An Overview of the RAINS Model

Environmental Research Centre Report

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Executive Summary

The Regional Air Pollution Information and Simulation (RAINS) model is a European-scale integrated assessment model dealing with air quality and associated effects. The model outputs are used in the negotiation, setting and assessment of emission ceiling targets for 2020 under both the Gothenburg Protocol and the EU National Emission Ceilings Directive (NECD). The 2010 national emission reductions targets for species linked to acidification and eutrophication have been established based on optimisation runs of the RAINS model.

The model has three principal modules, which are employed in the assessment of emissions from the United Nations Economic Commission for Europe (UNECE) countries and EU Member States and their associated effects. The first module establishes the emissions of each nation based on a detailed analysis of sectoral activities and existing abatement technologies. This module also considers the costs of both existing and potential abatement technologies so as to establish possible abatement paths and abatement cost curves. The second module draws the emissions information from the first module and applies them to a European 50 km × 50 km grid map. A weather pattern/chemical transfer module is engaged and through this the model can assess the health, acidification and eutrophication impacts of the pollution levels on the individual grid cells. The final module is the optimisation module. This module works with available data on emissions, their incidence and the abatement options at each source in order to deliver a given set of European threshold targets. Thus, the model works back from a limit of, for example, acceptable health impacts, to determine how this target can be achieved at least cost. The model uses forecasts up to 2030 and a range of potential scenarios in order to assess effects at this range and potential to abate.

Understanding of, and engagement with, the RAINS model and other processes for analysis of issues and identification of solutions, in relation to the objectives of the UNECE Convention on Long-Range Transport of Pollution and the Clean Air For Europe (CAFE) programme, is required to ensure that the analysis is correct for Ireland and that designated targets are optimisations that achieve the target-level environmental benefits at lowest cost.

1 Introduction

The purpose of this brief is to synopsise key literature on the Regional Air Pollution Information and Simulation (RAINS) model and the National Emission Ceilings Directive (NECD) process, in an effort to promote national stakeholder understanding and engagement. This work draws on a number of official model reports and reviews as documented in the bibliography. Additional sources of information include TREMOVE and European Monitoring and Evaluation Programme (EMEP) reports along with notes, minutes and observations from relevant workgroups and meetings. This paper is the first in a series of papers which will consider aspects of the RAINS model and the NECD process. The subsequent paper in the series will address national specific model issues, with a focus on data provision.

Whilst the focus of this paper is on the RAINS model methodology, this paper will also be relevant to those who will engage with the extension of the RAINS model – the Greenhouse Gas–Air Pollution Interactions and Synergies (GAINS) model. The GAINS model is to be used in forthcoming EU air policy work and will include greenhouse gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)) and the fluorinated gases (F-gases) as an addition to the pollutants currently covered within RAINS. There are also plans under way to include black carbon (BC) and carbon monoxide (CO) in the model framework for future work. At present, the NECD is still using the RAINS model as the default; however, the GAINS model is a direct extension of RAINS and can be activated as necessary. The GAINS model has additional data requirements, however, and only when these are met is there potential to move the process to a GAINS model assessment.

This paper is structured into the following sections:

- Context for the paper and model element overview
- Functions of the model from a user perspective
- Model inputs and the relationships of key inputs within the model modules
- A discussion of the types of output which can be derived from the model
- A summary and conclusion of the key points of the paper
- An annex of the identified pollution sources within RAINS.

1.1 Context and Outline

Nitrogen oxide (NO_x), sulphur dioxide (SO_2), ammonia (NH_3), volatile organic compounds (VOC) and particulate matter (PM) are pollutants which contribute to measurable effects such as acidification, eutrophication and poor air quality. These effects have costs in terms of damage to human health, ecosystems and our environment generally. The reductions of such negative effects are key targets of the Clean Air for Europe (CAFE) programme of DG Environment which works toward the implementation of the Thematic Strategy on Air Pollution (TSAP). The objectives of the TSAP are highlighted in Table 1.1 below and remain the key drivers and motivation behind the European Commission's process of emission reductions of the listed pollutants. Similarly, the reduction of these pollutant emissions are covered under the protocols of the Convention on Long-Range Transboundary Air Pollution

Table 1.1. Clean Air for Europe Thematic Strategy on Air Pollution objectives.

Improvements by 2020 relative to 2000	% Reductions
Life years lost from PM (million)	47
Acute mortality from ozone	10
Ecosystem forest areas exceeded from acidification	74
Ecosystem freshwater areas exceeded from acidification	39
Ecosystem area exceeded from eutrophication	43
Forest area exceeded by ozone	15

(CLRTAP) established by the United Nations Economic Commission for Europe (UNECE).

The approach taken to address the above objectives is a 'community' approach, and the reason for this pan-European (and beyond) strategy is that whilst pollution impacts as described above can be local, they are not exclusively so. Our natural meteorological system can serve to either intensify or diminish the catalogued effects of the individual pollutants mentioned through localised conditions such as extreme heat or heavy rain. However, the meteorological system can also intensify or diminish the effects of the pollutants by means of atmospheric transportation. Medium- and long-range transport of pollutants including cross-border transport can lead to pollutant deposition in areas of increased environmental sensitivity, thereby resulting in a higher level of damage to the ecosystem. Similarly, the pollution may be carried from an area of low population density to a densely populated area where the health impacts may be accentuated by virtue of increased exposure rates.

International cooperation is required to address the transboundary components of these pollutants in the most effective manner for the community. As a means of moving to address this issue, the UNECE countries (i.e. EU Member States and a number of Central and Eastern European countries), Canada and the USA adopted the Gothenburg or 'Multi-Pollutant' Protocol in 1999, as Parties to the Convention on Long-Range Transboundary Air Pollution.[1] Under Gothenburg (31 signatories), the 20 ratifying Parties committed to Emission Ceilings (ECs) for the four key acidifying pollutants (nitrogen oxide, sulphur dioxide, ammonia and volatile organic compounds) with targets set for 2010. A review process for this agreement will likely set further targets for 2020.

The ceilings in the Gothenburg Protocol are somewhat less ambitious than those set out under the European Union's NECD.[2] The NECD has established legally binding national emission ceilings (NECs) targets for 2010 – with a proposed revision set to introduce targets for 2020 – in order to satisfy EU Gothenburg Protocol ambitions and deliver on the CAFE health and air quality objectives described above.

1. However, in most cases Canada and the USA have different emission reduction provisions than those for other parties.
2. See http://europa.eu.int/eur-lex/pri/en/oj/dat/2001/l_309/l_30920011127en00220030.pdf for the text of Directive 2001/81/EC.

2 The RAINS Model

The TSAP and Gothenburg objectives require a comprehensive assessment of pollution sources, emission levels, several abatement technologies and environmental and human health-effects mitigation options if the objectives are to be met at minimum cost to the community. The RAINS model, assuming the input data and calculation parameters are properly calibrated and implemented, offers a framework for all stakeholders to engage in the efforts to make this assessment and thereby facilitates the development of a strategy to meet emission ceilings, CAFE objectives and the Gothenburg targets.

The RAINS model is an integrated assessment model (IAM) developed by the International Institute for Applied Systems Analysis (IIASA).[3] An IAM is a model or network of linked models which employs a broad set of data to examine a complex interrelated issue. The model has three key modules for performing integrated assessment in this field. The three modules are listed below with a short description of the tasks and purpose of each module. Further details on aspects of the modules are presented later in the paper.

1. Emission-Cost (EMCO) Module

   The emission-cost module takes account of national data on existing pollution sources and associated activity levels.[4] It also takes stock of information relating to the existing and expected abatement technology penetration and relevant costs throughout all sectors. These data are used initially to form a reference baseline scenario of national emissions which is in line with emission inventory statistics[5] and the legislation currently implemented (CLE). The model then employs data relating to the expected energy development path together with projections of key socio–economic drivers to determine plausible future states of pollution levels from this baseline for each country. Similarly, the activity levels concerning non-energy sectors (e.g. agriculture, livestock and solvents) are projected for future years.

   The cost side of the module considers the fixed (investment) and variable (maintenance) costs of the abatement technologies and their effectiveness to allow the development of cost curves.[6] This affords the model the opportunity to rank the effectiveness of abatement options with respect to the marginal cost. This is crucial to the running of the optimisation module described below as it allows the model to consider the abatement potential and associated costs from all sources, Europe wide, when seeking the cost-minimising allocation of measures to achieve a given community effect target.

   The EMCO model does not **predict** future emission levels; rather, it provides an insight into what the pollution levels would be, given assumptions on likely future variables (e.g. GDP, energy scenario, population growth). Thus, the EMCO module can provide a picture of the expected pollution levels in a given year for a given scenario.

2. Deposition and Critical Loads Assessment (DEP) Module and RAINS*Health*

   The DEP module considers the atmospheric dispersion and deposition of pollution. This module links with the long-range transport model developed by EMEP (Eulerian Unified Model) under the UNECE. This EMEP model operates on a 50 km × 50 km grid map and simulates atmospheric chemical interactions, likely transport patterns, and it identifies the incidence levels at deposition sites. This model relies on an accepted meteorological base year (currently 1997) for estimating likely transport paths and expected impact of meteorological factors. Once levels of pollution, their transport and incidence have been determined, the DEP module then compares

3. For more on the IIASA developers , see www.iiasa.ac.at.
4. Activities in the RAINS model refer both to fuel types and other anthropogenic activities (industry production, agriculture, livestock, solvents, etc.). In the case of energy, activity levels then are quantified in terms of energy of a given fuel type consumed; thus, an activity level may be the petajoules of energy used in a given sub-sector process, e.g. power plants (PP) using high quality hard coal (HC1).
5. This process is conducted bilaterally with national experts.
6. Cost curves are discussed in greater detail later in the document.

deposition levels against critical load maps for assessment of acidification and eutrophication. These critical load maps essentially provide a profile of environmental sensitivity (maximum allowed deposition levels for a given ecosystem) for each square cell on the EMEP 50 km × 50 km grid and thereby help determine the impact in terms of critical load exceedance.

Similarly, RAINS*Health* uses indicators developed by the World Health Organization (WHO) to determine the impacts in terms of premature deaths based on exposure to particulate matter and ozone.

3. Optimisation (OPT) Module

The final module within the RAINS IAM is the optimisation module. This module is responsible for considering all the outputs and data from previous modules for the broader area. It enables the identification of how to achieve a given objective at minimum cost – e.g. a health target objective for the RAINS Europe area. The module can deliver an optimal[7] **package** of measures as well as a number of sub-optimal alternatives based on user-specified constraints. The optimisation is focused on cost allocation while the targets can be emission ceilings, depositions or impact on ecosystems or human health.

Thus, the RAINS model integrates data from a wide range of sources in order to help policy makers and Member States to assess potential abatement policies and their cost-effectiveness for transition to our collective air quality goals. Accurate data are of paramount importance to this process.[8]

2.1 Aspects of the Model

The RAINS model has evolved over the past 20 years guided by developing scientific research and policy needs. The model has played an important role in the advancement of transboundary air pollution policy over the last two decades. It is also the primary model used in the target setting and policy assessment aspects of the NECD and also the Gothenburg and Sulphur Protocols of the CLRTAP. The model is not a predictive tool, but rather it offers a consistent appraisal framework for both national stakeholders and EU authorities to evaluate a range of related issues from pollution levels under certain scenarios to optimised strategies for achieving pollution effect-based targets.

However, with so many elements and causal links in regard to pollution sources, abatement costs, impacts and cost-effectiveness, there is an imperative to work towards achieving a balance between complexity and functionality. If the demands on the IAM are allowed to grow unchecked, so too will the model demands for detailed data, data which may often be unavailable. The danger is that if the IAM grows too complex it will lose support, transparency and thereby the faith of those who use it. Thus, the developers of the RAINS model have sought to strike a balance between complexity (and associated data requests) and maintaining valuable output for policy and decision making. As such the model has flaws and weaknesses.[9] However, the model is addressing a complex issue and amongst the greatest assets of the model are the support and engagement it has from the broader community, and the focus it provides for addressing the costs associated with degraded air quality. This section will address in qualitative general terms the **questions** which the RAINS model can help to answer.

Once calibrated with the necessary data, an early function of the RAINS model is to serve as a repository of key community information. Baseline data for the community will answer four key questions:

1. What sectors/sub-sectors are responsible for polluting activities?
2. Activity levels (see earlier note) for a given source?
3. What abatement technologies are in place (or expected for the future according to the CLE) across all sources?
4. What are the relevant country-specific costs?

The model can then use these data in the EMCO module, along with common data[10] on costs and emission factors, to deliver a response to the following queries:

7. Where optimal is defined as cost minimisation.
8. The issue of national data requirements for the modelling process in Ireland will be explored in detail in a subsequent paper.
9. Inevitable given the limited representation of the real world.
10. ‘Common’ data refers to data which the RAINS model holds in common for all Member States and which is not submitted by national experts, e.g. most emission factors and technology investment costs.

- How much of a given pollutant is emitted from each source?
- What are the total national emission levels for a given pollutant?
- What is the marginal abatement cost for a given unit of pollutant from each source/sector?
- Which are the most cost-effective abatement measures to achieve a selected target?

The third point is important as it represents the cost of reducing the next unit of pollution. Thus, the model takes account of the *in situ* technologies, the applicability of new technologies to be installed and the variance in emission control costs and effectiveness for individual measures.

In order to look forward in terms of emission levels, the RAINS model requires projection data from each Member State. These data allow the model to determine expected future states of emissions based on variables such as economy development and planned installation of abatement technologies gradually over time:

- Expected penetration of abatement technologies across all sources up to 2030
- Expected changes in socio–economic drivers of polluting activity levels up to 2030.

In the absence of national data, the IIASA team will utilise alternative sources for an estimate (e.g. EU statistics such as EUROSTAT). The model then employs these data to determine future baselines[11] of emission levels and costs across all sectors and the expected total emission factors to be applied based on the projections of the penetration of abatement technologies. This allows the RAINS EMCO module to deliver emission estimates every 5 years up to 2030. However, two critical elements of the EMCO forecasts are the applied energy (for SO_2, NO_x, PM) and agricultural scenarios (for NH_3) which are used. These scenarios are heavily dependent upon information such as the estimated cost of fuels (generally the 'driving' variable of the energy scenario development) and the expected time profile of livestock and agricultural activities.

11. The term baseline is used to refer to future years as well and is usually linked with the abatement technologies implemented according to the current legislation (CLE).

At the next level, the RAINS model considers all national pollution sources within the 'RAINS Europe' area and engages the DEP module. This module takes the output from the EMCO module and applies the following procedures:

- The source/origin of pollution is loaded into the 50 km × 50 km EMEP grid of the RAINS Europe area.[12]
- The data across the grid are altered according to expected chemical interactions and the impact of meteorological factors.
- The expected transfer of pollutants by the meteorological system is calculated and the deposition sites determined.
- The 'critical load' sensitivity of deposition sites is checked against deposition levels to determine critical load exceedance and thereby the impacts of the pollutants with regard to the two policy targets of eutrophication and acidification.

The two other policy targets assessed by the RAINS model are ozone formation and health impact. These are calculated by the RAINS*Health* module. The Health-Impact Module, recently introduced in RAINS, provides an estimation of the impact on human health of exposure to the calculated concentrations of $PM_{2.5}$ and ozone. Two special impact indicators have been developed by the WHO to take account of these impacts. The indicators are:

1. Life expectancy reduction for $PM_{2.5}$
2. Premature deaths from ozone.

These indicators are the result of applying a statistical correlation developed by the WHO on the basis of a cohort epidemiological study, carried out in the US by Pope *et al*. (1995). In the end, changes in emission levels, due to different control policies, are directly correlated with statistical impact on the health of the population.

The final function of the RAINS model is the OPT module. Here the model utilises a non-linear optimisation mode to identify the cost-minimal allocation of emission controls to meet a desired target. In this mode, the RAINS model will

12. Point sources and estimated distribution of pollution in Ireland are reported to the UNFCC/EMEP by the EPA. These data allow more specific allocation of pollution to grid squares. This is necessary as activity levels reported to the RAINS model are aggregate for the entire country.

take account of the broader region defined and determine the cost-minimal approach for this area. As such, rather than considering national interests or costs alone, the model will look at the potential abatement across the countries, the associated costs, and the atmospheric transfer of pollution and associated impact. In this mode, the model is performing as an integrated assessment model, by broadening the scope of measures and options to move closer to a full issue analysis. Here, the model provides answers to the following pollution strategy questions:

- What are the broader effects of reducing pollution from specific sources with respect to achieving targets?
- How do the abatement costs for specific measures and sources compare, and what are their corresponding expected impacts on the environment and human health?
- What are the costs and impacts on the environment and human health of a specified set of emission control policies for a given agricultural/energy scenario?
- How can the community most efficiently use resources to achieve a given target under a given agricultural/energy scenario?

2.2 Overview of Model Inputs

In this section, the principal inputs to the RAINS model are detailed. As explained in the previous section, the RAINS model has a number of different facets which require data or calibration of some form in order for the model to deliver useful output. It is also important to note that not all data utilised within the RAINS model are obtained directly through submissions under the 'RAINS process' or the bilateral consultations with the IIASA. Ireland, as with all Member States and signatories to agreements, has a number of reporting requirements wherein data may indirectly feed into the modelling process. As an example, the Irish EPA submits data to the UNFCCC on emission point sources which assists the EMEP model grid in allocating the distribution of pollution sources to the 50 km × 50 km squares. All primary data required for the RAINS model will be considered in this section.

The first stage of data input to the RAINS model is related to the calibration of a base year. The present base year used in the RAINS model is the year 2000. These data were chosen as historical data should present all Member States with the opportunity to deliver a verified set of the requisite information. This in turn allows the IIASA team to ensure that input data are calibrated such that emissions calculated by RAINS for the year 2000 are consistent with the national emission inventory of the same year.

Baseline data input requirements can broadly be broken into the following categories.

Activity levels

Activity levels refer to the quantities of fuel (defined as activities in the model) used in a given anthropogenic activity in a given sector in a given year (energy scenario). Activities also cover the expected industrial processes (iron, steel, cement, sulphur acid, nitrogen acid, etc.), use of fertilisers and livestock projections (agricultural scenario), as well as a great number of activity variables characterising the production activities linked with VOC emissions (solvent use, chemicals, printing, painting, etc.).

Within the RAINS model, there are six main activity sectors and 18 of the fuel types are linked with energy-related activities. Four of the 18 fuel types are categorised under renewables, hydro, nuclear and electricity (PJ produced). These are not used directly for emissions calculation but rather for energy balance purposes.

The RAINS model identifies 22 fuel types of varying emission characteristics from brown coal to nuclear. A 23rd activity is NOF – representing emissions from activities with no fuel use such as fertiliser use or emissions from non-combustion industrial processes. Activity levels for the baseline are submitted by the Member States.

Emission factors and removal efficiencies

Emission factors (EF) allow the model to calculate the expected unabated emissions from a given activity, whilst the impact of any given abatement technology is reflected in removal efficiency (RE) value. The emission factors used in RAINS are derived primarily from the *EMEP/CORINAIR Emission Inventory Guidebook*[13] prepared by the European Environment Agency (EEA). However, not all emission factors are uniformly transferable across the RAINS Europe area, and as such

13. Additional information available online http://reports.eea.europa.eu/

national studies and submissions from national experts can be used to justify altering an emission factor for a specific Member State as a country-specific factor or parameter. All removal efficiencies are carefully assessed and revised as soon as new studies are available for the concerned technologies, particularly in the case of newer abatement technologies.

The EF and RE together provide the total abatement and the remaining emissions after abatement for a given technology. The reason that the two factors are separated is to facilitate the evaluation of technology efficiency and costs within the model.

Control strategies and technology penetration

Control strategies refer to the current and expected penetrations of abatement technologies across all sectors within the specified time interval (typically 1990–2030). They are expressed in terms of the current or expected percentage of implementation of a specific technology in a given sector for a given time period. If 100% of a given activity level is expected to be covered by a given abatement technology in 2025, then the associated EF for all of that activity in 2025, the related RE, and the implementation factor (100%) will be applied to the emission calculation for that specific sector.

Technology penetration covers all data pertaining to the existing installations (fixed sources) and market penetration (mobile sources) of abatement technologies. These penetration data are included in the input data by accounting for the proportion of a given activity covered by a given technology, e.g. 50% covered by FGD, 50% uncontrolled/unabated. These data are primarily sourced from the Member States and/or EU statistical data (EUROSTAT). The calculation of emissions and the role of emission control options within the model will be dealt with in more detail in Sections 2.3.1 and 2.3.2.

Cost data

Cost data in the model are both country specific and common to all. The country-specific cost data requested by the model are comparatively limited as many of the costs are considered common to all Member States within the model (e.g. investment costs). In broad terms, the cost data refer to the cost of installation and maintenance of a given abatement technology. This affords the model the opportunity to rank the efficacy of a technology's abatement potential *versus* the marginal increasing cost. The types of cost data requested and the distinction between country specific and common costs are detailed later.

In addition to the data described under the headings above, additional 'forecast' data are required to establish steady-state base scenarios for future years to 2030. Information is requested with regard to expected developments in the following areas:

- Socio–economic drivers
  The socio–economic drivers refer to aspects of a Member State's development which are expected to affect emission levels and projections. These drivers include population growth, GDP, sectoral shares of GDP[14] and expected indexed growth of key sectors/activities from the year 2000. These factors are necessary to determine the likely development of polluting activities, i.e. projected emissions from a given source will be a function of the expected growth or shrinkage in overall activity for that sector. These socio–economic parameters are again exogenous and are determined exclusively by the skill of the user.

- Energy/agricultural scenarios/forecasts
  Perhaps the most significant data set requested for forecasting comprises the expected energy and agricultural scenario data. The scenario data include critical information such as assumed fuel costs and consumption and synergies with climate policies and other key sectoral developments. Scenario data can be sourced from a number of places and multiple scenarios can then be employed within the model to assess varied future states. Sources for scenario data are discussed in more detail in Section 2.3.4.

2.3 Input Relationships

The model outputs are based on the interrelationship of the key model elements. The interrelationships of inputs within the three modules of the RAINS model are considered here. The mathematical formulae have been omitted from this paper as a number of academic papers are available online from the IIASA[15] which cover this in detail. As such, reproducing the mathematical formulae without adequate description would serve little purpose. Instead, a more qualitative assessment of model interactions is presented.

14. Industry, tertiary and energy/others sector.
15. www.iiasa.ac.at

Figure 2.1 is a familiar schema which outlines the inputs, elements and outputs of the RAINS model. Broadly speaking, the first three columns on the left side of the schema represent elements and functions of the EMCO module, whilst the fourth and fifth columns represent the functions of the DEP and OPT modules, respectively.

As indicated, the RAINS model has a considerable data requirement spanning economic assumptions, development paths, abatement technology penetration and potential, costs and anthropogenic activity levels.

Sections 2.3.1, 2.3.2, 2.3.3 and 2.3.5 examine the relationships of these inputs in terms of:

- Emission Calculation **EMCO MODULE**
- Emission Control Options **EMCO MODULE**
- Cost Calculation **EMCO MODULE**
- Source-Receptor relationship **DEP MODULE**

An additional note is included on the TREMOVE model, given that it will play a role in the RAINS modelling process at some point.

2.3.1 *Emission calculation*

In this section, the process by which the RAINS model calculates emissions for a given activity is demonstrated in individual stages. Through this descriptive process, the underlying mechanism for individual pollution estimate calculation is presented.

This individual emission calculation occurs at a highly disaggregated level as illustrated using NO_x in the road transport sector in the following hierarchy chart (Fig. 2.2).

Table 2.1 presents the emission calculation table as constructed within the RAINS model for the bottom level of the hierarchy chart shown in Fig. 2.2. Thus, this table and the worked example will look only at the emissions for light-duty four-stroke road vehicles (TRA_RD_LD4) running on gasoline (-GSL). It is also noted that activity

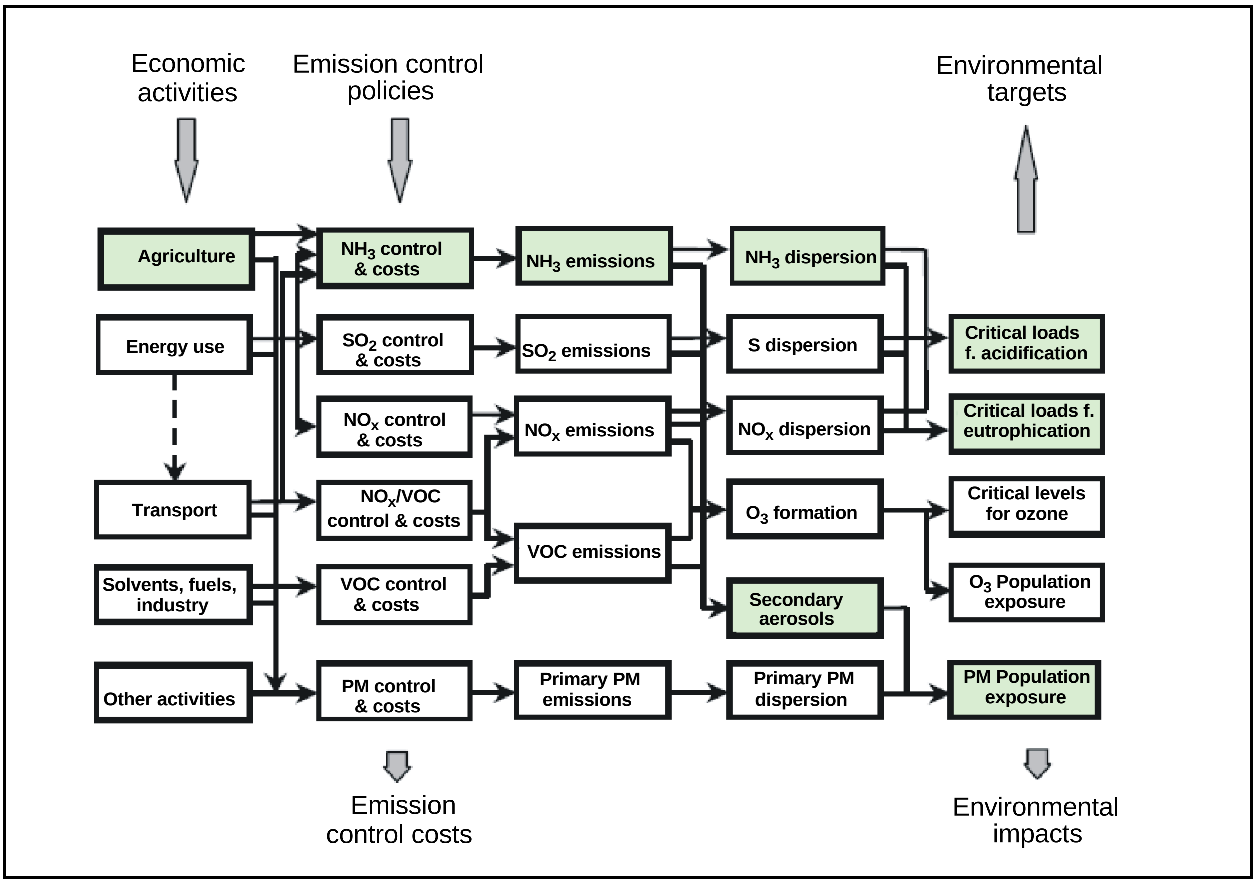

Figure 2.1. RAINS model structure with ammonia elements highlighted. Source: Interim Report IR-04-048 Klimont and Brink.

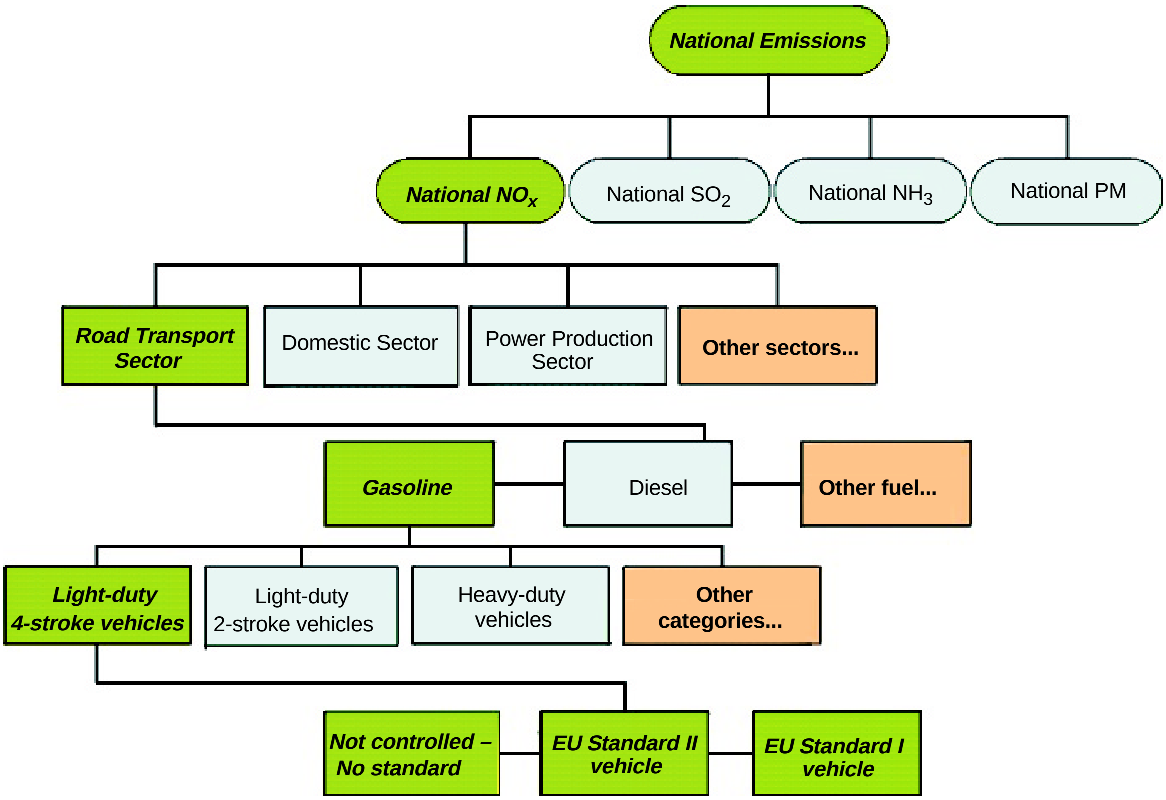

Figure 2.2. RAINS disaggregation example chart.

levels (amount of energy used under a particular heading) are recorded in petajoules, as indicated by the bracketed PJ at the end of the sub-sector identifier code.

Under this level of disaggregation there are three types of emission abatement technology options which are considered for emission calculation, i.e. the total level of NO_x pollution from this category of road vehicle is dependent on how much of the total vehicle activity is covered by each of these three possible technology options (text in italics and highlighted in yellow).

The three options in this example are the EU I standard for vehicles, the EU II standard and the default option in all cases of NSC (not suitable for control) or NOC (no control). In the case of NSC/NOC, there is no technology applied to that share of activity, and hence there is no removal efficiency as highlighted in bold in Table 2.1. In these cases, the total emission factor is equal to the unabated EF, as there is no technological abatement to reduce the unabated level of NO_x emissions for this uncontrolled share of activity.

For the removal efficiency values of EU I and EU II technology levels, we can see that vehicles conforming to EU I and EU II standards reduce the unabated emission factor by 71% and 87%, respectively. Thus, as an example, for vehicles in the category identified (TRA_RD_LD4-GSL), which conform to the EU I standard, the unabated emission factor of 0.75 is reduced to a total emission factor of 0.218.

Table 2.1. RAINS disaggregated emissions calculation example – basic.

Main sector	Sector-Activity-Tech-Unit	Activity level (PJ)	Unabated emission factor	Removal efficiency (%)	Abated emission factor (kton/PJ)	Capacity controlled (%)	Calculated emission (kton)
TRA_RD	TRA_RD_LD4-GSL-*LFEUI-[PJ]*	200	0.75	71	0.218	30	13
TRA_RD	TRA_RD_LD4-GSL-*LFEUII-[PJ]*	200	0.75	87	0.098	50	9.8
TRA_RD	TRA_RD_LD4-GSL-*NSC_TRA-[PJ]*	200	0.75	**0**	0.75	20	30

In Table 2.2, the next elements of the calculation to consider are highlighted in bold. These values are the activity level for this sub-sector and the capacity of that total activity which are controlled by each technology. In this example, the total activity level for our chosen sub-sector is 200 PJ. It is important to note that within the RAINS model the activity level column represents the total activity for the level of disaggregation before separating technology types. Therefore, 200 PJ represents a combined value of fuel consumption (i.e. activity level) for all light-duty four-stroke vehicles running on gasoline, irrespective of technology level.

The distribution of the 200 PJ of activity in this sub-sector is performed instead by the capacity-controlled column values. These values of 30%, 50% and 20% apportion the appropriate level of activity to each technology based on their value (i.e. market penetration of the abatement technology weighted on the fuel consumption).

Thus, in our example, and as highlighted in Table 2.2, we see that the 200 PJ of activity by this category is divided on the three technology penetration figures. In the first row, we can see that 30% of the 200 PJ of activity is by vehicles which conform to the EU I standard, whilst in the second row we see that 50% of the vehicle activity is covered by the EU II standard. The 20% balance of the 200 PJ of activity is accounted for in row three by vehicles which have no abatement technology.

Table 2.3 highlights the final emission levels in bold. The calculation of these values is a straightforward computation using the elements discussed in Tables 2.1 and 2.2.

The calculation of the NSC (i.e. no abatement technology vehicles) row is done by assigning the appropriate share of the 200 PJ of activity to this ‘technology’. In this case 20% of the vehicles are NSC and so there are 40 PJ (200 × 0.20) of activity here. The next stage is quite simple given that there is no abatement technology. The unabated emission factor for a PJ of activity remains the same (0.75). Thus, the 30 units of NO_x emissions are derived from simply multiplying the activity level (40) by the abated emission factor (0.75).

In the case of the other two technologies, the same process is applied. The EU II standard has a 50% market penetration and therefore accounts for half of the 200 PJ of activity (100), whilst the EU I standard has a 30% market penetration and accounts for the remaining 60 PJ of activity for this sub-sector.

However, the presence of an abatement technology for both EU I and EU II means that the total abated emission factor is lower than the unabated factor of 0.75. For example, in the EU II standard the removal efficiency of the technology serves to reduce the unabated emission factor by 87%. This gives an abated emission factor value of 0.098 [0.75 × (1–0.87)]. This total abated emission factor is then applied to the share of activity for this technology (100 PJ) delivering an emission level of 9.8 units of NO_x (0.098 × 100). This same process delivers an

Table 2.2. RAINS disaggregated emissions calculation– second stage.

Main sector	Sector-Activity-Tech-Unit	Activity level (PJ)	Unabated emission factor	Removal efficiency (%)	Abated emission factor (kton/PJ)	Capacity controlled (%)	Calculated emission (kton)
TRA_RD	TRA_RD_LD4-GSL-LFEUI-[PJ]	**200**	0.75	71	0.218	**30**	13
TRA_RD	TRA_RD_LD4-GSL-LFEUII-[PJ]	**200**	0.75	87	0.098	**50**	9.8
TRA_RD	TRA_RD_LD4-GSL-NSC_TRA-[PJ]	**200**	0.75	0	0.75	**20**	30

Table 2.3. RAINS disaggregated emissions calculation – final stage.

Main sector	Sector-Activity-Tech-Unit	Activity level (PJ)	Unabated emission factor	Removal efficiency (%)	Abated emission factor (kton/PJ)	Capacity controlled (%)	Calculated emission (kton)
TRA_RD	TRA_RD_LD4-GSL-LFEUI-[PJ]	200	0.75	71	0.218	30	**13**
TRA_RD	TRA_RD_LD4-GSL-LFEUII-[PJ]	200	0.75	87	0.098	50	**9.8**
TRA_RD	TRA_RD_LD4-GSL-NSC_TRA-[PJ]	200	0.75	0	0.75	20	**30**

NO_x emission level of 13 units for vehicles under the EU I standard.

In this example then the 200 PJ of activity from the light-duty four-stroke gasoline road vehicles gives a total level of 52.8 units of NO_x. This process is repeated for all sub-sectors under road transport to give an NO_x emission factor for this area, and so on back up the hierarchy chain in Fig. 2.2 until we have a national NO_x emission level.

2.3.2 Emission control options

Prior to engaging with the methodology employed within RAINS to calculate the cost of pollution abatement, this section will consider how emission control options are handled (or not handled) within the model. Outside of the model, emission controls can be broadly segregated into three categories. These are listed as follows.

1. *Human Behaviour*

   This category covers the spectrum of anthropogenic activities which, if altered, by whatever means, would impact on pollution levels through an alteration of the related sectoral activity levels. An example of such a measure could be a road-pricing charge or environmental levy which encourages a reduction of polluting activities such as driving.

   Such changes are not calculated internally within the RAINS model. Rather, the model can take account of the effect of such measures by consideration of alternative exogenous scenarios (e.g. modified energy scenario).

2. *Structural Measures*

   This category refers to measures which reduce polluting activities without any impact on anthropogenic activities. In other words, these are measures which alter pollution levels without having an effect on people's behaviour. Examples of structural measures include means of energy saving or fuel substitution to cleaner fuels.

   Structural measures such as the above are not currently included within the RAINS model, but once again, can be accounted for by importing values from exogenous scenarios. However, the GAINS model, which will deal with both the above-mentioned pollutants and greenhouse gases, will include structural measures such as fuel switching and emissions trading as options. In addition, the TREMOVE transport model may feed in the expected response of certain transport-related structural measures. The TREMOVE model is discussed briefly in Section 2.3.6.

3. *Technical Measures – 'End of Pipe'*

   This category refers to technical measures which reduce emissions at their source via an abatement technology. These measures reduce emissions without affecting anthropogenic activity or fuel composition for energy. Such measures are often referred to as 'end-of-pipe' (EOP) measures. EOP measures are included in the RAINS model and a database of technical measures, their costs and removal efficiency for abatement, has been developed. These data are drawn from a range of sources such as international literature and Integrated Pollution Prevention and Control (IPPC) reports on best available technology (BAT). An additional source of EOP relevant information has come from the UNECE Expert Group on Techno–Economic Issues (EGTEI). Thus far, reports from the EGTEI relating to road transport (on and off road), the glass industry and solvent use have been incorporated into the RAINS database.

   The emission factors and associated costs of EOP measures are important for the cost calculation within the RAINS model which is discussed in the following section. It is also important to note that given the RAINS focus on EOP measures, the RAINS model scenario calculations range between the current legislation (CLE) and the maximum technical feasible reduction (MTFR[16]). Thus, when the model assesses the MTFR, it is important to remember that the focus is on technical measures[17] only. An extended MTFR would include non-technical measures also.

2.3.3 Cost calculation

Following on from emission calculations, a core objective of the RAINS model is to assist in determining cost-effective/cost-minimised allocations of pollution control measures across Member States and their respective economic sectors to achieve specific objectives. This optimisation function is now carried out externally to the

16. The definition of MTFR and the inclusion of emerging technologies is itself an ongoing debate.
17. Although there is scope to take account of non-technical measures through exogenous inputs from alternative models/research, e.g. TREMOVE transport policy assessments.

RAINS model using the General Algebraic Modeling System (GAMS) optimisation software. However, the cost curves used for the optimisation are taken from the RAINS EMCO module.

The cost calculation module of the RAINS modelling process considers the variation of emission reduction costs and their effectiveness across the individual pollution sources of Member States. It is through this process that the model develops what are known as ‘cost curves’. Cost curves identify the emission reduction levels and associated costs for a given pollutant in each of the Member States. They allow the model to determine the marginal cost of abatement from a given source, i.e. the cost of reducing the next unit of pollution from a specific source.

Generally, the cost curve will indicate a favourable emission reduction to cost ratio[18] which gradually develops into a vertical line as abatement capacity is reached and options are exhausted. This is demonstrated

18. In other words, the cost curve begins with the most cost-effective abatement option per unit of pollution and gradually becomes **less favourable** in terms of pollution abated with respect to cost.

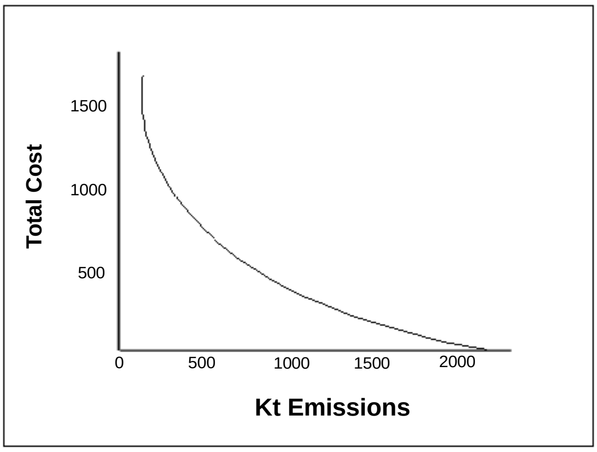

Figure 2.3. Cost curve example.

in Fig. 2.3, where initially the cost of reducing emissions is comparatively low relative to the quantity abated. However, as technology options are exhausted the curve moves in a vertical manner from right to left as the **best** options for abatement are exhausted and only measures with high marginal costs of abatement remain.

An actual example of a RAINS model cost curve is presented in Fig. 2.4. In this example, a cost curve for SO_2

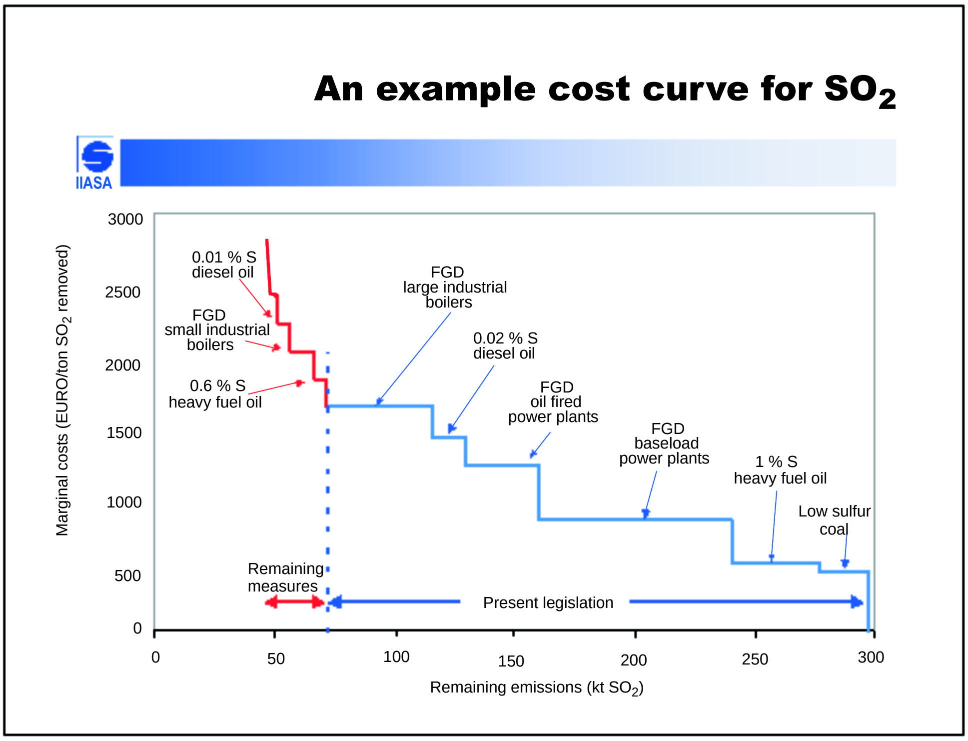

Figure 2.4. Actual cost curve example for SO_2 within RAINS. Source: Presentation by Janusz Cofala on RAINS emissions control and cost modelling.

abatement is displayed. Along the curve, the individual measures are labelled with their position representing their cost and abatement efficiency. The blue horizontal line indicates measures which are part of current legislation (CLE), whilst the red horizontal line indicates 'additional' measures for SO_2 abatement. The curve is a visual representation of the ranking which the RAINS model employs when optimising for a given target and determining the cost-minimal set of measures for target achievement.

In the estimation of cost curves, the following aspects are considered within the RAINS model:

1. The existing abatement technology in place at the pollution source.
2. The implementation cost of more efficient technologies (evaluations of upgrading cost of technologies has not been included).
3. The expected level of improvement in terms of pollution abatement for new technologies over existing technology.
4. The activity level for a given pollution source and expected impact on emission levels.

It is critical with regard to the development of cost curves that accurate data are available from each Member State on each of the above elements. In the absence of accurate data, a country could mistakenly be perceived as a highly cost-effective location for emission abatement. In the optimisation process, this could then lead to a country being asked to meet an abatement measure which is in fact unfeasible and/or inefficient, thereby damaging the overall capacity of the model to determine the best community **package** of measures to adopt.

In terms of the 'cost' side of developing a cost curve for an abatement technology, the emission control cost assessment within the RAINS model considers the following when developing a cost curve for a given abatement technology in a Member State:

- Abatement Efficiency
- Initial Investment
- Fixed Operating Cost
- Variable Operating Cost.

Once again these data are critically important for the model to function accurately. The tables below present the cost-related parameters considered by RAINS. These are broken into 'common parameters' which are held in common for all countries (Table 2.4) and country-specific parameters (Table 2.5).

These country-specific data are therefore important as they allow the model to fairly assess the true cost of further abatement in a given country. In their absence, or in the presence of inaccurate data, the model will fail to allocate the EU-wide burden of pollution abatement in a cost-effective manner. This highlights the importance of Member State engagement with the process and the significance of accurate data; part of this process is carried out within the EGTEI with the participation of

Table 2.4. Common cost parameters.

Fixed-type costs and factors	Variable-type costs
Technology removal efficiencies	Added labour demand for technology
Technology unit investment cost	Added energy demand for technology
Fixed operation costs	Added materials demand for technology
Maintenance costs	–

Table 2.5. Country-specific parameters.

Country-specific factors	
Size of installations in a given sector	Price of labour
Characteristics of plants	Price of electricity
Annual fuel consumption	Price of fuel
Annual vehicle mileage	Price of materials
Cost of waste disposal	–

national experts. This issue will be addressed in detail in a further paper.

2.3.4 Projection calculation

This section identifies the driving forces behind how the RAINS model calculates projected emissions to 2030. The RAINS model draws on the following external sources as exogenous inputs.

In terms of economy and growth, the RAINS model takes account of the following key drivers by incorporating projections of same up to 2030:

- Population growth
- Economic growth
- Individual sectoral growth rates.

Information related to these key drivers is drawn from multiple sources or base input data. The base input data are important assumptions underpinning the model calculations. For example, part of an energy scenario might contain information on the expected fuel and energy prices for the future, obviously a key factor with regard to future demand levels and, by association, pollution levels.

The broadly dominant sectors of anthropogenic activity responsible for air pollution can be loosely categorised as below:

- Energy sector consumption
- Industrial process activity levels
- Agricultural sector activity levels
- Transport sector activity levels
- VOC sources activity levels.

Although widely acknowledged that projections to 2030 are susceptible to higher levels of uncertainty, what the RAINS model seeks to achieve is not so much a projection as a series of probable scenario states. As such, the model can, and will, be tested under a range of varied assumptions to highlight the expected impact of such a situation with regard to air pollution and health/environment impacts. Thus, the model serves as a tool to assess how to achieve our health and environmental targets in a cost-effective manner given certain assumptions. Projections have been and continue to be reviewed as the NECD and the Gothenburg Protocol reviews progress.

For energy, the RAINS model draws on three baseline sources which are as follows:

1. The PRIMES baseline
2. DG-TREN 2030 energy outlook
3. National energy outlooks.

Similarly, for agriculture, the RAINS model draws on exogenous sources of information:

- European projections without CAP reform
- European projections with CAP reform (once DG-AGRI finalises plan)
- National projections from Member States' own models/research.

For transport, a number of models may contribute to projections:

- National transport models
- COPERT IV
- TREMOVE.

2.3.5 Source–receptor (SR) relationship

In this section, the basic interactions of the SR element of pollution analysis within the RAINS model are explained. For source receptor analysis, the EMEP models[19] and EMEP grid[20] (see Fig. 2.5) are drawn on by the RAINS model to estimate the dispersion, atmospheric chemical reactions and subsequent deposition/impact of pollution across the full RAINS Europe region.

The first step of this process involves the RAINS team determining national emission levels by pollutant type via the EMCO module. These data are then utilised in a 'country-to-grid' EMEP model analysis. This 'country-to-grid' analysis describes the impact of changing **national** emissions on **individual grid cells** in the RAINS Europe area. This means that – technically – the RAINS model process does not allocate computed national emissions to

19. Detailed EMEP model information can be found at http://www.emep.int/index_model.html
20. Section 2.5 details how the increased resolution of a national grid can pinpoint 'hotspots' and provide better impact assessment.

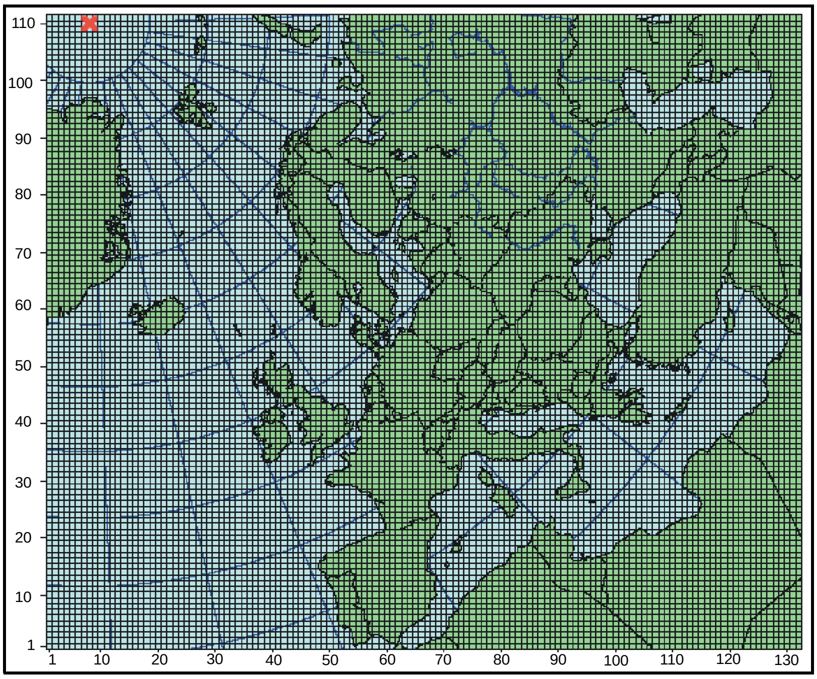

Figure 2.5. EMEP 50 km × 50 km grid. Source: www.emep.int.

each relevant national grid cell (i.e. identifying the national location of a given pollution source), and then calculate the grid-to-grid dispersion of pollutants across the RAINS Europe area. Instead, the model applies 'country-to-grid' relationships, which are derived assuming a constant spatial pattern of **sectoral** emissions within each country. Thus, RAINS calculations are accurate for measures which uniformly apply to all emission sources of a sector in a country, but might result in inaccuracies for cases such as single point sources. However, given the fact that point sources are generally controlled in Europe via the IPPC, the resulting error has been found to be small. In any case, as an additional check, policy scenarios are always validated with the full EMEP model, which applies a grid-to-grid calculation.

The next stage of the DEP module is to determine the transportation and chemical reactions of pollutants and thereby determine the location and level of pollution incidence across the grid as per the example in Fig. 2.6.

With the source and ultimate receptor of pollution determined, the model can then evaluate the 'exceedance' levels across the region. In this process, the model considers the 'critical load' levels of the grid cells with regard to a pollutant and determines if these levels have been exceeded and what the likely impact of the exceedance would be in terms of policy objectives, e.g. acidification and eutrophication targets.

2.3.6 TREMOVE model and interaction with RAINS

The exact interaction of the TREMOVE model with the RAINS modelling effort and the NECD is not yet clear. However, the model will be used in some capacity so as to take advantage of the more advanced sector-specific (transport) emissions calculation and the capacity to model the impact of 'non-technical' abatement policies. Output from the TREMOVE model with regard to cost curves for the transport sector is likely to be incorporated in some form into the RAINS model calculations.

The TREMOVE model has a number of core modules which allow it to undertake a broader assessment of policy change impacts, particularly with regard to emissions from the road transport sector. These modules are as follows:

- Transport Demand Module
- Emissions Module
- Vehicle Stock and Turnovers Module
- Welfare Module
- Lifecycle Emissions Module.

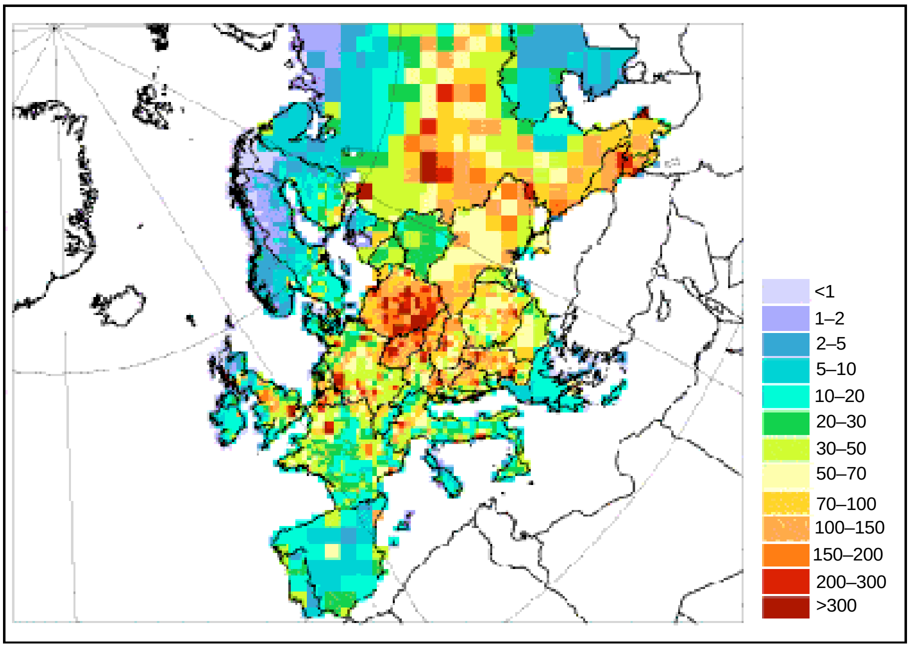

Figure 2.6. Example of EMEP pollution deposition map. Source: www.emep.int.

An overview of the model elements is presented in Fig. 2.7. In this diagram, the yellow boxes represent inputs to the model, red boxes represent calibration variables and green boxes represent module outputs. The modules themselves are in the blue boxes. An additional housing module which takes account of ozone formation is not included in the diagram.

From the diagram, it is notable that there are no dispersion or chemical interaction elements. However, the TREMOVE model can provide valuable emission and cost assessments of a range of transport policies which should at some level be incorporated into the RAINS modelling work under the NECD. Ongoing updates with regard to the TREMOVE model can be found at the project website – www.tremove.org.

2.4 Output

The RAINS model is available for use online[21] and provides access to a number of scenarios and potential outputs for each individual country in RAINS-Europe.

Using the online version of RAINS, one can explore and export data which had been previously inputted to the model. Thus, one can browse through each type of input data, as detailed in this paper, for each country. In addition, the RAINS online model allows viewing and exporting of output data from the model as results from scenarios.

21. The online version of the RAINS model can be found at the following web address: http://www.iiasa.ac.at/RAINS

In general, the RAINS online model will allow (assuming access privileges) a user to investigate the impact of varied values on basic model output. Thus, whilst the EMCO module is available online and allows a user to examine model output and present inputs with regard to pollution activity levels, emission levels, control penetration and costs, it is not possible to run alternative European optimisations via the online service.

This principal output of the model derived from the optimisation process of the RAINS methodology is made available in time; however, the process is managed exclusively by the IIASA team. This process can determine the cost-minimised community **package** of measures which will deliver on user-specified air quality targets – this target can include the full range of pollutants and effects. This output then provides policy makers with a strong indicator for community strategy development to meet targets.

2.5 National RAINS Models

Outside of the RAINS-Europe model hosted by the IIASA, at present there are two national versions of the RAINS model in operation. Italy and the Netherlands, in cooperation with the IIASA, have both developed their

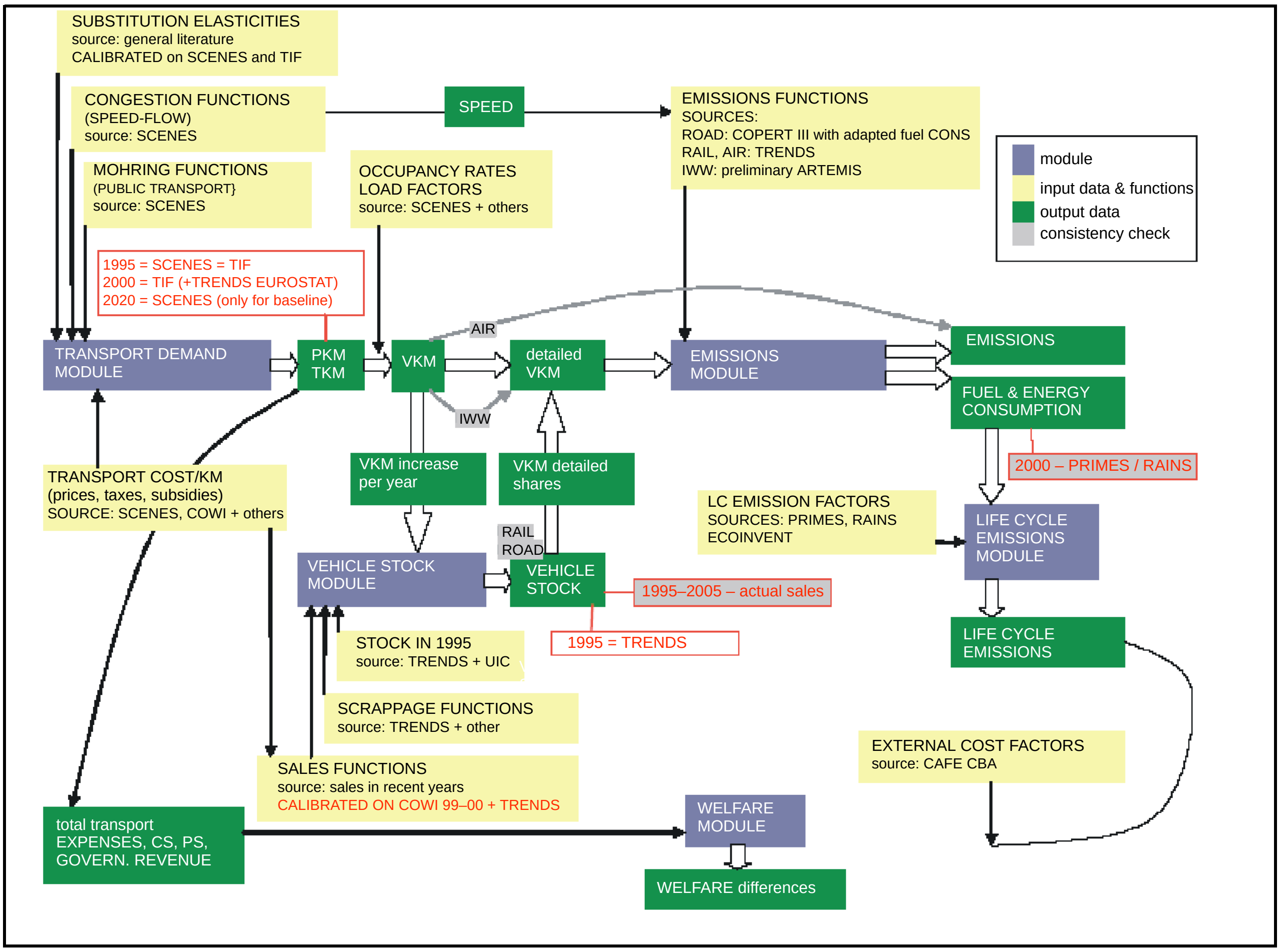

Figure 2.7. TREMOVE modules and interactions. Source: www.tremove.org.

own national versions of the RAINS-Europe Model. The main advantages of these national versions with respect to the RAINS-EU model are as follows:

- Higher spatial resolution – 20 km × 20 km in RAINS-Italy and 5 km × 5 km in RAINS-NL The improved resolution allows national specific analysis of the dispersion of the pollutants and the chemistry of the atmosphere.

- Availability of a sub-national scenario approach (RAINS-IT only). This feature allows the assessment of local policy measures.

- Ability at European level for the national RAINS Model to elaborate, independently, on emission scenarios and cost curves, based upon national data.

- Development of national expertise in the model and full compatibility between the national- and EU-level models for easy transfer of information and comparative studies of results such as analyses between national and IIASA scenarios.

Given these advantages, Sweden is currently evaluating the possibility of a similar project, at a ‘Scandinavian Countries Level’, whilst Poland has also closely followed the Italian project and has started an internal discussion on the subject.

Whilst Ireland currently lacks a national dispersion model, the timeline of the NECD and the Gothenburg Protocol and potential future integration of air quality and greenhouse gas policy suggest that an investment in RAINS/GAINS Ireland may be of significant value for future negotiations and interaction.

3 Conclusion

This paper has outlined the form and function of the RAINS model and the general role it is expected to play in the assessment and achievement of national emission targets under the NECD and Gothenburg Protocol. The model has been explored through an analysis of the inputs, their relationship within the modules, and ultimately the type of outputs generated.

This paper establishes a base from which to explore further aspects of the RAINS process. The next paper in this series will highlight the importance of accurate national data and will investigate data gaps and measures to improve national reporting mechanisms for RAINS and TREMOVE. Subsequent papers will then advance to alternative scenario analysis using the RAINS model.

An important final note is that the RAINS model has been extended into a model known as GAINS which takes account of not only air quality and acid precursors but also greenhouse gases. This new model will allow integrated assessment of air quality and climate change policy, and represents a significant development in this broader field. As such, and given that this new model is an extension of the RAINS model, using similar architecture, there is every reason to engage and understand the RAINS model and to work toward a thorough national engagement with the GAINS model in anticipation of a potential shift in European and global agreements toward fully integrated GHG and air quality policies.

Future work as a progression from the overview of the RAINS model will focus on three specific areas. The first area for future work will be a more detailed assessment of the requirements of the model from a national perspective and how to facilitate and improve Irish engagement with the RAINS model and team. The second area will involve an assessment of alternative scenario runs within the model and an examination of the impacts of varied abatement or development strategies. The third area to progress will be an assessment of the NECD policy process and the contribution of RAINS outputs to the new 2020 targets.

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Annex I Sectors, Codes and Comments

In this annex, the sectors and specific sources for each pollutant considered in the RAINS model are presented. The pollutants are considered individually with breakdowns for mobile and stationary sources as well as some other pollutant-specific disaggregations. In some cases, the RAINS model will aggregate sources of a given pollutant for simplicity's sake. The IIASA team use the following criteria when evaluating the possible aggregation of pollution sources:

"*Importance, uniform activity rates and emission factors, potential for plausible forecasts, availability and applicability of similar control technologies, availability of relevant data.*".

The information presented in this annex is drawn **directly** from official RAINS model documentation and is included here as a reference for emission sources by pollutant and sector.

Table A1. NH_3 – ammonia.

RAINS sector	Comments	RAINS code[a)]	NFR code
Livestock			
Dairy cows	Excluding suckling cows; Distinguishing between liquid and solid manure systems	AGR_COWS (DL, DS)	4B1a
Other cattle	All other cattle incl. bulls, beef cattle, suckling cows, young stock; Distinguishing between liquid and solid manure systems	AGR_BEEF (OL, OS)	4B1b
Pigs	Including fattening pigs and sows; Distinguishing between liquid and solid manure systems	AGR_PIG (PL, PS)	4B8
Laying hens		AGR_POULT (LH)	4B9
Other poultry	All poultry except laying hens, including broilers, turkeys, ducks, geese, etc.	AGR_POULT (OP)	4B9
Sheep and goats		AGR_OTANI (SH)	4B3, 4B4
Fur animals	In some countries this category might be used for other animals, e.g, rabbits	AGR_OTANI (FU)	4B13
Horses	Including mules and asses	AGR_OTANI (HO)	4B6, 4B7
Fertilizer use			
Urea		FCON_UREA (FR)	4Di
Other N-fertilizers	Refers to other mineral N fertilizers, excluding urea	FCON_OTHN (FN)	4Di
Industry			
Fertilizer production	Production of nitrogen fertilizers	FERTPRO (IN, IND[b)])	2B1, 2B5
Industrial combustion	Power plants, fuel conversion, combustion in industry	PP_..., IN_..., CON_COMB (PP_IND_COMB)	1A1, 1A2
Industrial processes	Includes coking, nitric acid, other production processes	IO_NH3_EMISS (IO, INDb)), IND_PROC)	1A2
Residential combustion	Emissions from combustion of solid fuels in domestic, residential and commercial sectors	DOM (DOM)	1A4bi, 1A4ci
Transport	Road and off-road mobile sources	TRA_... (TRANSPORT)	1A3, 1A4bii, 1A4cii, 1A5b
Waste treatment	Treatment and disposal of waste, including sludge application on the fields	WT_NH3_EMISS (WT)	6A-D
Other	Various activities reported in national emission reports including humans, pets, cigarette smoking, etc.	OTH_NH3_EMISS (OT)	

[a)]Codes refer to the Web version of the model and PC implementation (in brackets). The latter are also used in the tables in this document.

[b)]Code "IND" is used for displaying result of emission calculation only and it represents the sum of IN and IO, i.e., N fertilizer production and other industrial process.
Source: Interim Report IR-04-048 Klimont and Brink (2004).

Table A2. Mobile VOCs.

Sectors	
Primary	Secondary
Road transport	Light-duty trucks
	Passenger cars
	Gasoline evaporation
	Trucks and busses
	Motorcycles and mopeds
Other transport	Air traffic (LTO)
	Off-road vehicles
	Railways
	Ships

Table A3. Stationary VOCs.

Sectors	
Primary	**Secondary**
Solvent Use	Dry cleaning
	Metal degreasing
	Treatment of vehicles
	Domestic solvent use (excluding paint)
	Architectural painting
	Domestic use of paints
	Manufacture of automobiles
	Other industrial uses of paints and *Vehicle refinishing*
	Products incorporating solvents
	Products not incorporating solvents
	Pharmaceutical industry
	Printing industry
	Application of glues and adhesives in industry
	Preservation of wood
	Other industrial use of solvents
Chemical Industry	Inorganic chemical industry
	Organic chemical industry
Refineries	Refineries – processes
Fuel Extraction and Distribution	Gaseous fuels: extraction, loading, distribution
	Liquid fuels: extraction, loading, distribution
Gasoline Distribution	Service stations
	Refineries (storage), transport, depots
Stationary Combustion	Public power, co-generation, district heating
	Industrial combustion
	Commercial and residential combustion
Miscellaneous	Stubble burning and other agricultural waste
	Food and drink industry
	Other industrial sources
	Waste treatment and disposal

Table A4. Mobile NO_X.

RAINS sector		CORINAIR
Primary	**Secondary**	**SNAP97 code**
Road transport (TRA_RD)	Heavy duty vehicles (trucks, buses and others) (TRA_RD_HD)	0703
	Light duty vehicles, four-stroke (cars, vans, motorcycles) (TRA_RD_LD4)	
	Light duty vehicles, two-stroke (cars, motorcycles) (TRA_RD_LD2)	0701,02,04,05
Off-road (TRA_OT)	Other mobile sources and machinery with two-stroke engines (TRA_OT_LD2)	03, 08 exc. 0804 and 0805
	Other land-based mobile sources and machinery with four-stroke engines (TRA_OT_LB)	
Maritime activities (TRA_OTS)	Medium vessels (TRA_OTS_M)	080402,
	Large vessels (TRA_OTS_L)	080403

Table A5. Stationary NO_X.

RAINS sector		CORINAIR
Primary	**Secondary**	**SNAP97 code**
Power plants and district heating plants (PP)	New boilers (PP_NEW)	
	Existing boilers, dry bottom (PP_EX_OTH)	0101, 0102
	Existing boilers, wet bottom (PP_EX_WB)	
Fuel production and conversion (other than power plants) (CON)	Combustion (CON_COMB)	0103, 0104,
	Losses (CON_LOSS)	0105, 05
Domestic (DOM)	Residential, commercial, institutional, agriculture	02
Industry (IN)	Combustion in boilers, gas turbines and stationary engines (IN_BO)	0301
	Other combustion (IN_OC)	03 exc. 0301
	Process emissions (IN_PR)	04
Non-energy use of fuels (NONEN)	Use of fuels for non-energy purposes (feedstocks, lubricants, asphalt)	
Other emissions (OTHER)	Other sources: (air traffic LTO cycles, waste treatment and disposal, agriculture)	080501, 080502, 09, 10

Table A6. Mobile SO_2.

RAINS sector		CORINAIR
Primary	**Secondary**	**SNAP code**
Road transport (TRA_RD)	Heavy duty vehicles (trucks, buses and others) (TRA_RD_HD)	0703
	Light duty vehicles, four-stroke (cars, light commercial vehicles, motorcycles) (TRA_LD_LD4)	0701,02,04,05
	Light duty vehicles, two-stroke (cars, motorcycles) (TRA_RD_LD2)	0701,02,04,05
Off-road (TRA_OT)	Machinery with two-stroke engines (TRA_OT_LD2)	0801
	Other machinery and land-based sources (four stroke) (TRA_OT_LB)	0801,02,05
Ships (TRA_OTS)	Medium vessels (TRA_OTS_M)	0803,0804
	Large vessels (TRA_OTS_L)	0803,0804

Table A7. Stationary SO_2.

RAINS sectors		CORINAIR
Primary	**Secondary**	**SNAP code**
Power plants and district heating plants (PP)	New boilers (PP_NEW)	01
	Existing boilers, wet bottom (PP_EX_WB)	
	Existing boilers, dry bottom (PP_EX_OTH)	
Fuel production and conversion (other than power plants) (CON)	Combustion (CON_COMB)	05
	Losses (CON_LOSS)	
Domestic (DOM)	Residential, commercial, institutional, agriculture	02
Industry (IN)	Combustion in boilers, gas turbines and stationary engines (IN_BO)	0301
	Other combustion (IN_OC)	03 excl. 0301
	Process emissions (IN_PR)	04
Non-energy use of fuels (NONEN)	Use of fuels for non-energy purposes (feedstocks, lubricants, asphalt)	
Other emissions (OTHER)	Other sources (air LTO cycle, waste treatment and disposal)	0805

Table A8. PM stationary combustion sources.

RAINS sector	RAINS code	NFR category	SNAP sector
Centralized power plants and district heating			
New power plants	PP_NEW		
New power plants, grate combustion	PP_NEW1		
New power plants, fluidized bed combustion	PP_NEW2		0101, 0102,
New power plants, pulverized fuel combustion	PP_NEW3		020101,
Existing plants[1], wet bottom boilers	PP_EX_WB	1A1a	020102,
Existing plants[1], other types (of boilers)	PP_EX_OTH		020201,
Other types, grate combustion	PP_EX_OTH1		020301
Other types, fluidized bed combustion	PP_EX_OTH2		
Other types, pulverized fuel combustion	PP_EX_OTH3		
Fuel conversion			
Energy consumed in fuel conversion process	CON_COMB		
Fuel conversion, grate combustion	CON_COMB1		
Fuel conversion, fluidized bed combustion	CON_COMB2	1A1c	0104
Fuel conversion, pulverized fuel combustion	CON_COMB3		
Residential, commercial, institutional, agricultural use			
Combustion of liquid fuels	DOM	1A4a	
Fireplaces	DOM_FPLACE		
Stoves	DOM_STOVE		020103-06,
Single house boilers (<50 kW) – manual	DOM_SHB_M	1A4b	020202-03,
Single house boilers (<50 kW) – automatic	DOM_SHB_A		020302-05
Medium boilers (<1 MW) – manual	DOM_MB_M		
Medium boilers (<50 MW) – automatic	DOM_MB_	A 1A4a	
Fuel combustion in industrial boilers			
Combustion in boilers	IN_BO		
Combustion in boilers, grate combustion	IN_BO1		010301-03,
Comb. in boilers, fluidized bed combustion	IN_BO2		010501-03,
Comb. in boilers, pulverized fuel combustion	IN_BO3	0301	
Other combustion	IN_OC		
Other combustion, grate combustion	IN_OC1		010304-06,
Other combustion, fluidized bed combustion	IN_OC2		010504-06,
Other combustion, pulverized fuel combustion	IN_OC3	1A2	0302, 0303

[1]Refers to all sources that came on line before or in 1990.

Table A9. PM stationary non-combustion sources.

RAINS sector	RAINS code	NFR category	SNAP sector
Iron and steel industry			
Coke production	PR_COKE	1B1b	040201, 04
Pig iron production	PR_PIGI		
Pig iron production (fugitive)	PR_PIGI_F	2C1	040202,03
Pelletizing plants	PR_PELL		
Sinter plants	PR_SINT		
Sinter plants (fugitive)	PR_SINT_F	1A2a	030301, 040209
Open heart furnace	PR_HEARTH		040205
Basic oxygen furnace	PR_BAOX		040206
Electric arc furnace	PR_EARC	2C1	040207
Iron and steel foundries	PR_CAST		
Iron and steel foundries (fugitive)	PR_CAST_F	1A2a	030303, 040210
Non-ferrous metal industry			
Primary aluminum	PR_ALPRIM	2C3	040301
Secondary aluminum	PR_ALSEC		030310
Other non-ferrous metals (lead, nickel, zinc, copper)	PR_OT_NFME	1A2b	030304-09, 24;040305, 09
Other industrial processes			
Coal briquettes production	PR_BRIQ	1A1c	0104
Cement production	PR_CEM		030311, 040612
Lime production	PR_LIME		030312, 040614
Glass production	PR_GLASS	1A2f	030314-15, 17; 040613
Petroleum refining	PR_REF	1B2a	030311, 040612
Carbon black production	PR_CBLACK		040409
Fertilizer production	PR_FERT	2B5	040404-08, 14
Other production processes (glass fiber, PVC, gypsum, other)	PR_OTHER		040416, 040508, 040527
Small industrial plants, fugitive	PR_SMIND_F	2D	
Mining			
Brown coal mining	MINE_BC		
Hard coal mining	MINE_HC	1B1a	050101, 050102
Other (bauxite, copper, iron ore, etc.)	MINE_OTH	2A7	040616
Agriculture			
Livestock – poultry	AGR_POULT	4B9	100507-09
Livestock – pigs	AGR_PIG	4B8	100503-04
Livestock – dairy cattle	AGR_COWS	100501	
Livestock – other cattle	AGR_BEEF	4B1	100502
Livestock – other animals	AGR_OTANI	4B3-7, 13	100505, 06
Ploughing, tilling, harvesting	AGR_ARABLE	4D	
Other	AGR_OTHER	7	
Waste			
Flaring in gas and oil industry	WASTE_FLR	1B2c	090206
Open burning of agricultural waste	WASTE_AGR		0907, 1003
Open burning of residential waste	WASTE_RES	6C	
Storage and handling of bulk materials			
Coal	STH_COAL	1B1a	050103
Iron ore	STH_FEORE	2A7	040616
N, P, K fertilizers	STH_NPK	2B5	040415
Other industrial products (cement, coke, etc.)	STH_OTH_IN	2A7	040617
Agricultural products (crops)	STH_AGR	2D	
Other sources			
Construction activities	CONSTRUCT	1A2f	
Meat frying, food preparation, BBQ	RES_BBQ		
Cigarette smoking	RES_CIGAR	7	
Fireworks	RES_FIREW		
Other	OTHER		

Table A10. PM mobile exhaust sources.

RAINS sector	RAINS code	NFR category	SNAP sector
Road transport			
Heavy duty vehicles (trucks, buses and others)	TRA_RD_HD		0703
Motorcycles, four-stroke	TRA_RD_M4		0704
Motorcycles and mopeds (also cars), two-stroke	TRA_RD_LD2		0704
Light duty cars and vans, four-stroke	TRA_RD_LD4		0701-02
Light duty cars, four-stroke, gasoline direct injection	TRA_RDXLD4	1A3b	0701-02
Off-road transport			
Two-stroke engines	TRA_OT_LD2	1A4b	
Construction machinery	TRA_OT_CNS	1A2	
Agricultural machinery	TRA_OT_AGR	1A4c	
Rail	TRA_OT_RAI	1A3c	0801-02, 0806-10
Inland waterways	TRA_OT_INW	1A3d	
Air traffic (LTO)	TRA_OT_AIR	1A3a	
Other; four-stroke (military, households, etc.)	TRA_OT_LB	1A4c	
Maritime activities, ships			
Medium vessels	TRA_OTS_M		0803,
Large vessels	TRA_OTS_L	1A3d	080402-03

Table A11. PM mobile non-exhaust sources.

RAINS sector	RAINS code	NFR category	SNAP sector
Road transport, Tire wear			
Heavy duty vehicles (trucks, buses and others)	TRT_RD_HD		
Motorcycles, four-stroke	TRT_RD_M4		
Motorcycles and mopeds (also cars), two-stroke	TRT_RD_LD2	1A3b	0707
Light duty cars and vans, four-stroke	TRT_RD_LD4		
Light duty cars, four-stroke, gasoline direct injection	TRT_RDXLD4		
Road transport, brake wear			
Heavy duty vehicles (trucks, buses and others)	TRB_RD_HD		
Motorcycles, four-stroke	TRB_RD_M4		
Motorcycles and mopeds (also cars), two-stroke	TRB_RD_LD2	1A3b	0707
Light duty cars and vans, four-stroke	TRB_RD_LD4		
Light duty cars, four-stroke, gasoline direct injection	TRB_RDXLD4		
Road transport, abrasion of paved roads			
Heavy duty vehicles (trucks, buses and others)	TRD_RD_HD		
Motorcycles, four-stroke	TRD_RD_M4		
Motorcycles and mopeds (also cars), two-stroke	TRD_RD_LD2	1A3b	
Light duty cars and vans, four-stroke	TRD_RD_LD4		
Light duty cars, four-stroke, gasoline direct injection	TRD_RDXLD4		