectively tailored to user groups having access to the Basic and Advances privileges of the model (see also the [Access rights/Installation](#) Section).

### Introduction and Basic Features (Basic Users)

The first part (Chapter 1) provides a comprehensive introduction to the GAINS model. It explains the model's utility, general principles, and objectives. This section outlines the scope of the GAINS online tool, guiding users in understanding its fundamental features and accessing the online tool. This part also functions as a tutorial for users interested in viewing IIASA's public domain assumptions and scenario results. Users in this category possess VIEWER privileges.

### User Privileges and Scenario Creation (Advanced Users)

The second part (Chapter 2) is geared towards users with USER privileges. This user group is empowered to craft GAINS scenarios under their ownership. The tutorial delves into advanced data management functions and editors. It covers aspects like creating new input data and organizing data sets into an emission scenario. The tutorial is accompanied by a series of screenshots that illustrate the sequence of operations required for scenario creation.

The GAINS User Guide skillfully blends reference manual-style explanations with step-by-step examples, catering to both new users and those looking to delve into more advanced operations.

## 4.1.5 References

## 4.2 Frequently Asked Questions (FAQ)

This Section includes frequently asked questions and their answers.

1. How to cite the GAINS model?

Should you publish any research results obtained through the use of the GAINS model, please cite GAINS as in the [References](#) section, under [2]: Amann, M., et al. (2011). Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. *Environmental Modelling & Software*, 26(12):1489–1501. If you are working with a specific (set of) scenario(s), please contact the [GAINS Developer](#) team, who will provide you with a citable DOI.

## 4.3 Glossary

This glossary provides explanations for abbreviations of the regions, sectors, and activities used in the GAINS model.

### 4.3.1 Regions

The GAINS model encompasses 183 regions, all of which are covered by the *global version*. Below, you can explore specific model instances and find out which regions they include.

#### GAINS Global

Abbreviation	Region
AFGH_WHOL	Afghanistan (Islamic Republic of)
ALBA_WHOL	Albania
ARGE_WHOL	Argentina
ARME_WHOL	Armenia
AUST_WHOL	Austria
AUTR_WHOL	Australia
AZER_WHOL	Azerbaijan
BANG_DHAK	Bangladesh Dhaka
BANG_REST	Bangladesh Rest of Bangladesh
BELA_WHOL	Belarus
BELG_WHOL	Belgium
BHUT_WHOL	Bhutan
BOHE_WHOL	Bosnia and Herzegovina
BOLV_WHOL	Bolivia
BRAZ_WHOL	Brazil
BRUN_WHOL	Brunei
BULG_WHOL	Bulgaria
CAMB_WHOL	Cambodia
CANA_WHOL	Canada
CARB_WHOL	Caribbean
CEAM_WHOL	Central America
CHIL_WHOL	Chile
CHIN_ANHU	China Anhui
CHIN_BEIJ	China Beijing
CHIN_CHON	China Chongqing
CHIN_FUJI	China Fujian
CHIN_GANS	China Gansu
CHIN_GUAD	China Guangdong
CHIN_GUAX	China Guangxi
CHIN_GUIZ	China Guizhou
CHIN_HAIN	China Hainan
CHIN_HEBE	China Hebei
CHIN_HEIL	China Heilongjiang
CHIN_HENA	China Henan
CHIN_HONG	China Hong Kong & Macau
CHIN_HUBE	China Hubei
CHIN_HUNA	China Hunan
CHIN_JILI	China Jilin
CHIN_JINU	China Jiangsu
CHIN_JINX	China Jiangxi
CHIN_LIAO	China Liaoning
CHIN_NEMO	China Inner Mongolia
CHIN_NINX	China Ningxia

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Table 4.1 – continued from previous page

Abbreviation	Region
CHIN_QING	China Qinghai
CHIN_SHAA	China Shaanxi
CHIN_SHAN	China Shanghai
CHIN_SHND	China Shandong
CHIN_SHNX	China Shanxi
CHIN_SICH	China Sichuan
CHIN_TIAN	China Tianjin
CHIN_TIBE	China Tibet (Xizang)
CHIN_XING	China Xinjiang
CHIN_YUNN	China Yunnan
CHIN_ZHEJ	China Zhejiang
COLO_WHOL	Colombia
CROA_WHOL	Croatia
CYPR_WHOL	Cyprus
CZRE_WHOL	Czech Republic
DENM_WHOL	Denmark
EAFR_WHOL	Eastern Africa (excl Kenya, Tanzania)
ECUA_WHOL	Ecuador
EGYP_WHOL	Egypt
ESTO_WHOL	Estonia
FINL_WHOL	Finland
FRAN_WHOL	France
FSUA_WHOL	Other Former USSR, Asia
GEOR_WHOL	Georgia
GERM_WHOL	Germany
GREE_WHOL	Greece
HUNG_WHOL	Hungary
ICEL_WHOL	Iceland
INDI_ANPR	India Andhra Pradesh
INDI_ASSA	India Assam
INDI_BENG	India West Bengal
INDI_BIHA	India Bihar
INDI_CHHA	India Chhattisgarh
INDI_DELH	India Delhi
INDI_EHIM	India North East (excl. Assam)
INDI_GOA	India Goa
INDI_GUJA	India Gujarat
INDI_HARY	India Haryana
INDI_HIPR	India Himachal Pradesh
INDI_JHAR	India Jharkhand
INDI_KARN	India Karnataka
INDI_KERA	India Kerala
INDI_MAHA	India Maharashtra-Dadra-Nagar Haveli-Daman-Diu
INDI_MAPR	India Madhya Pradesh
INDI_ORIS	India Orissa
INDI_PUNJ	India Punjab (I)
INDI_RAJA	India Rajasthan
INDI_TAMI	India Tamil Nadu
INDI_UTAN	India Uttaranchal
INDI_UTPR	India Uttar Pradesh

continues on next page

Table 4.1 – continued from previous page

Abbreviation	Region
INDI_WHIM	India Jammu and Kashmir
INDO_JAKA	Indonesia Jakarta
INDO_JAVA	Indonesia Java
INDO_REST	Indonesia Rest of Indonesia
INDO_SUMA	Indonesia Sumatra
IRAN_WHOL	Islamic Republic of Iran
IREL_WHOL	Ireland
ISRA_WHOL	Israel
ITAL_WHOL	Italy
JAPA_CHSH	Japan Chugoku-Shikoku
JAPA_CHUB	Japan Chubu
JAPA_HOTO	Japan Hokkaido-Tohoku
JAPA_KANT	Japan Kanto
JAPA_KINK	Japan Kinki
JAPA_KYOK	Japan Kyushu-Okinawa
KAZA_WHOL	Kazakhstan
KENY_WHOL	Kenya
KORN_WHOL	Korea (North)
KORS_NORT	Korea (South) North
KORS_PUSA	Korea (South) Pusan
KORS_SEOI	Korea (South) Seoul-Inchon
KORS_SOUT	Korea (South) South
KOSO_WHOL	Kosovo
KYRG_WHOL	Kyrgyzstan
LAOS_WHOL	Laos
LATV_WHOL	Latvia
LITH_WHOL	Lithuania
LUXE_WHOL	Luxembourg
MACE_WHOL	North Macedonia
MALA_KUAL	Malaysia Kuala Lumpur
MALA_PENM	Malaysia Peninsular Malaysia
MALA_SASA	Malaysia Sarawak-Sabah
MALT_WHOL	Malta
MEXI_WHOL	Mexico
MIDE_WHOL	Middle East
MOLD_WHOL	Republic of Moldova
MONG_WHOL	Mongolia
MONT_WHOL	Montenegro
MYAN_WHOL	Myanmar
NAFR_WHOL	Northern Africa (excl Egypt)
NEPA_WHOL	Nepal
NETH_WHOL	Netherlands
NIGE_WHOL	Nigeria
NORW_WHOL	Norway
NZEL_WHOL	New Zealand
PAKI_KARA	Pakistan Karachi
PAKI_NMWP	Pakistan NW Frontier Provinces-Baluchistan
PAKI_PUNJ	Pakistan Punjab (P)
PAKI_SIND	Pakistan Sind
PARA_WHOL	Paraguay

continues on next page

Table 4.1 – continued from previous page

Abbreviation	Region
PERU_WHOL	Peru
PHIL_BVMI	Philippines Bicol-Visayas-Mindanao
PHIL_LUZO	Philippines Luzon
PHIL_MANI	Philippines Metro Manila
POLA_WHOL	Poland
PORT_WHOL	Portugal
ROMA_WHOL	Romania
RSAF_WHOL	Remaining Southern Africa
RUSS_ASIA	Russia Asian part
RUSS_EURO	Russia European part
SAAR_WHOL	Kingdom of Saudi Arabia
SAFR_WHOL	Republic of South Africa
SERB_WHOL	Serbia
SING_WHOL	Singapore
SKRE_WHOL	Slovak Republic
SLOV_WHOL	Slovenia
SPAI_WHOL	Spain
SRIL_WHOL	Sri Lanka
SWED_WHOL	Sweden
SWIT_WHOL	Switzerland
TAIW_WHOL	Taiwan
TAJI_WHOL	Tajikistan
TANZ_WHOL	Tanzania
THAI_BANG	Thailand Bangkok Metropolitan Region
THAI_CVAL	Thailand Central Valley
THAI_NEPL	Thailand NE Plateau
THAI_NHIG	Thailand N Highlands
THAI_SPEN	Thailand S Peninsula
TKME_WHOL	Turkmenistan
TURK_WHOL	Turkey
UKRA_WHOL	Ukraine
UNKI_WHOL	United Kingdom
URUG_WHOL	Uruguay
USAM_ALAS	USA Alaska
USAM_MAIN	USA excl. Alaska
UZBE_WHOL	Uzbekistan
VENE_WHOL	Venezuela
VIET_NORT	Vietnam North: Red River Delta-Hanoi
VIET_SOUT	Vietnam South: Mekong River Delta-Ho Chi Minh City
WAFR_WHOL	Western Africa (excl Nigeria)

## GAINS Europe

Abbreviation	Region
ALBA_WHOL	Albania
ARME_WHOL	Armenia
AUST_WHOL	Austria
AZER_WHOL	Azerbaijan
BELA_WHOL	Belarus
BELG_WHOL	Belgium
BOHE_WHOL	Bosnia and Herzegovina
BULG_WHOL	Bulgaria
CROA_WHOL	Croatia
CYPR_WHOL	Cyprus
CZRE_WHOL	Czech Republic
DENM_WHOL	Denmark
ESTO_WHOL	Estonia
FINL_WHOL	Finland
FRAN_WHOL	France
GEOR_WHOL	Georgia
GERM_WHOL	Germany
GREE_WHOL	Greece
HUNG_WHOL	Hungary
ICEL_WHOL	Iceland
IREL_WHOL	Ireland
ITAL_WHOL	Italy
KOSO_WHOL	Kosovo
LATV_WHOL	Latvia
LITH_WHOL	Lithuania
LUXE_WHOL	Luxembourg
MACE_WHOL	North Macedonia
MALT_WHOL	Malta
MOLD_WHOL	Republic of Moldova
MONT_WHOL	Montenegro
NETH_WHOL	Netherlands
NORW_WHOL	Norway
POLA_WHOL	Poland
PORT_WHOL	Portugal
ROMA_WHOL	Romania
RUSS_EURO	Russia European part
SERB_WHOL	Serbia
SKRE_WHOL	Slovak Republic
SLOV_WHOL	Slovenia
SPAI_WHOL	Spain
SWED_WHOL	Sweden
SWIT_WHOL	Switzerland
TURK_WHOL	Turkey
UKRA_WHOL	Ukraine
UNKI_WHOL	United Kingdom

## GAINS South-East Asia

Abbreviation	Region
BANG_DHAK	Bangladesh Dhaka
BANG_REST	Bangladesh Rest of Bangladesh
BHUT_WHOL	Bhutan
BRUN_WHOL	Brunei
CAMB_WHOL	Cambodia
CHIN_ANHU	China Anhui
CHIN_BEIJ	China Beijing
CHIN_CHON	China Chongqing
CHIN_FUJI	China Fujian
CHIN_GANS	China Gansu
CHIN_GUAD	China Guangdong
CHIN_GUAX	China Guangxi
CHIN_GUIZ	China Guizhou
CHIN_HAIN	China Hainan
CHIN_HEBE	China Hebei
CHIN_HEIL	China Heilongjiang
CHIN_HENA	China Henan
CHIN_HONG	China Hong Kong & Macau
CHIN_HUBE	China Hubei
CHIN_HUNA	China Hunan
CHIN_JILI	China Jilin
CHIN_JINU	China Jiangsu
CHIN_JINX	China Jiangxi
CHIN_LIAO	China Liaoning
CHIN_NEMO	China Inner Mongolia
CHIN_NINX	China Ningxia
CHIN_QING	China Qinghai
CHIN_SHAA	China Shaanxi
CHIN_SHAN	China Shanghai
CHIN_SHND	China Shandong
CHIN_SHNX	China Shanxi
CHIN_SICH	China Sichuan
CHIN_TIAN	China Tianjin
CHIN_TIBE	China Tibet (Xizang)
CHIN_XING	China Xinjiang
CHIN_YUNN	China Yunnan
CHIN_ZHEJ	China Zhejiang
INDI_ANPR	India Andhra Pradesh
INDI_ASSA	India Assam
INDI_BENG	India West Bengal
INDI_BIHA	India Bihar
INDI_CHHA	India Chhattisgarh
INDI_DELH	India Delhi
INDI_EHIM	India North East (excl. Assam)
INDI_GOA	India Goa
INDI_GUJA	India Gujarat
INDI_HARY	India Haryana
INDI_HIPR	India Himachal Pradesh
INDI_JHAR	India Jharkhand

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Table 4.3 – continued from previous page

Abbreviation	Region
INDI_KARN	India Karnataka
INDI_KERA	India Kerala
INDI_MAHA	India Maharashtra-Dadra-Nagar Haveli-Daman-Diu
INDI_MAPR	India Madhya Pradesh
INDI_ORIS	India Orissa
INDI_PUNJ	India Punjab (I)
INDI_RAJA	India Rajasthan
INDI_TAMI	India Tamil Nadu
INDI_UTAN	India Uttaranchal
INDI_UTPR	India Uttar Pradesh
INDI_WHIM	India Jammu and Kashmir
INDO_JAKA	Indonesia Jakarta
INDO_JAVA	Indonesia Java
INDO_REST	Indonesia Rest of Indonesia
INDO_SUMA	Indonesia Sumatra
JAPA_CHSH	Japan Chugoku-Shikoku
JAPA_CHUB	Japan Chubu
JAPA_HOTO	Japan Hokkaido-Tohoku
JAPA_KANT	Japan Kanto
JAPA_KINK	Japan Kinki
JAPA_KYOK	Japan Kyushu-Okinawa
KORN_WHOL	Korea (North)
KORS_NORT	Korea (South) North
KORS_PUSA	Korea (South) Pusan
KORS_SEOI	Korea (South) Seoul-Inchon
KORS_SOUT	Korea (South) South
LAOS_WHOL	Laos
MALA_KUAL	Malaysia Kuala Lumpur
MALA_PENM	Malaysia Peninsular Malaysia
MALA_SASA	Malaysia Sarawak-Sabah
MONG_WHOL	Mongolia
MYAN_WHOL	Myanmar
NEPA_WHOL	Nepal
PAKI_KARA	Pakistan Karachi
PAKI_NMWP	Pakistan NW Frontier Provinces-Baluchistan
PAKI_PUNJ	Pakistan Punjab (P)
PAKI_SIND	Pakistan Sind
PHIL_BVMI	Philippines Bicol-Visayas-Mindanao
PHIL_LUZO	Philippines Luzon
PHIL_MANI	Philippines Metro Manila
SING_WHOL	Singapore
SRIL_WHOL	Sri Lanka
THAI_BANG	Thailand Bangkok Metropolitan Region
THAI_CVAL	Thailand Central Valley
THAI_NEPL	Thailand NE Plateau
THAI_NHIG	Thailand N Highlands
THAI_SPEN	Thailand S Peninsula
VIET_NORT	Vietnam North: Red River Delta-Hanoi
VIET_SOUT	Vietnam South: Mekong River Delta-Ho Chi Minh City

### 4.3.2 Sectors

GAINS covers 364 sectors listed hereunder along with their corresponding abbreviations used in the model.

Abbreviation	Sector
AERO	Aerosols
AGR_ARABLE	Ploughing, tilling, harvesting
AGR_BEEF	Other cattle
AGR_COWS	Dairy cattle
AGR_COWS_MILK	Milk produced - dairy cows
AGR_OTANI	Other livestock (sheep, horses)
AGR_OTHER	Other agricultural emisisions
AGR_PIG	Pigs
AGR_POULT	Poultry
ALU_CWPB	Primary aluminium production: Centre Worked Pre-bake technology
ALU_PFPB	Primary aluminium production: Point Feeder Pre-bake technology
ALU_SWPB	Primary aluminium production: Side Worked Pre-bake technology
ALU_VSS	Primary aluminium production: Vertical Stud Soderberg technology
ANY	valid for all sectors (used in connection with population)
APPLIC_L	Manure application on large farms
APPLIC_M	Manure application on medium farms
APPLIC_S	Manure application on small farms
AUTO_P	Vehicles manufacturing
AUTO_P_NEW	Vehicles manufacturing (new plants)
AU_LGP	Large-scale gold production
AU_SGP	Small-scale artisanal gold production
CAC_B	Commercial air conditioning using water chilling, emissions banked in equip- ment
CAC_S	Commercial air conditioning using water chilling, emissions from scrapped equipment
COAL_ABAND	Abandoned coal mines
COIL	Coil coating
COMM_B	Commercial refrigeration, emissions banked in equipment
COMM_S	Commercial refrigeration, emissions from scrapped equipment
CONSTRUCT	Construction activities (fugitive)
CON_COMB	Transformation - combustion
CON_COMB1	Fuel conversion (grate firngr)
CON_COMB2	Fuel conversion (fluidized bed boiler)
CON_COMB3	Fuel conversion (pulverized bed boiler)
CON_LOSS	Transformation - losses
COWS_3000_MILK	Milk yield over 3000 kg/animal treshold
CROP_RESID	N from crops left on field
DECO_P	Decorative paints
DEGR	Degreasing
DEGR_NEW	Degreasing (new installations)
DOM	Residential-commercial
DOM_COM	Commercial (combustion)
DOM_COM_MB_A	Medium boilers (<50MW) - automatic (commercial)
DOM_COM_MB_M	Medium boilers (<1MW) - manual (commercial)
DOM_FPLACE	Fireplaces
DOM_LIGHT	Residential - kerosene lamps
DOM_MB_A	Medium boilers (<50MW) - automatic

continues on next page

Table 4.4 – continued from previous page

Abbreviation	Sector
DOM_MB_M	Medium boilers (<1MW) - manual
DOM_OS	Domestic use of solvents (other than paint)
DOM_OTH	Services, agriculture, etc.
DOM_OTH_FPLACE	Fireplaces (agr, forestry, other)
DOM_OTH_MB_A	Medium boilers (<50MW) - automatic (agr, forestry, other)
DOM_OTH_MB_M	Medium boilers (<1MW) - manual (agr, forestry, other)
DOM_OTH_PIT	Three-stone stove (agr, forestry, other)
DOM_OTH_SHB_A	Single house boilers (<50 kW) - automatic (agr, forestry, other)
DOM_OTH_SHB_M	Single house boilers (<50 kW) - manual (agr, forestry, other)
DOM_OTH_STOVE_C	Cooking stoves (agr, forestry, other)
DOM_OTH_STOVE_H	Heating stoves (agr, forestry, other)
DOM_PIT	Three-stone stove
DOM_RES	Residential
DOM_RES_FPLACE	Fireplaces (households)
DOM_RES_PIT	Three-stone stove (households)
DOM_RES_SHB_A	Single house boilers (<50 kW) - automatic (households)
DOM_RES_SHB_M	Single house boilers (<50 kW) - manual (households)
DOM_RES_STOVE_C	Cooking stoves (households)
DOM_RES_STOVE_H	Heating stoves (households)
DOM_RUR	Residential - rural
DOM_RURAL	Residential - rural
DOM_RUR_FPLACE	Rural Fireplaces (households)
DOM_RUR_PIT	Rural Three-stone stove (households)
DOM_RUR_SHB_A	Rural Single house boilers (<50 kW) - automatic (households)
DOM_RUR_SHB_M	Rural Single house boilers (<50 kW) - manual (households)
DOM_RUR_STOVE_C	Rural Cooking stoves (households)
DOM_RUR_STOVE_H	Rural Heating stoves (households)
DOM_S	Domestic small hermetic refrigerators, emissions from scrapped equipment
DOM_SHB_A	Single house boilers (<50 kW) - automatic
DOM_SHB_M	Single house boilers (<50 kW) - manual
DOM_STOVE_C	Cooking stoves
DOM_STOVE_H	Heating stoves
DOM_URB	Residential - urban
DOM_URBAN	Residential - urban
DOM_URB_FPLACE	Urban Fireplaces (households)
DOM_URB_PIT	Urban Three-stone stove (households)
DOM_URB_SHB_A	Urban Single house boilers (<50 kW) - automatic (households)
DOM_URB_SHB_M	Urban Single house boilers (<50 kW) - manual (households)
DOM_URB_STOVE_C	Urban Cooking stoves (households)
DOM_URB_STOVE_H	Urban Heating stoves (households)
DRY	Dry cleaning
DRY_NEW	Dry cleaning (new installations)
D_GASST	Gasoline distribution - service stations
D_REFDEP	Gasoline storage & distribution (excl. gasoline stations)
D_REFDEP_S	Gasoline storage & distribution (excl. transport sector)
EXD_GAS	Production & distribution of natural gas
EXD_GAS_NEW	Production & distribution of natural gas - new mains
EXD_LQ	Extraction of oil (incl delivery to terminals)
EXD_LQ_NEW	Extraction of oil (incl delivery to terminals; with recovery)
FATOIL	Fat and oil extraction (seeds)

continues on next page

Table 4.4 – continued from previous page

Abbreviation	Sector
FCON_OTHN	Mineral N fertilizers use (excl. urea)
FCON_UREA	Urea application (incl. ABC)
FERTPRO	Mineral N fertilizer production
FEXT_B	Fire extinguishers, emissions banked in equipment
FEXT_S	Fire extinguishers, emissions from scrapped equipment
FGAS_IND	Other F-gas industrial emissions (activity given as other FGAS emissions in kt)
FOOD	Food and drink industry
FOREST	Forest
GLUE_INH	Industrial application of adhesives (high performance)
GLUE_INT	Industrial application of adhesives (traditional)
GRASSLAND	Grassland and soils
GRAZE_L	Grazing on large farms
GRAZE_M	Grazing on medium farms
GRAZE_S	Grazing on small farms
GSHP_B	Ground source heat pumps, emissions banked in equipment
GSHP_S	Ground source heat pumps, emissions from scrapped equipment
HCFC22_E	HCFC-22 production for emissive use
HCFC22_F	HCFC-22 production for feedstock use
HELP	none
HFC_OTH	Other (solvents, fire extinguishers, etc.)
HISTOSOLS	Organic soils
HMVES	SF6 use in high and mid voltage switches
IND_B	Industrial refrigeration, including food and agricultural, emissions banked in equipment
IND_FOOD_COD	COD in wastewater - food manufacturing industry
IND_FOOD_NOC	Wastewater without treatment: food manufacturing industry
IND_FOOD_TRM	Wastewater with treatment: food manufacturing industry
IND_OS	Other industrial use of solvents
IND_OTH	Other industrial sources
IND_OTH_COD	COD in wastewater - other organic manufacturing industry
IND_OTH_NOC	Wastewater without treatment: other organics manufacturing industry
IND_OTH_TRM	Wastewater with treatment: other organics manufacturing industry
IND_PAP_COD	COD in wastewater - pulp and paper manufacturing industry
IND_PAP_NOC	Wastewater without treatment: pulp and paper manufacturing industry
IND_PAP_TRM	Wastewater with treatment: pulp and paper manufacturing industry
IND_P_CNT	Industrial paint use (continuous processes)
IND_P_OT	Industrial paint use (other)
IND_P_PL	Industrial paint use (plastic parts)
IND_S	Industrial refrigeration, including food and agricultural, emissions from scrapped equipment
INORG	Inorganic chemical industry
INW_FOOD	Solid waste: food manufacturing industry
INW_OTH	Solid waste: other manufacturing industry
INW_PAP	Solid waste: pulp and paper manufacturing industry
INW_RUB	Solid waste: rubber and plastics manufacturing industry
INW_TEX	Solid waste: textile manufacturing industry
INW_TOT	Solid waste from manufacturing industry (total)
INW_WOOD	Solid waste: wood manufacturing industry
IN_BO_CHEM	Chemical industry (boilers)
IN_BO_CON	Transformation sector (boilers)

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Table 4.4 – continued from previous page

Abbreviation	Sector
IN_BO_OTH	Other industry (boilers; liquid and gaseous fuels)
IN_BO_OTH_L	Other industry (large coal boilers; > 50 MWth )
IN_BO_OTH_S	Other industry (small coal boilers; < 50 MWth )
IN_BO_PAP	Paper & pulp (boilers)
IN_OC	Industrial furnaces
IN_OC1	Industry: Other combustion, grate firing
IN_OC2	Industry: Other combustion, fluidized bed
IN_OC3	Industry: Other combustion, pulverized
IN_OCTOT	Other industry (furnaces)
IN_OC_CHEM	Chemical industry (furnaces)
IN_OC_ISTE	Iron and steel (furnaces)
IN_OC_NFME	Non-ferrous metals (furnaces)
IN_OC_NMMI	Non-metallic minerals (furnaces)
IN_OC_OTH	Other Industry (furnaces)
IN_OC_PAP	Paper & pulp (furnaces)
IO_NH3_EMISS	Other industrial NH3 emissions
LARGE_AREA	Share of area occupied by large farms
LEAD_GASOL	Leaded gasoline
LEATHER	Leather coating
MACRO	Macro parameters ( Population, GDP, etc.)
MAGNPR	SF6 use in magnesium production and casting
MANURE	Manure treatment and manure distributed on soils
MEDIUM_AREA	Share of area occupied by medium size farms
MINE_BC	Brown coal mining
MINE_BC_POST	Mining: Brown coal -post-mining emissions
MINE_BC_PRE	Mining: Brown coal -pre-mining emissions
MINE_BC_VAM	Mining: Brown coal - ventilation air methane
MINE_HC	Hard coal mining
MINE_HC_POST	Mining: Hard coal -post-mining emissions
MINE_HC_PRE	Mining: Hard coal -pre-mining emissions
MINE_HC_VAM	Mining: Hard coal - ventilation air methane
MINE_OTH	Mining: Bauxite, copper, iron ore, other
MSW_FOOD	Municipal solid waste: food & garden
MSW_GLA	Municipal solid waste: glass
MSW_MET	Municipal solid waste: metals
MSW_OTH	Municipal solid waste: other waste
MSW_PAP	Municipal solid waste: paper
MSW_PLA	Municipal solid waste: plastics
MSW_RUR	Rural Municipal solid waste (total) generated
MSW_RUR_FOOD	Rural Municipal solid waste: food & garden
MSW_RUR_GLA	Rural Municipal solid waste: glass
MSW_RUR_MET	Rural Municipal solid waste: metals
MSW_RUR_OTH	Rural Municipal solid waste: other waste
MSW_RUR_PAP	Rural Municipal solid waste: paper
MSW_RUR_PLA	Rural Municipal solid waste: plastics
MSW_RUR_TEX	Rural Municipal solid waste: textiles
MSW_RUR_WOOD	Rural Municipal solid waste: wood
MSW_TEX	Municipal solid waste: textiles
MSW_TOT	Municipal solid waste (total)
MSW_URB	Urban Municipal solid waste (total) generated

continues on next page

Table 4.4 – continued from previous page

Abbreviation	Sector
MSW_URB_FOOD	Urban Municipal solid waste: food & garden
MSW_URB_GLA	Urban Municipal solid waste: glass
MSW_URB_MET	Urban Municipal solid waste: metals
MSW_URB_OTH	Urban Municipal solid waste: other waste
MSW_URB_PAP	Urban Municipal solid waste: paper
MSW_URB_PLA	Urban Municipal solid waste: plastics
MSW_URB_TEX	Urban Municipal solid waste: textiles
MSW_URB_WOOD	Urban Municipal solid waste: wood
MSW_WOOD	Municipal solid waste: wood
N2O_USE	Use of nitrous oxide
NONEN	Nonenergy use of fuels
OC	Polyurethane one component foam
OF	Other foam
ORG_STORE	Organic chemical industry - storage
OTHER_CH4	Other CH4 emissions not included separately in GAINS and statistical differences
OTHER_CO	Other CO emissions
OTHER_CO2	Other CO2 emissions
OTHER_FGAS	Other F-gas emissions (activity given as other FGAS emissions in kt)
OTHER_HG	Other Hg emissions
OTHER_N2O	Other N2O emissions
OTHER_NOX	Other NOx emissions
OTHER_PM	Other PM emissions
OTHER_SO2	Other SO2 emissions
OTHER_VOC	Other NMVOC emissions
OTH_NH3_EMISS	Other NH3 emissions (incl. humans & pets)
OTH_ORG_PR	Organic chemical industry - downstream units
PFC_OTH	PFC use in other applications including tyres, tennis balls, sport shoes and sometimes in the semiconductor industry
PHARMA	Pharmaceutical industry
PIS	Products incorporating solvents
PLSTYR_PR	Polystyrene processing
PP_ENG	Diesel generator sets
PP_EX_L	Power & district heat plants - existing coal (>50 MWth)
PP_EX_OTH	Power & district heat plants - existing (excl. coal)
PP_EX_S	Power & district heat plants - existing coal (<50 MWth)
PP_IGCC	Power & district heat plants - IGCC
PP_IGCC_CCS	Power & district heat plants - IGCC with CCS
PP_MOD	Modern power plants (coal: ultra & supercritical; gas: CCGT)
PP_MOD_CCS	Modern power plants (coal: ultra & supercritical; gas: CCGT) with CCS
PP_NEW	Power & district heat plants - new (excl. coal)
PP_NEW_L	Power & district heat plants - new coal (>50 MWth)
PP_TOTAL	Power & district heat plants (total)
PROCESSES	Industrial processes
PROD	Production of oil/gas
PROD_AGAS	Production of oil or gas: venting of flaring of APG
PROD_LEAK	Production of oil or gas: emissions from unintended leakage during extraction
PRT_OFFS	Offset printing (existing)
PRT_OFFS_NEW	Offset printing (new)
PRT_PACK	Flexography & rotogravure - packaging

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Table 4.4 – continued from previous page

Abbreviation	Sector
PRT_PACK_NEW	Flexography & rotogravure - packaging (new inst.)
PRT_PUB	Rotogravure in publication (existing)
PRT_PUB_NEW	Rotogravure in publication (new)
PRT_SCR	Screen printing (existing)
PRT_SCR_NEW	Screen printing (new)
PR_ADIP	adipic acid production
PR_ALPRIM	Aluminum production - primary
PR_ALSEC	Aluminum production - secondary
PR_AUP	Total gold production
PR_BAOX	Basic oxygen furnace
PR_BRICK	Brick production
PR_BRIQ	Briquettes production
PR_CAPR	Caprolactam
PR_CAST	Cast iron (grey iron foundries)
PR_CAST_F	Cast iron (grey iron foundries) (fugitive)
PR_CBLACK	Carbon black production
PR_CEM	Cement production
PR_COKE	Coke oven
PR_CSP	Chlorine & caustic soda production - electrolysis using mercury cells
PR_EARC	Electric arc furnace
PR_FERT	Fertilizer production
PR_GLASS	Glass production (flat, blown, container glass)
PR_HEARTH	Open hearth furnace
PR_LIME	Lime production
PR_NIAC	Nitric acid production
PR_OTHER	Production of glass fiber, gypsum, PVC, other
PR_OT_NFME	Non-ferrous metals prod. (excl aluminum)
PR_PELL	Agglomeration plant - pellets
PR_PIGI	Pig iron, blast furnace
PR_PIGI_F	Pig iron, blast furnace (fugitive)
PR_PULP	Paper pulp mills
PR_REF	Petroleum refineries
PR_SINT	Agglomeration plant - sinter
PR_SINT_F	Agglomeration plant - sinter (fugitive)
PR_SMIND_F	Small industrial and business facilities - fugitive
PR_SUAC	Sulfuric acid production
PVC_PR	Polyvinylchloride production by suspension process
RAC_B	Residential air conditioning using water chilling, emissions banked in equipment
RAC_S	Residential air conditioning using water chilling, emissions from scrapped equipment
RAILAC_B	Mobile air conditioning in railway coaches, emissions banked in equipment
RAILAC_S	Mobile air conditioning in railway coaches, emissions from scrapped equipment
RES_BBQ	Meat frying, food preparation, BBQ
RES_CIGAR	Cigarette smoking
RES_CREM	Traditional (open-air) cremation
RES_FIREW	Fireworks
RICE_FLOOD	Continuously flooded rice cultivation area
RICE_INTER	Intermittently flooded rice cultivation area
RICE_UPLAND	Upland (non-wetland) rice cultivation area
SEMICOND	PFC use in semiconductor industry

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Table 4.4 – continued from previous page

Abbreviation	Sector
SF6_OTH	SF6 use in other applications including tyres, tennis balls, sport shoes and sometimes in the semiconductor industry
SHOE	Manufacturing of shoes
SH_BIOF	Share of biofuel
SH_NONRICE_L	Share of mineral fertilizers applied on non-rice fields - large farms
SH_NONRICE_M	Share of mineral fertilizers applied on non-rice fields - medium farms
SH_NONRICE_S	Share of mineral fertilizers applied on non-rice fields - small farms
SH_RICE_L	Share of mineral fertilizers applied on rice fields - large farms
SH_RICE_M	Share of mineral fertilizers applied on rice fields - medium farms
SH_RICE_S	Share of mineral fertilizers applied on rice fields - small farms
SMALL_AREA	Share of area occupied by small size farms
SOLV_PEM	Solvents used in precision, electronics and metal cleaning
STCRACK_PR	Steam cracking (ethylene & propylene production)
STH_AGR	Storage & handling of agricultural crops
STH_COAL	Storage & handling of coal
STH_FEORE	Storage & handling of iron ore
STH_NPK	Storage & handling of N,P,K fertilizers
STH_OTH_IN	Storage & handling of other industrial bulk products
SWD_HIST	Historical solid waste disposal - prior to 1980
SYNTH_RUB	Synthetic rubber production
TRANS	Transmission of natural gas
TRANS_KM	Length of onshore gas transportation pipelines
TRA_F_CH4	Fugitive emissions from gas distribution to transport sector
TRA_OT	Non-road, other
TRA_OTS	Coastal shipping
TRA_OTS_L	Coastal shipping, large vessels
TRA_OTS_M	Coastal shipping, medium vessels
TRA_OT_AGR	Agriculture
TRA_OT_AIR	Aviation - LTO
TRA_OT_AIR_DOM	Domestic aviation
TRA_OT_CNS	Construction machinery
TRA_OT_EV	Non-road gasoline engines - evaporative
TRA_OT_INW	Inland waterways
TRA_OT_LB	Other non-road machinery
TRA_OT_LD2	2-stroke engines (non-road)
TRA_OT_RAI	Railways
TRA_RD	Road vehicles
TRA_RD_EV	Road - gasoline engines - evaporative
TRA_RD_HDB	Buses
TRA_RD_HDB_B	Mobile air conditioning in buses, emissions banked in equipment
TRA_RD_HDB_S	Mobile air conditioning in buses, emissions from scrapped equipment
TRA_RD_HDT	Heavy duty vehicles
TRA_RD_HDT_B	Mobile air conditioning in heavy duty trucks, emissions banked in equipment
TRA_RD_HDT_S	Mobile air conditioning in heavy duty trucks, emissions from scrapped equipment
TRA_RD_LD2	Mopeds
TRA_RD_LD4C	Cars
TRA_RD_LD4C_B	Mobile air conditioning in cars, emissions banked in equipment
TRA_RD_LD4C_EV	Cars - evaporative
TRA_RD_LD4C_S	Mobile air conditioning in cars, emissions from scrapped equipment

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Table 4.4 – continued from previous page

Abbreviation	Sector
TRA_RD_LD4T	Light duty vehicles
TRA_RD_LD4T_B	Mobile air conditioning in light duty trucks, emissions banked in equipment
TRA_RD_LD4T_EV	Light duty vehicles - evaporative
TRA_RD_LD4T_S	Mobile air conditioning in light duty trucks, emissions from scrapped equipment
TRA_RD_M4	Motorcycles
TRA_RD_OTH	Generic road vehicles as 3-wheelers and others
TRA_REFB	Refrigerated transport, emissions banked in equipment
TRA_REFS	Refrigerated transport, emissions from scrapped equipment
TYRES	Tyre production
VEHR_P	Vehicle refinishing
VEHR_P_NEW	Vehicle refinishing (new installations)
VEHTR	(De)Waxing and underbody treatment of vehicles
WASTE_AGR	Agricultural waste burning
WASTE_FLR	Flaring in refineries
WASTE_VOC	Waste treatment and disposal
WIND_B	SF6 use in soundproof windows
WIRE	Winding wire coating
WOOD	Wood preservation (excl. creosote)
WOOD_CR	Wood preservation (creosote)
WOOD_P	Wood coating
WT_NH3_EMISS	Waste treatment and disposal (incl. sludge application)
WW_DOM	Domestic wastewater
WW_DOM_CC_NOC	Domestic wastewater: centralized collection without treatment
WW_DOM_CC_TRM	Domestic wastewater: centralized collection with treatment
WW_DOM_DC_NOC	Domestic wastewater: decentralized collection without treatment
WW_DOM_DC_TRM	Domestic wastewater: decentralized collection with treatment

### 4.3.3 Activities

GAINS comprises 147 activities listed hereunder with their corresponding abbreviations used in the model.

Abbreviation	Activity
ABRASION	Road abrasion
ADH	Adhesives
ARD	Agricultural residues
AREA	Area of activity
BC1	Brown coal/lignite grade 1
BC2	Brown coal/lignite grade 2 (also peat)
BGS	Bagasse
BIOG	Biogas
BLIQ	Black liquor
BMG	Biomass gasification
BRAKE	Brake wear
BS	Buffalos
CB_GAS	Coalbed gas
CHCOA	Charcoal
CM	Camels
CRU	Crude oil

continues on

Table 4.5 – continued from previous page

Abbreviation	Activity
CTG	Coating
DC	Derived coal (coke, briquettes)
DL	Dairy cows - liquid systems
DL_F	Dairy cows - liquid (slurry) systems - enteric fermentation
DNG	Dung
DS	Dairy cows - solid systems
ELE	Electricity
ELE_KM	Kilometres travelled on Electricity
ELE_NV	Number of vehicles driving on Electricity
EMI	Emissions of NMVOC
ENW	Enamelled wire
EP	Ethylene and Propylene
EPS	Expandable polystyrene beads consumption
EX_CTTL	Grazing cattle N-excretions
EX_SH	Grazing sheep N-excretions
FGAS	Fluorinated greenhouse gas
FIRE_MASS	Forest, grassland burning
FU	Fur animals
FWD	Fuelwood
GAS	Natural Gas (incl. other gases)
GAS_KM	Kilometres travelled on Natural Gas (incl. other gases)
GAS_M	Natural Gas (incl. other gases)
GAS_NV	Number of vehicles driving on Natural Gas (incl. other gases)
GDP	Gross domestic product (market exchange rate - MEX)
GDP_PPP	Gross domestic product (purchasing power parity - PPP)
GSL	Gasoline
GSL_BIO	Bio Gasoline
GSL_KM	Kilometres travelled on Gasoline
GSL_M	Gasoline
GSL_NV	Number of vehicles driving on Gasoline
GSL_NV_HE	Number of High emitter vehicles driving on Gasoline
GTH	Geothermal
H2	Hydrogen
H2_KM	Kilometres travelled on Hydrogen
H2_NV	Number of vehicles driving on H2
HC1	Hard coal, grade 1
HC2	Hard coal, grade 2
HC3	Hard coal, grade 3
HCFC	Hydrochlorofluorocarbon
HELP	Get me out of here
HF	Heavy fuel oil
HFC	Hydrofluorocarbon
HF_NV	Number of vehicles driving on HF
HO	Horses
HT	Heat (steam, hot water)
HYD	Hydro
INK	Printing inks
LFL	Leaded gasoline
LH	Laying hens
LPG	Liquefied petroleum gas

continues on

Table 4.5 – continued from previous page

Abbreviation	Activity
LPG_KM	Kilometres travelled on Liquefied petroleum gas
LPG_NV	Number of vehicles driving on Liquefied petroleum gas
MANURE_N	N contained in animal manure
MD	Diesel
MD_BIO	Bio diesel
MD_KM	Kilometres travelled on Medium distillates (diesel, light fuel oil)
MD_M	Diesel
MD_NV	Number of vehicles driving on Medium distillates (diesel, light fuel oil)
MD_NV_HE	Number of High emitter vehicles driving on Medium distillates (diesel, light fuel oil)
NOF	No fuel use
NUC	Nuclear
N_INPUT	Mass of Nitrogen added
OL	Other cattle - liquid systems
OL_F	Other cattle - liquid (slurry) systems - enteric fermentation
OP	Other poultry
OS	Other cattle - solid systems
OS1	Biomass fuels
OS2	Other biomass and waste fuels
PFC	Perfluorocarbons
PG	Paint and glue produced
PL	Pigs - liquid systems
PNT	Paint use
POP	Population
POP_TOT	Total population (in macro tables)
PS	Pigs - solid systems
PVC	PVC produced by suspension process
REN	Renewable energy other than biomass
RICE_N	Mineral N fertilizer added to rice fields
RUB	Synthetic rubber
RURAL	Rural activity
RURAL_10YR_BP	Rural activity at 10yr before the respective - present year
RURAL_20YR_BP	Rural activity at 20yr before the respective - present year
SC	Coated surface
SD	Seeds
SF6	Sulfur hexafluoride
SH	Sheep and goats
SHARE	Share of
SHO	Shoes
SHP	Small hydro power
SLV	Solvent use
SOIL_N	Mineral N fertilizer added to agricultural soils
SPV	Solar photovoltaic
STH	Solar thermal
S_GAS	Shale gas
TEX	Textiles (clothing)
TIM	Wood treated
TYR	Tyres
TYRE	Tyre wear
T_GAS	Tight gas
URBAN	Urban activity

continues on

Table 4.5 – continued from previous page

Abbreviation	Activity
URBAN_10YR_BP	Urban activity at 10yr before the respective - present year
URBAN_20YR_BP	Urban activity at 20yr before the respective - present year
VA_AGR	Value added - agriculture, forestry, fishing
VA_COMM	Value added - commercial sector (trade, other services)
VA_CONSTR	Value added - construction
VA_ELGW	Value added - electricity, gas and water supply
VA_ENER	Value added - energy
VA_IND	Value added - manufacturing industry (except energy)
VA_INDCHEM	Value added - chemicals
VA_INDFOOD	Value added - food, beverages, tobacco
VA_INDISTE	Value added - iron and steel
VA_INDMET	Value added - basic metals
VA_INDNFME	Value added - non-ferrous metals
VA_INDNMMI	Value added - non-metallic minerals
VA_INDOTH	Value added - other industries
VA_INDPAP	Value added - pulp, paper, paper products and printing
VA_INDRUB	Value added - plastics and rubber
VA_INDTEX	Value added - textile, leather, footwear
VA_INDWOOD	Value added - wood and wood products
VA_MINE	Value added - mining and quarrying
VA_ORCKNF	Value added - mineral oil refining, coke and nuclear fuel
VA_PRINT	Value added - printing and publishing
VA_TERT	Value added - tertiary sector (transport, trade, other services)
VA_TOT	Gross value added - total
VA_TRANS	Value added - transport
VEH	Vehicles
WND	Wind
WSFNR	Waste fuels, non-renewable
WSFR	Waste fuel, renewable
10YR_BP	Activity at 10yr before the respective - present year, i.e. 1980 and 1985 - Used to emulate stocks (pools) of land
20YR_BP	Activity at 20yr before the respective - present year, i.e. 1970 and 1975 - Used to emulate stocks (pools) of land

### 4.3.4 Technologies

Below, the 522 technologies available in GAINS for emission reduction are listed hereunder along with their corresponding abbreviations used in the model.

Abbreviation	Technology
ACA	Activated carbon adsorption
AGR1	A generic option for other animals - good practice
ALTER	Low-till farming, alternative cereal harvesting
ALT_CO2	Alternative refrigerant CO2
ALT_HC	Alternative hydrocarbon (propane, butane, etc.)
ALT_HFC	Alternative low GWP HFC (e. g. HFC-152a)
ALT_HFO	Alternative HFO refrigerant ( switch from HFC to HFOs )
ALT_MAGN	Alternative protection gas: SF6 replaced by SO2
ALT_NH3	Alternative refrigerant NH3
A_INC	Adsorption, incineration

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Table 4.6 – continued from previous page

Abbreviation	Technology
BAN	Ban on open burning
BASE	Simulation of changes in paint formulation and application patterns between 1990 and 2000
BAT	Best available technology as implemented in plant in Graz, Austria
BC_DEGAS	Degasification
BEMT	Basic emissions management techniques
BEMT+ACA	Basic emissions management techniques and carbon adsorption
BF	Air scrubber
BF_CS	Combination of BF_CS
BF_CS_LNA	Combination of BF_CS_LNA
BF_LNA	Combination of BF_LNA
BF_LNA_high	Combination of BF_LNA_high
BF_LNA_low	Combination of BF_LNA_low
BIO	Biofiltration
BISUB	Switch from cutback to emulsion bitumens (road paving)
BREED	Genetic engineering aimed at reducing CH <sub>4</sub> formation in rumen
CAGEUI	Stage 1
CAGEUII	Stage 2
CAGEUIII	Stage 3A
CAGEUIII_PF	Stage 3A with DPF
CAGEUIV	Stage 3B
CAGEUV	Stage 4
CAGEUVI	Stage 5
CCCM	Conventional closed circuit machine
CCCM+ACA	Combination of the above options
CLSD_A3	Closed (sealed) degreaser: use of A3 solvents
CLSD_A3+ACA	Combination of the above options
CLSD_CL	Closed (sealed) degreaser: use of chlorinated solvents
CLSD_HF	Closed (sealed) degreaser: use of fluoro (HFC, HFE) solvents
CLSD_HF+ACA	Combination of the above options
COLD	Cold cleaner
COMB1_RICE	Combining ALT_RICE and SULF_RICE
COMB2_RICE	Combining ALT_RICE and SULF_RICE and INTER_RICE
COMPRESS	Reduction of gas leakages at compressor stations in gas transmission pipelines
CONTROL_SLV	Controlling solvent emissions VOC
CONT_NET	Doubling of leak control frequency of gas distribution network
CONVCWPB	Conversion of centre worked pre-bake (CWPB) to point feeder prebake (PFPB) technology
CONVSWPB	Conversion of Side worked prebake (SWPB) to point feeder prebake (PFPB)
CONVVSS	Conversion of Vertical stud S <sub>z</sub> derberg (VSS) to point feeder prebake (PFPB)
COWS	Covers on oil/water separators
CR	Catalytic reduction (selective or non-selective)
CS	Covered outdoor storage of manure; mean efficiency
CSBP	Use of current standard solvent based paints (60% solvent content) and application efficiency 65%
CSBP+INC	Combination of the above options
CS_LNA	Combination of CS_LNA
CS_high	Covered outdoor storage of manure; high efficiency
CS_low	Covered outdoor storage of manure; low efficiency
CYC	Cyclone

continues on next page

Table 4.6 – continued from previous page

Abbreviation	Technology
CYC_REM	Cyclone - remaining capacity
DDK	Down Draft Kiln
DGCCOM	Comb. modification on gas use in commercial sector
DGCCR	Combustion modification on gas use in commercial and residential sectors
DHFCM	Combustion modification on heavy fuel oil use in commercial sector
DMDCCO	Combustion modification on gasoil use in commercial sector
DMDCCR	Combustion modification on gasoil use in commercial and residential sectors
DOM_CC_23	Urban domestic wastewater -centralized collection with anaerobic secondary and/or tertiary treatment (incl. treatment with bacteria and/or flaring of residual methane) (MCF=0)
DOM_CC_23U	Urban domestic wastewater -centralized collection with anaerobic secondary and/or tertiary treatment with gas recovery, upgrading and use (MCF=0)
DOM_CC_AER	Urban domestic wastewater -centralized collection with aerobic treatment without temporary overloads (MCF=0)
ELEC	Electric cremation
EMU	Emulsions, water-based dispersion paints
ENC+ACA	Enclosure and adsorption
ENC+INC	Enclosure and incineration
ESP1	Electrostatic precipitator: 1 field
ESP1_REM	Electrostatic precipitator: 1 field - remaining capacity without overlap from other pollutant controls
ESP2	Electrostatic precipitator: 2 fields
ESP2_REM	Electrostatic precipitator: 2 field - remaining capacity without overlap from other pollutant controls
ESPSINJ	Sorbent injection, combined with particulate matter control via electrostatic precipitators (ESP1, ESP2)
ESP_FGD	Electrostatic precipitator (any type) combined with flue gas desulphurization
FALLOW	Lay fallow
FARM_AD	Farm-scale anaerobic digestion plants
FARM_AD_L	large Farm-scale anaerobic digestion plants
FBC	Fluidized bed combustion
FBC_CM	Combustion modification in fluidized bed combustion
FCBTK	Fixed Chimney Bull's Trench Kiln
FEED	Mix of feed changes (includes e.g., increased feed intake, replacement of roughage for concentrates, change to more fat and non-structural carbohydrates in diet)
FEED_MOD	Feed modification (all livestock)
FF	Fabric filters
FFSINJ	Fabric filters - power plants with injection
FF_FGD	Fabric/baghouse filter, combined with flue gas desulphurization
FF_REM	Fabric/baghouse filter - remaining capacity without overlap from other pollutant controls
FF_SN	Fabric filters - power plants + S,N meas.
FILTER	Filters in households (kitchen)
FK	Fluoro-ketone (FK-5-1-12)
FLA_REF	Flaring instead of venting of gas in oil refinery
FLOODING	Flooding of entity
FLR_GP	Good practice in oil and gas industry - flaring
FOOD_AD	Food industry waste treated in anaerobic digestion (biogasification) plant with energy recovery
FOOD_BURN	FOOD_BURN
FOOD_COM	Food industry waste treated in compost

continues on next page

Table 4.6 – continued from previous page

Abbreviation	Technology
FOOD_INC	Food industry: waste incinerated in plant without energy recovery
FOOD_INC_ENE	Food industry: waste incinerated in plant with energy recovery
FP_IMP	Improved fireplace
FP_NEW	New fireplace
FREE	Free range poultry
FSED	Simulation of possible developments beyond Product Directive
F_IMP	Improved ignition systems on flares
GHDOM	Good housekeeping: domestic oil boilers
GHIND	Good housekeeping: industrial oil boilers
GP	Good practice: leakage control
GP_HIGH	Good practice: High leakage control
GP_MEDIUM	Good practice: Medium leakage control
HAMP	Improved application (HVLP), gunwash, SMP
HAMP+SUB1	Primary measures and 25% of high solids and water based paints
HAMP+SUB2	Primary measures and 40% high solids, 60% water based paints
HAY_SIL	Hay-silage for cattle
HCM	Hydrocarbon machine
HC_DEGAS	Hard Coal degasification
HDEUI	EURO I
HDEUII	EURO II
HDEUIII	EURO III
HDEUIV	EURO IV
HDEUV	EURO V
HDEUVI	EURO VI
HDEUVII	EURO VII
HDSEI	Stage 1
HDSEII	Stage 2
HDSEIII	Stage 3
HED	High efficiency deduster
HEDSINJ	Sorbent injection, combined with particulate matter control via high-efficiency deduster (HED)
HED_FGD	High-efficiency deduster, combined with with flue gas desulphurization
HED_REM	High-efficiency deduster - remaining capacity without overlap from other pollutant controls
HED_SN	High efficiency deduster - power plants + S,N meas.
HF2MD	Fuel switching for SO <sub>2</sub> for PP_ENG sectors
HK	Hoffman Kilns
HOTM	Hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100%)
HOUS_AD	Household anaerobic digestion
HR	Hurricane lamp
HSE	Good housekeeping
HSE+BISUB	Good housekeeping in steel industry and switch to emulsion bitumen
HSS	High solids coating systems (20% solvent content), application process with an efficiency of 35%
HSS+PRM	High solids coating systems (20% solvent content), application process with an efficiency of 75%
IDK_BTK	Mix of Intermittent Downdraught (IDK) and Bull's Trench Kiln (BTK)
IFC	Internal floating covers or secondary seals
IFC+ST_IAD	IFC and Stage IA (double stage) controls

continues on next page

Table 4.6 – continued from previous page

Abbreviation	Technology
IFC+ST_IAS	IFC and Stage IA (single stage) controls
IFC+VRU_I	Internal floating covers/sec.seals,vapour recovery (single stage)
IFC+VRU_II	Internal floating covers/sec.seals,vapour recovery (double stage)
INC	Incineration
INC_HFC23	Incineration: post combustion of HFC-23 emitted from production of HCFC-22
INDOTH_BURN	INDOTH_BURN
INDOTH_INC	Other manufacturing industry: waste incinerated in plant without energy recovery
INDOTH_INC_ENE	Other manufacturing industry: waste incinerated in plant with energy recovery
IND_FOOD_AERO	Industrial wastewater:pulp-and paper industry-aerobic treatment (MCF=0)
IND_FOOD_ANAE_NO	Industrial wastewater:pulp-and paper industry-anaerobic treatment in digester,reactor or deep lagoon without gas recovery (MCF=0.5)
IND_FOOD_ANAE_USI	Industrial wastewater:pulp-and paper industry-anaerobic treatment in digester,reactor or deep lagoon with gas recovery, upgrading and use (MCF=0)
IND_OTH_AERO	Industrial wastewater:other industry-aerobic treatment (MCF=0)
IND_OTH_ANAE_NON	Industrial wastewater:other industry-anaerobic treatment without gas recovery(MCF=0)
IND_OTH_ANAE_USE	Industrial wastewater:other industry-anaerobic treatment with gas recovery(MCF=0)
IND_PAP_AERO	Industrial wastewater:pulp-and paper industry-aerobic treatment (MCF=0)
IND_PAP_ANAE_NON	Industrial wastewater:pulp-and paper industry-anaerobic treatment in digester,reactor or deep lagoon without gas recovery (MCF=0.5)
IND_PAP_ANAE_USE	Industrial wastewater:pulp-and paper industry-anaerobic treatment in digester,reactor or deep lagoon with gas recovery, upgrading and use (MCF=0)
INHIB	Nihiliation Inhibitory
IN_CYC	Cyclone
IN_CYC_REM	remaining Cyclone industry
IN_ESP1	Electrostatic precipitator: 1 field
IN_ESP1_FGD	Electrostatic precipitator: 2 field combined with flue gas desulphurization, applied in the industrial combustion sector
IN_ESP1_REM	Electrostatic precipitator: 1 field - remaining capacity without overlap from other pollutant controls, applied in the industrial combustion sector
IN_ESP2	Electrostatic precipitator: 2 fields
IN_ESP2_FGD	Electrostatic precipitator: 2 field combined with flue gas desulphurization, applied in the industrial combustion sector
IN_ESP2_REM	Electrostatic precipitator: 2 field - remaining capacity without overlap from other pollutant controls, applied in the industrial combustion sector
IN_ESPSINJ	Sorbent injection, combined with particulate matter control via electrostatic precipitation (ESP1, ESP2), applied in the industrial combustion sector
IN_FFSINJ	Sorbent injection, combined with particulate matter control via fabric/baghouse filter, applied in the industrial combustion sector
IN_HED	High efficiency deduster
IN_HEDSINJ	Sorbent injection, combined with particulate matter control via high-efficiency deduster, applied in the industrial combustion sector
IN_HED_FGD	High-efficiency deduster, combined with with flue gas desulphurization, applied in the industrial combustion sector
IN_HED_REM	High-efficiency deduster - remaining capacity without overlap from other pollutant controls, applied in the industrial combustion sector
IN_HED_SN	High efficiency deduster - industrial combustion + S,N meas.
IN_LHGCO	Industry low Hg coal
IN_LHGCO_CYC	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with cyclone; in industrial combustion sector

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Table 4.6 – continued from previous page

Abbreviation	Technology
IN_LHGCO_ESP_FGD	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with electrostatic precipitator and flue gas desulfurization; industrial combustion sector
IN_LHGCO_HED_FGD	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with high-efficiency deduster and flue gas desulfurization; industrial combustion sector
IN_LHGCO_PM	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with PM control (ESP, HED); in industrial combustion sector
IN_LHGCO_PM_FGD	IN_LHGCO_PM_FGD
IN_LHGCO_REM	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition) - remaining capacity without overlap form other control technologies; industrial combustion sector
IN_PMSINJ	IN_PMSINJ
IN_PM_FGD	IN_PM_FGD
IN_PM_REM	IN_PM_REM
IN_SINJ	Industry S injection
IN_SPC	Sorbent polymer catalyst modules, applied in the industrial combustion sector
IN_WSCRBR	Wet scrubber
IOGCM	Combustion modification on oil and gas industrial boilers and furnaces
IOGCSC	Combustion modification and selective catalytic reduction on oil and gas industrial boilers and furnaces
IOGCSN	Combustion modification and selective non-catalytic reduction on oil and gas industrial boilers and furnaces
ISBP	Use of improved solvent based paints (55%), application efficiency as above
ISBP+INC	Combination of the above options
ISFCM	Combustion modification on solid fuels fired industrial boilers and furnaces
ISFCSC	Combustion modification and selective catalytic reduction on solid fuels fired industrial boilers and furnaces
ISFCSN	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces
IWFGD	Industry - wet flue gases desulphurisation
I_LAND	Improved Landfills
LDAR_I	Leak detection and repair program, stage I
LDAR_I+COWS	Combination of the above options
LDAR_II	Leak detection and repair program, stage II
LDAR_II+COWS	Combination of the above options
LDAR_III	Leak detection and repair program, stage III
LDAR_IV	Leak detection and repair program, stage IV
LED	LED lamp
LFEUI	EURO 1
LFEUII	EURO 2
LFEUIII	EURO 3
LFEUIV	EURO 4
LFEUV	EURO 5
LFEUVI	EURO 6
LHGCO	low HG coal usage
LHGCO_CYC	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with cyclone

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Table 4.6 – continued from previous page

Abbreviation	Technology
LHGCO_ESP_FGD	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with electrostatic precipitator and flue gas desulfurization
LHGCO_FF_FGD	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with fabric filter and flue gas desulfurization;
LHGCO_HED_FGD	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with high-efficiency deduster and flue gas desulfurization;
LHGCO_PM	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with PM control (ESP, HED); in industrial combustion sector
LHGCO_PM_FGD	LHGCO_PM_FGD
LHGCO_REM	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition) - remaining capacity without overlap form other control technologies
LHGCO_WSCRB	Measures that lower Hg emissions through fuel modification (e.g. coal washing, beneficiation, Br addition), combined with wet scrubber; in industrial combustion sector
LINJ	In-furnace control - limestone injection
LNA	Low ammonia application; mean efficiency
LNA_high	Low ammonia application; high efficiency
LNA_low	Low ammonia application; low efficiency
LNF	Low nitrogen feed
LNF_BF	Combination of LNF_BF
LNF_BF_CS	Combination of LNF_BF_CS
LNF_BF_CS_LNA	Combination of LNF_BF_CS_LNA
LNF_BF_LNA	Combination of LNF_BF_LNA
LNF_BF_LNA_high	Combination of LNF_BF_LNA_high
LNF_BF_LNA_low	Combination of LNF_BF_LNA_low
LNF_CS	Combination of LNF_CS
LNF_CS_LNA	Combination of LNF_CS_LNA
LNF_LNA	Combination of LNF_LNA
LNF_LNA_high	Combination of LNF_LNA_high
LNF_LNA_low	Combination of LNF_LNA_low
LNF_SA	Combination of LNF_SA
LNF_SA_LNA	Combination of LNF_SA_LNA
LOW_GWP	Alternative refrigerant ; Low GWP refrigerant (e. g. HFC-152a)
LPB	Low pentane (4%) expandable beads
LSCK	Low sulphur coke (0.6 %S)
LSCO	Low sulphur coal (0.6 %S)
LSGSL	Low sulphur gasoline (0.001 %S)
LSHF	Low sulphur fuel oil (0.6 %S)
LSI+ENC	Low solvent inks and enclosure
LSI+ENC+ACA	Low solvent inks, enclosure and adsorption
LSI+ENC+INC	Low solvent inks, enclosure and incineration
LSI+ENC+INC-ACA	Low solvent inks, enclosure and incineration or adsorption
LSI+ENC+INC_ACA	Low solvent inks, enclosure and incineration or adsorption
LSMD1	Low sulphur diesel oil - stage 1 (0.2 % S)
LSMD2	Low sulphur diesel oil - stage 2 (0.045 % S)
LSMD3	Low sulphur diesel oil - stage 3 (0.001 % S)
LSS+PRM	Low solids systems (80% solvent content) and application process with an efficiency of 75% (electrostatic, roller coating, curtain coating, dipping)
LSS+PRM+INC	Combination of the above options
LSWBI	Low solvent or water based inks

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Table 4.6 – continued from previous page

Abbreviation	Technology
LSWBI+ENC+ACA	Low solvent/water based inks, enclosure and adsorption
LSWBI+ENC+INC	Low solvent/water based inks, enclosure and incineration
LSWBI+ENC+INC-A	Low solvent/water based inks and incineration/adsorption
LSWBI+ENC+INC_A	Low solvent/water based inks and incineration/adsorption
MB_CYC	Cyclone
MB_HED	High efficiency deduster
MB_HED_A	High efficiency deduster
MB_HED_F	High efficiency deduster
MB_PELL	Pellet boiler
MCBTK	Moving Chimney Bull's Trench Kiln
MDEUI	EURO 1
MDEUII	EURO 2
MDEUIII	EURO 3
MDEUIV	EURO 4
MDEUV	EURO 5
MDEUVI	EURO 6
MDEUVII	EURO 7 on light duty diesel road vehicles
MDEUVIp	EURO 6a/b
MDEUVIt	EURO 6 t
MINE_GP	Good practice in mining industry
MK	Marques Kilns
MMO2I	Stage 1 (2-stroke)
MMO2II	Stage 2 (2-stroke)
MMO2III	Stage 3 (2-stroke)
MMO2IV	Stage 4 (2-stroke)
MMO2V	Stage 5 (2-stroke)
MMO2VI	Stage 6 (2-stroke)
MOT4I	Stage 1 (4-stroke)
MOT4II	Stage 2 (4-stroke)
MOT4III	Stage 3 (4-stroke)
MOT4IV	Stage 4 (4-stroke)
MOT4V	Stage 5 (4-stroke)
MOT4VI	Stage 6 (4-stroke)
MSS	Medium solids systems (55% solvent content), conventional application process with an efficiency of 35%
MSS+INC	Combination of the above options
MSS+PRM	Medium solids systems (55% solvent content), application process with an efficiency of 75%
MSW_HIST_SWD_FL A	Historical solid waste diverted to landfill with gas recovery and flaring
MSW_HIST_SWD_USE	Historical solid waste diverted to landfill with gas recovery and utilization
M_INC	Modernized plant (lower fugitives) and improved thermal oxidation
NAGR	Agrochemicals - new products
NCCM	New generation closed circuit machine
NEWCWPB	Conversion of centre worked pre-bake (CWPB) to new technologies (i. e. inert anodes, wetted drained cathodes etc.)
NEWFPB	Conversion of point feeder pre-bake (FPB) to new technologies (i. e. inert anodes, wetted drained cathodes etc.)
NEWSWPB	Conversion of side worked pre-bake (SWPB) to new technologies (i. e. inert anodes, wetted drained cathodes etc.)

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Abbreviation	Technology
NEWVSS	Conversion of vertical stud soderberg (VSS) to new technologies (i. e. inert anodes, wetted drained cathodes etc.)
NF3	Alternative solvent: use of NF3
NOC	No control
NPR	New process
NSC_CH4	Stock not suitable for CH4 control
NSC_NOX	Stock not suitable for NOx control
NSC_PM	Stock not suitable for control
NSC_SO2	Stock not suitable for SO2 control
NSC_TRA	Stock not suitable for control - transport sources
NSC_VOC	Stock not suitable for VOC control
OPT	VIS plus optimisation of the process
OPTIM	Optimize process parameters towards low N2O yield
OPTPR	Process optimization
OTHI	Generic technology I for TRA_RD_OTH sector
OTHII	Generic technology II for TRA_RD_OTH sector
OTHIII	Generic technology III for TRA_RD_OTH sector
PAP_BURN	PAP_BURN
PAP_INC	Paper industry: black liquor recovery and incineration without energy recovery
PAP_INC_ENE	Paper industry: black liquor recovery and incineration with energy recovery
PB+REC	6% Pentane expandable beads (85%) and recycled EPS waste (15%)
PB+REC+INC	Combination of the above options
PBCCM	Combustion modification on existing brown coal power plants
PBCCSC	Combustion modification and selective catalytic reduction on existing brown coal power plants
PBCSCR	Selective catalytic reduction on new brown coal power plants
PHCCM	Combustion modification on existing hard coal power plants
PHCCSC	Combustion modification and selective catalytic reduction on existing hard coal power plants
PHCSCR	Selective catalytic reduction on new hard coal power plants
PMOF	Primary measures in offset printing, incl. enclosure
PMOF+INC	Primary measures (offset) and incineration
PMOF+SF	Primary measures (offset) and solvent free inks
PMOF+SF-INC	Primary measures (offset), solvent free inks, incineration
PMOF+SF_INC	Primary measures (offset), solvent free inks, incineration
PMSINJ	PMSINJ
PM_FGD	PM_FGD
PM_INC	Burning of Poultry Manure
PM_REM	PM_REM
POGCM	Combustion modification on existing oil and gas power plants
POGCSC	Combustion modification and selective catalytic reduction on existing oil and gas power plants
POGSCR	Selective catalytic reduction on new oil and gas power plants
POWDER	Powder coating system (solvent free)
PP_REM	PP_REM
PRECFARM	Precision farming
PRF_GP1	Good practice: ind.process - stage 1 (fugitive)
PRF_GP2	Good practice: ind.process - stage 2 (fugitive)
PRM	Process modification
PRM+NAGR	Primary and new agrochemical products

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Table 4.6 – continued from previous page

Abbreviation	Technology
PRM+SUB	Process modification and substitution
PRM+SUB+A_INC	Process modification, substitution, adsorption, incineration
PRM1+LEOP	Primary measures package one and low level employment of end-of-pipe measures (incl. thermal incineration, condensation, and other)
PRM2+HEOP	Primary measures package two and high level employment of end-of-pipe measures (incl. thermal incineration, carbon adsorption, condensation, and other)
PRMPLUS	Primary (lower solvent content of enamel and reduced fugitive emissions) and secondary measures (increased efficiency of the oven)
PRNOX1	Stage 1 - Process NOx control
PRNOX2	Stage 2 - Process NOx control
PRNOX3	Stage 3 - Process NOx control
PRWFGD	Wet flue gases desulphurisation (retrofitted)
PR_AP	PR_AP
PR_BNP	Boliden-Norzink mercury removal process, applied in industrial processes
PR_CYC	Cyclone
PR_CYC_REM	remaining Cyclone process
PR_ESP1	Electrostatic precipitator: 1 field
PR_ESP2	Electrostatic precipitator: 2 fields
PR_ESPSINJ	Sorbent injection, combined with particulate matter control via electrostatic precipitation (ESP1, ESP2), applied in industrial processes
PR_FF	PR_FF
PR_FFSINJ	Sorbent injection, combined with a fabric filter specifically installed for Hg control, applied in industrial processes
PR_HED	High efficiency deduster
PR_HEDSINJ	Sorbent injection, combined with particulate matter control via high-efficiency deduster (HED), applied in industrial processes
PR_HED_FGD	High-efficiency deduster, combined with with flue gas desulphurization, applied in industrial processes
PR_HED_REM	High-efficiency deduster - remaining capacity without overlap from other pollutant controls, applied in industrial processes
PR_HED_SN	High efficiency deduster with sulphur and nox control - industrial processes
PR_PMSINJ	PR_PMSINJ
PR_PM_FGD	PR_PM_FGD
PR_PM_REM	PR_PM_REM
PR_SINJ	Process sorbent injection
PR_SPC	Sorbent polymer catalyst modules in industrial processes
PR_WSCRB	Wet scrubber
PR_WSCRB_REM	remaining Wet scrubber process
PSFCSN	Selective non-catalytic reduction on other biomass and waste fuels for existing powerplants
PSFSNC	Selective non-catalytic reduction on other biomass and waste fuels for new powerplants
PWFGD	Wet flue gases desulphurisation
REC_USE	Recovery and use
REC_USE2	High eff. Recovery and use
REDUCE	Combined application of N2O with other anaesthetics
REDUCE2	Improved removal efficiency of technology reducing N2O
REF	Product reformulation
REF1	Reformulation of products (stage 1 - see BIPRO, 2002 study; researched options)
REF2	Reformulation of products (stage 2 - see BIPRO, 2002 study; feasible but more expensive options)

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Table 4.6 – continued from previous page

Abbreviation	Technology
REF3	Reformulation of products (stage 3 - see BIPRO, 2002 study; more work required on real potential, options might be prohibitively expensive)
REPLACE	Exchange N2O by the anaesthetics
REPL_NET	Replacement of grey cast iron gas distribution network
RESPI	Generic, e.g. street washing
RES_SPC	Sorbent polymer catalyst modules in residential emission sources
RETCWPB	Retrofitting of centre worked pre-bake (CWPB) technology
RETSWPB	Retrofitting of side worked pre-bake (SWPB) technology
RETVSS	Retrofitting of vertical stud soderberg (VSS) technology
RFGD	High efficiency flue gases desulphurisation
RUB_BURN	RUB_BURN
RUB_INC	Rubber and plastics industry: waste incinerated in plant without energy recovery
RUB_INC_ENE	Rubber and plastics industry: waste incinerated in plant with energy recovery
SA	Low emission housing
SA_LNA	Low emission housing and manure application
SED	Simulation of changes in paint formulation and application patterns in order to comply with the EU Product Directive
SF+SMP	Solvent free inks and solvent management plant
SHB_HED	High efficiency deduster for single house boiler using coal
SHB_IMP_B	Biomass single house boiler improved
SHB_NEW_B	Biomass single house boiler new
SHB_NEW_C	Coal single house boiler new
SHB_PELL	Biomass single house boiler - pellets
SHB_PLESP	Biomass single house boiler - pellets and electrostatic precipitator
SHM+ACA	Schumacher type desolventiser-toaster-dryer-cooler plus an old hexane recovery section
SHM+ACAN	Schumacher type desolventiser-toaster-dryer-cooler plus a new hexane recovery section and process optimization
SINJ	sorbent injection
SO2PR1	Stage 1 - Process SO2 control
SO2PR2	Stage 2 - Process SO2 control
SO2PR3	Stage 3 - Process SO2 control
SPC	Sorbent polymer catalyst modules
SPRAY	Spraying water at construction places
SPRM	Good housekeeping and substitution (60% solvent based and 40% water based adhesives)
SPRM+BIO	Combination of the above options
SPRM+INC	Combination of the above options
SPRMPLUS	As SPRM plus automatic application
ST(II+IB)	Stage II and IB at service station
STH_GP	Good practice: storage and handling
STLHCM	Combustion modification on large vessels using residual oil
STLMCM	Combustion modification on large vessels using marine diesel fuel
STLSCR	Selective catalytic reduction on large vessels using residual oil
STMCM	Combustion modification on medium vessels using marine diesel fuel
STMSCR	Selective catalytic reduction on large vessels using residual oil
STRIP	Combination of STRIP
STVNT	Stripping and vent gas treatment
STVNT+LK	STVNT plus leak detection and repair program to reduce fugitive emissions
STVNTOPT	STVNT plus optimization of emission treatment
STVNTOPT+LK	Combination of the above options
STV_BRIQ	Briquette stove

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Table 4.6 – continued from previous page

Abbreviation	Technology
STV_ESP_B	New stove with electrostatic precipitator
STV_FAN_B	Fan assisted cooking stove
STV_IMP_B	Improved stove - biomass
STV_IMP_C	Improved stove - coal
STV_LPG	switch to LPG
STV_NEW_B	New stove - biomass
STV_NEW_C	New stove - coal
STV_PELL	Pellet stove
STV_PLESP	Pellet stove with electrostatic precipitator
ST_IAD	Stage IA (double stage) at gasoline depots
ST_IAS	Stage IA (single stage) at gasoline depots
ST_IB	Stage IB controls at service stations
ST_II	Stage II controls at service stations
SUB1_VT	Use of 30% solvent based additives and 70% low solvent additives (90% vulcanized rubber and 10% thermoplastic rubber produced)
SUB1_VT+INC	Combination of the above options
SUB2_VT	Use of 10% solvent based additives and 90% low solvent additives (90% vulcanized rubber and 10% thermoplastic rubber produced)
SUB_U	Urea substitution
SUB_V	Use of 30% solvent based additives and 70% low solvent additives (100% vulcanized rubber produced)
SUB_V+INC	Combination of the above options
SWD	SWD
SWD_COMP	Managed SWDS compressed without cover
SWD_COVER	Managed SWDS with cover but without gas recovery
SWD_FLA	Managed SWDS covered and with gas recovery and flaring
SWD_UNM_HIGH	Unmanaged SWDS > 5 meters deep and/or high humidity and arbitrary self-ignition
SWD_UNM_LOW	Unmanaged SWDS < 5 meters deep and /or low humidity and arbitrary self-ignition
SWD_USE	Managed SWDS covered and with gas recovery and utilization
TEX_BURN	TEX_BURN
TEX_INC	Textile industry: waste incinerated in plant without energy recovery
TEX_INC_ENE	Textile industry: waste incinerated in plant with energy recovery
TIWEUI	Stage 1
TIWEUII	Stage 2
TIWEUIII	Stage 3A
TIWEUIII_PF	Stage 3A with DPF
TIWEUIV	Stage 3B
TIWEUV	Stage 4
TIWEUVI	Stage 5
TK_COAL	Tunnel Kilns (Coal)
TK_EOF	Tunnel Kiln with end of pipe abatement
TK_OTHER	Tunnel Kilns burning other fuels than coal
TREAT_AD	Source separated and treated in anaerobic digestion (biogasification) plant with energy recovery
TREAT_BURN	TREAT_BURN
TREAT_HSC	Source separated and treated in household composts
TREAT_INC	Mixed waste incinerated in plant without energy recovery
TREAT_INC_ENE	Mixed waste incinerated in plant with energy recovery
TREAT_LSC	Source separated and treated in large-scale (municipality/village-size) composts
TREAT_REC	Source separated and recycled

continues on next page

Table 4.6 – continued from previous page

Abbreviation	Technology
TSBP_IA	Use of traditional solvent based paints but improved application efficiency up to 65%
TSBP_IA+INC	Combination of the above options
TWIN_RED	Twin reduction system in parallel avoids N2O leakage
UNC_BURN	Uncollected waste - open burned
UPACA	Upgrade of the condensation units or carbon adsorption and solvent recovery
VAMOX	VAMOX descr. missing
VAMOX_VENT	VAMOX_VENT descr. missing
VBAL	Vapour balancing on tankers and loading facilities
VBAL+VF_ALT	Vapour balancing and alternatives for venting and flaring
VBAL+V_ALT	Vapour balancing and alternatives for venting
VEH_IM	Inspection and maintenance
VHSS	Very high solids systems (5% solvent content), application process with an efficiency of 35%
VHSS+PRM	Very high solids systems (5% solvent content), application process with an efficiency of 75%
VIS	Improved application technique (vacuum impregnation system)
VIS+ACA	Combination of the above options
VIS+INC	Combination of the above options
VRT	Variable Rate Technology
VRU_I	Vapour recovery unit (single stage)
VRU_II	Vapour recovery unit (double stage)
VSBK	Vertical Shaft Brick Kiln with basic dust control
V_ALT	Alternatives and increased recovery for venting
WBC_L	Use of water based coating
WBD	Water based cleaning process
WBI	Water based inks
WBI+BIO	Water based inks and biofiltration (large inst.)
WBI+ENC+ACA	Water based inks, enclosure and adsorption
WBI+ENC+INC	Water based inks, enclosure and incineration
WBI+ENC+INC-ACA	Water based inks, enclosure and incineration or adsorption
WBI+ENC+INC-BIO	Water based inks, enclosure and incineration or biofiltration
WBI+ENC+INC_ACA	Water based inks, enclosure and incineration or adsorption
WBI+ENC+INC_BIO	Water based inks, enclosure and incineration or biofiltration
WBI+INC	Water based inks, incineration (for new inst. with enclosure)
WBP	Use of water based paints (5%): application efficiency as above
WCLEAN	Water cleaning
WOOD_BURN	WOOD_BURN
WOOD_INC	Wood industry: waste incinerated without energy recovery
WOOD_INC_ENE	Wood industry: waste incinerated with energy recovery
WOOD_REC	Wood industry: waste recycled into chipboards and similar
WPR	Use of water based preservatives (conventional application methods)
WPR+VIS	Combination of the above options
WSCRB	Wet scrubber
WSCRB_REM	Wet scrubber - remaining capacity
ZIG_ZAG	Zig-Zag kilns

### 4.3.5 Pollutants

The air pollutants and greenhouse gases used in GAINS are listed hereunder, including the Particulate Matter fractions.

Abbreviation	Pollutant
CH4	Methane
CO	Carbon monoxide
CO2	Carbon dioxide
FGAS	Fluorinated gases
HG	Mercury
N2O	Nitrous oxide
NH3	Ammonia
NOX	Nitrogen oxides
PM_1	Particulate Matter with a diameter less than 1 micrometer
PM_10	Particulate Matter with a diameter less than 10 micrometer
PM_2_5	Particulate Matter with a diameter less than 2.5 micrometer
PM_BC	Particulate Matter from Black Carbon emissions
PM_COA	Particulate Matter from Condensed Organic Aerosols
PM_OC	Particulate Matter from Organic Carbon emissions
PM_RES	Particulate Matter from combustion Residues
PM_TSP	Total Suspended Particulate, representing all particulate matter suspended in the air
PN_NONUFP	Particulate Number for Non-Ultrafine Particles
PN_UFP	Particulate Number for Ultrafine Particles
SO2	Sulfur dioxide
VOC	Volatile Organic compounds
VOC1	Volatile Organic compounds, with a single carbon atom, such as methane (CH4)

## 4.4 Release notes

This Section includes the various implemented changes since the previous version/release. The latest version of GAINS is the version 4.03 and has been released in October 2023. The release notes summarizing such changes with respect to the previous versions of GAINS can be accessed [here](#).

## 4.5 Contact

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## **GETTING INVOLVED - THE GAINS COMMUNITY**

### **5.1 Community news**

This Section includes general community news such as upcoming hackathon, annual meetings or further plans.



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