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# Working Paper

## Constructing Regional Energy Scenarios from Global Energy Models

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WP-95-112
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# Preface

Emissions from energy combustion have a variety of environmental impacts, with geographical scales ranging from local over regional to global extensions. Comprehensive assessments of the options for environmentally compatible energy strategies must therefore consider not only emissions having impacts on different spatial scales (e.g., sulfur dioxide and nitrogen oxides as major precursors of acid rain and emissions of carbon dioxide as an important greenhouse gas), but also the sources for these emissions, i.e., energy consumption on global and local levels in a consistent fashion.

At IIASA, currently two research projects explore the different scales of environmental impacts of energy use. The IIASA Environmentally Compatible Energy Strategies (ECS) Project studies energy trends and development options on a global scale, with special emphasis on emissions relevant for global climate change. The IIASA Transboundary Air Pollution (TAP) Project explores regional air pollution problems caused by energy combustion, such as acid rain and tropospheric ozone. Regional analyses have been carried out for Europe and South-East Asia. Although current levels and future expectations on energy consumption are a crucial element for both groups, it is in the nature of the problem that the underlying statistical databases and scenario assumptions used by the two projects are not always identical.

This paper describes a methodology to put both analyses on a common basis. In particular, the paper introduces an approach to derive from global energy scenarios (e.g., developed by IIASA's ECS project) with limited spatial resolution a consistent picture of regional energy consumption with the resolution required for the analysis of regional air pollution problems. Thereby, the integrated assessment of environmental impacts of energy consumption can be expanded to air pollution problems with different spatial and temporal scales.

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## 1. Introduction

Energy consumption is a major source of various species of emissions to the atmosphere. Environmental impacts of emissions may occur on different geographical scales. Whereas emissions of greenhouse gases exert an influence on the global climate, emissions of acidifying compounds such as sulfur dioxide and nitrogen oxides have impacts on a regional and local scale. Consequently, also strategies to reduce emissions must be formulated at the corresponding levels.

Since greenhouse gases influence climate on a global scale, the location of emission sources is not important for their actual environmental impacts; only a global budget of sources and sinks of emissions is decisive. Thus such strategies may be explored based on highly aggregated energy forecasts, e.g., for a few world regions. Regions may be distinguished according to similar economic structures.

The IIASA Environmentally Compatible Energy Strategies (ECS) Project has developed a set of models to analyze and develop energy scenarios on a global scale. The model system consists of two energy models (11R and MESSAGE III). 11R is a top-down macro-economic model, which is implemented for the entire world distinguishing 11 regions (Manne and Richels, 1992). 11R is a nonlinear dynamic optimization model which maximizes output from the entire economy, taking into account the costs and benefits of resources devoted to investments, savings, labor, and energy. It treats energy in an aggregated manner, distinguishing only between electric and non-electric energy production and consumption.

The 'bottom-up' analysis of energy systems is performed with the MESSAGE III energy supply model (Messner, 1984). MESSAGE III is technology based, and it defines energy technologies by their cost, technical, ecological and socio-political parameters. MESSAGE III considers demand categories, secondary energy carriers, and conversion technologies. It is a dynamic linear optimization model whose objective function minimizes costs to society, including investments, operating, and resource costs. The MESSAGE III model describes the energy system for each world region in a rather detailed way, including fuel balances for about a dozen fuel types and the same number of economic sectors. The models are soft-linked through the so-called Clearing House process (Nakicenovic et al.,1993; Wene, 1995) which is used to make adjustments in specific parameters to compensate for model differences. Such an approach makes it possible to develop consistent scenarios for each of the world regions and explore strategies for reduction of greenhouse gas emissions.

Energy combustion is also an important source of emissions of other air pollutants like sulfur dioxide and nitrogen oxides with mainly regional and local impacts. Although the environmental effects of these pollutants are limited to smaller regions, they are often of transboundary nature influencing a large number of countries. A substantial portion of sulfur and nitrogen emissions is transported by winds hundreds to thousands of kilometers from their source before they are deposited on the earth surface. Once deposited they cause acidification of natural ecosystems. Environmental damage caused by acid deposition has far-reaching implications for commercial and cultural activities such as forestry, agriculture, and tourism.

The IIASA Transboundary Air Pollution (TAP) Project has developed the RAINS model of acidification which has been used for the integrated assessment of alternative strategies to reduce acid deposition in Europe (Alcamo et al., 1990). Recently the model has been further developed (version 7.0) to be applicable to any part of the world provided appropriate databases are prepared. Up to now this new version of the model has been implemented for Europe and for South-East Asia.

The RAINS 7 model describes the pathways of emissions and mechanisms of acidification in the environment for sulfur dioxide, which is a major acidifying component[1]. The model includes three major modules, i.e., energy-emissions, acid deposition and ecosystems impact module. The first module contains the database on sectoral energy consumption, calculates $SO_2$ emissions and estimates cost of emission control. Emissions of $SO_2$ are estimated based on historic energy statistics and projections for the next 20 - 30 years for each country or even country region. The second module provides estimates of ambient levels of acid precursors and acid deposition loading throughout the region under study as a function of changing emissions. The projection of acid deposition for future emissions scenarios is based on a transfer matrix describing the long range transport, which is calculated by using an atmospheric transport/deposition model. Finally, the ecosystems impact module assesses environmental effects of sulfur deposition. The module estimates critical loads, i.e., the maximum long-term deposition levels which can be tolerated without damage. The critical loads are compared with the estimates of sulfur deposition provided by the model to determine which ecosystems may be at risk under various emission scenarios. More detailed description of the RAINS 7 model, which has been recently implemented for South-East Asia, can be found in Carmichael *et al.*, 1993.

For the pollutants with regional relevance like sulfur dioxide the location of the emission source is an important factor for the extent of damage caused. Consequently, also the analysis will have to reflect these differences in geographical scales. Thus detailed energy scenarios for countries or even country regions are necessary.

The basic purpose of the RAINS model is to determine the environmental consequences of user-specified energy- and emission-reduction policies rather than to debate the energy projections themselves. Consequently, the RAINS energy data base provides energy scenarios developed elsewhere, e.g., by governmental agencies representing the official national expectations, projections, or policy targets. The European implementation of the RAINS model contains official energy projections submitted by governmental bodies to international organizations (IEA 1993, UN/ECE 1993). Consistent official projections are only available for few countries in Southeast Asia. Thus the reference RAINS scenarios (Green *et al.*, 1995) have been developed for each country with the use of a sector- and fuel-specific energy model (Foell *et al.*, 1991). The consistency of these reference scenarios, both in terms of the international consistency of the underlying assumptions (e.g., on energy price developments) and in terms of their long-term dynamics (e.g., sustainability of GDP growth rates, pace of energy efficiency improvements and decarbonization of energy supplies), is not

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[1] Modules for nitrogen oxides ($NO_x$) and ammonia ($NH_3$) will be incorporated in the future into the RAINS 7.0. These modules are already available in the previous (RAINS 6.0) version of the model for Europe.

the subject of research undertaken with the RAINS model. The Environmentally Compatible Energy Strategies Project (ECS) explores these aspects in more detail.

Problems of emissions of pollutants with global and regional relevance are closely interrelated, since both types of emissions have a common source in energy combustion. In order to develop effective strategies for reducing global and regional air pollution, both aspects must be considered simultaneously. Pursuing a combined approach, however, requires a consistent translation of global energy trends (and policies) to the regional and national level. This paper introduces a methodology to translate global and continental scale energy scenarios as for instance produced by the 11R-MESSAGE III model set into projections of energy demand on national and sub-national levels as required by the RAINS model. For this purpose a special interface model has been developed.

Section 2 of this paper discusses the differences and similarities of aggregation in the MESSAGE III and the RAINS models. The grouping of countries to world regions, as well as fuels and sectors aggregations are shown. In Section 3 the approach of the interface model is explained. Main principles of the methodology and the rules used for fuel consumption disaggregation for both final use sectors and for the power generation sector are discussed. In Section 4 the reader will find a short description of the computer procedure. Section 5 contains the illustrative results for selected countries in one of the world regions. The paper concludes with the summary of the task and the comments about applicability and limitations of the model.

## 2. Aggregation in the MESSAGE III and RAINS models

In order to explore global energy demand and supply with the 11R-MESSAGE III model framework, the world has been divided into 11 regions. As mentioned above, similarities in the economic development and structures of energy supply systems were the major guideline for grouping the countries. Out of 11 regions, seven regions include countries in Europe and in Southeast Asia, for which the RAINS model of acidification has been implemented. Country groups are listed in Tables 1 and 2. In the RAINS approach energy data for some big countries are further disaggregated into several sub-national regions. For instance, China is divided into 27 regions/provinces and India into 20 regions. Important large cities are treated as separate units. In total, the Asian implementation of the model includes 95 regions. The RAINS model for Europe includes energy data for 38 regions, of which 27 are countries, and seven are the newly independent states of the former USSR.

Energy scenarios from the ECS model set can be obtained for each of the world region in the aggregation as used by the MESSAGE III model. The MESSAGE III scenarios include more details than the aggregated scenarios produced by the 11R model. Thus they can be used as an appropriate starting point for further disaggregation into national energy demand scenarios.

Due to the different goals and spatial and temporal scales of the RAINS and MESSAGE III models, sector and fuel aggregations are different (Bertok et al., 1993, Messner, 1984). The first step in constructing national energy demand scenarios from world region scenarios developed with the help of the MESSAGE III model is the presentation of the regional energy demand in the RAINS aggregation. The following paragraphs outline the basic differences and establish the major links among the individual fuel categories and sectors considered in the models.

Table 1. Grouping of countries in Europe

| World Region | Country | |
|---|---|---|
| Western Europe | Austria | Luxembourg |
| | Belgium | Netherlands |
| | Denmark | Norway |
| | Finland | Portugal |
| | France | Spain |
| | Germany | Sweden |
| | Greece | Switzerland |
| | Ireland | Turkey |
| | Italy | United Kingdom |
| Central & Eastern Europe | Albania | Hungary |
| | Bulgaria | Poland |
| | Former Czechoslovakia | Romania |
| | Former Yugoslavia | |
| Former Soviet Union | Baltic States | European Russia |
| | Belarus | Ukraine |
| | Moldova | |

Table 3 compares fuel categories in the two models. Converting the MESSAGE III fuel categories into the RAINS classes uses the following rules:

- Coal

  In the MESSAGE III model all types of coal are aggregated together. RAINS contains up to two types of brown coal and up to three types of hard coal, based on differences in fuel quality (heat value and sulfur content). The interface model takes the aggregated coal consumption from MESSAGE III and distributes it among the RAINS categories proportionally to the values of the RAINS reference line scenario.

- Oil

  In the MESSAGE III model two types of liquid fuels are distinguished: residual fuel oil and all other oil products. The RAINS model considers three categories of oil products:

  - heavy fuel oil, equivalent to the MESSAGE III 'residual fuel oil',
  - medium distillates (diesel and gas oil),
  - light fractions (gasolines, kerosene, naphtas).

  The interface model splits the consumption of the "other oil products" category for each country into medium distillates and light fractions in proportion to the shares of the two fuels in the RAINS reference line scenario.

- All other fuel types

  For all other fuel categories the consistency between the models is almost perfect with a minor exception of the "other solids" category of the RAINS model; it is subdivided into low- and high sulfur fuels, whereas the MESSAGE III model contains only one category of "renewables with carbon emissions". Again, the division of consumption of "renewables with carbon emissions" category from the MESSAGE III model is done proportionally.

Table 2. Grouping of countries in Southeast Asia

| World Region | Country | |
|---|---|---|
| Centrally Planned Asia & China | Cambodia | Mongolia |
| | China | North Korea |
| | Laos | Vietnam |
| Other Pacific Asia | Brunei | Philippines |
| | Hong Kong | Singapore |
| | Indonesia | South Korea |
| | Malaysia | Thailand |
| | Myanmar | Taiwan |
| South Asia | Bangladesh | Nepal |
| | Buthan | Pakistan |
| | India | Sri Lanka |
| Pacific OECD / Japan | Japan | |

Table 3: Comparison of fuel types in the MESSAGE III and RAINS model

| MESSAGE III | RAINS | RAINS code |
|---|---|---|
| Coal | Brown coal (2 types*))<br>Hard coal (3 types*))<br>Derived coal (coke, briquettes) | BC<br>HC<br>DC |
| Residual fuel oil | Heavy fuel oil | HF |
| All other oil products | Medium distillates (diesel oil, light fuel oil)<br>Light fractions (gasoline, naphtha, kerosene, LPG) | MD<br>LF |
| Natural and synthetic gases | Natural gas (all gases as high methane natural gas equivalent) | GAS |
| Renewables with carbon emission | Other solid fuels incl. biomass and waste (2 types*)) | OS |
| Renewables without carbon emission | Renewables (other than biomass) | REN |
| Hydro | Hydro | HYD |
| Nuclear | Nuclear | NUC |
| Electricity | Electricity | ELE |
| Centrally supplied heat | Heat (steam and hot water) | HT |

*) depending on sulfur content

Also the aggregation of consumer groups in the two models is rather similar (Table 4). The main differences are as follows:

- Road/street transport:
  For this consumer group more detailed information is needed for the RAINS model than is available from the MESSAGE III. To solve this problem, data from MESSAGE III are distributed proportionally to the RAINS reference line scenario.

- Existing thermal power plants:
  In order to estimate emission control costs in the RAINS model, it is necessary to divide existing power plants according to the boiler type. Again, proportional distribution is used.

- Conversion sector:
  The RAINS sector contains fuel consumption for conversion processes other than power and district heat generation as well as transmission and distribution losses. Furthermore, the RAINS model distinguishes between fuel consumption for processes with combustion and losses. In the MESSAGE III model fuel consumption for the conversion sector is calculated as the difference between input of primary energy and the output of secondary or final energy.

Table 4. Comparison of economic sectors considered in the MESSAGE III and RAINS models

| MESSAGE III | RAINS |
|---|---|
| Industry: | Industry (IND): |
| boiler | boilers |
| specific furnace | specific furnace (other ind. combustion) |
| feedstocks | feedstocks (non-energy use) |
| Residential/Commercial: | Domestic (DOM): |
| specific<br>thermal<br>rural/countryside | households and other consumers |
| Transport: | Transport (TRA): |
| road/street | road: cars and light duty trucks<br>heavy duty vehicles |
| rail/water/pipe/air | other (i.a., rail,inland water, costal zone)*) |
| Power Plant Sector: | Power & District Heating Plants (PPL): |
| thermal power plants: | thermal power plants: |
| existing | existing wet bottom<br>existing other |
| new | new |
| hydro power plants | hydro power plants |
| nuclear power plants | nuclear power plants |
| Conversion (without power plants): | Fuel Production and Conversion (CON): |
| primary energy - final energy - (fuel consumption in power plants) | combustion<br>losses |

*) Fuel consumption by air transport is excluded from balances. Sulfur emission from air transport is negligible.

## 3. Approach

Obviously, a simple proportional 'down-scaling' of regional energy trends to national developments will fail to capture the country-specific characteristics of the energy demand and supply structures, e.g., national differences in indigenous coal resources or in the sectoral structures of national economies.

The erratic effects of a proportional "down-scaling" of scenarios for world regions to national level scenarios can be illustrated on a simple example. Let us assume that we have a world region consisting of two countries: A and B. We limit our considerations to one year and one economic sector only. In this sector two fuel types I and II are used. Assume further that energy consumption (in energy units, say Petajoules - PJ) in the RAINS reference ("old") scenario in our example is the following:

| | Country A | Country B | World Region |
|---|---|---|---|
| Fuel I | 20 | 80 | 100 |
| Fuel II | 80 | 20 | 100 |
| Total | 100 | 100 | 200 |

Let's assume that the world region fuel consumption for the same sector and year calculated with the MESSAGE III model is as follows:

| | World Region |
|---|---|
| Fuel I | 150 |
| Fuel II | 50 |
| Total | 200 |

The proportional "down-scaling" of such a scenario would produce the following country data:

| | Country A | Country B | World Region |
|---|---|---|---|
| Fuel I | 30 | 120 | 150 |
| Fuel II | 40 | 10 | 50 |
| Total | 70 | 130 | 200 |

Because of a change of fuel structure in the MESSAGE III scenario at a world region level (without a change in total fuel demand), total energy demand in country A would have been 30 percent lower and the demand in country B 30 percent higher than the demand in the reference scenario. Such changes do not have any reasonable justification.

The above example shows that creating national energy scenarios for more than a dozen countries from an aggregated world regional balance requires clear guiding principles together with a set of basic consistency checks. After careful examination of the two models, a simple algorithm was developed which creates national energy demand scenarios in the RAINS format while maintaining the overall balance on the regional aggregate, as provided by the MESSAGE III model. The basic idea of this approach is to start from a 'reference' scenario, describing for each country or sub-national region the 'common-wisdom' development of energy consumption over time. A new set of national energy balances is then constructed in such a way that: (1) the overall balance for the world region as provided by the MESSAGE III model is maintained, (2) for each country or region the deviations from the reference line are possibly minimized, and (3) the basic energy balances, e.g., electricity demand totalling the supply, etc., are maintained within each region.

To sketch the basic procedure we assume that a group of countries belongs to the same world region. For a certain year in the future a 'reference line' energy scenario is available for each country, e.g., in the RAINS energy database. This scenario is referred to as the "old" scenario. Furthermore, an aggregated energy scenario for the whole world region (in our case from the MESSAGE III model), is available. This scenario is referred to as the "new" scenario. The basic task to be performed is described as follows:

> Distribute the world region's energy demand among the countries so that the information on national energy systems embedded in the "old" scenario is preserved to a maximum possible extent. In other words, it is necessary to develop a reasonable set of "new" national energy scenarios which sum up to the given aggregated scenario for the world region.

An interface model was prepared to solve the described task. The algorithm of the model consists of a set of rules which are typically used by energy experts while developing energy balances with the use of simple energy models. Below the rules adopted for the final use sectors and for the power generation sector are discussed.

### *3.1. Rules for final use sectors*

For the final use sectors the model applies the following sequence of rules[2]:

1. In the "new" scenario each final energy demand sector in each country maintains its share in total energy demand as in the "old" scenario. Formalized, it can be written as follows:

---

[2] For simplicity, the same set of rules is applied to the CONversion sector.

$$d^{m}_{c,i} = d^{r}_{c,i} * D^{m}_{i} / D^{r}_{i} \qquad (1)$$

where:

$$d^{m}_{c,i} = \sum_{j} d^{m}_{c,i,j}$$

$$d^{r}_{c,i} = \sum_{j} d^{r}_{c,i,j}$$

$$D^{m}_{i} = \sum_{j} D^{m}_{i,j}$$

$$D^{r}_{i} = \sum_{j} D^{r}_{i,j}$$

$$D_{i,j} = \sum_{c} d_{i,j}$$

| | |
|---|---|
| D | is the world region energy demand, |
| d | is the country level energy demand, |
| c | is the country index belonging to the world region, |
| i | is the sector index, |
| j | is the fuel index, |
| r | denotes the "old" RAINS 'reference' scenario, |
| m | denotes the "new" scenario calculated from the MESSAGE III data for the world region. |

For example, $d^{r}_{c,i,j}$ means the country c consumption of fuel j in sector i in the RAINS reference scenario.

This rule ensures that total fuel consumption at the sectoral level in country A and B changes in the same proportion as the changes at a world region level.

2. For each economic sector a 'balancing fuel' is selected. The demand for this fuel is determined in such a way that all conditions are fulfilled and the balances met. The balancing fuel can be different for each economic sector. The share of this fuel in total sectoral fuel demand should be high enough to provide regional flexibility for future capacity development. In the present version of the model light fractions (LF) of liquid fuels are used as a balancing fuel in the transport sector. For all other sectors natural gas is the balancing fuel[3]. This is justified by the rapid expansion of natural gas use, providing regional

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[3] In the power plant sector it is possible to select for some scenarios a non-fossil fuel (e.g., nuclear or renewable energy) as a balancing fuel.

flexibility for future capacity expansion. Note, however, that the overall sectoral consumption of balancing fuels in the world region has to match the amounts as determined by the MESSAGE III model.

3. With the exception of the balancing fuel, the demand for each fuel category in each country in the "new" scenario changes proportionally to the relative change in the demand for that fuel at the world region level. Formalizing this principle means the following:

For all $j \neq jb$ (jb - index of the balancing fuel):

$$d^{m}_{c,i,j} = d^{r}_{c,i,j} * D^{m}_{i,j} / D^{r}_{i,j} \tag{2}$$

4. The residuum to be covered by the "balancing fuel" is calculated from the equation:

$$d^{m}_{c,i,jb} = d^{m}_{c,i} - \sum_{j \neq jb} d^{m}_{c,i,j} \tag{3}$$

Assume, that in our numerical example Fuel I is the 'balancing fuel'. After using the last two equations the result of calculations in our example is as follows:

| | Country A | Country B | World Region |
|---|---|---|---|
| Fuel I | 60 | 90 | 150 |
| Fuel II | 40 | 10 | 50 |
| Total | 100 | 100 | 200 |

Application of the "balancing fuel" concept prevents the occurrence of unjustified differences in total fuel demand among countries.

5. It might happen that for some countries the use of equation (3) will yield a negative demand for the balancing fuel. Then the additional correction of fuel consumption structure is necessary. The approach is described below.

First, the countries are divided into two groups, namely:

- those with negative consumption of balancing fuel before correction ($c \in C_1$). For those countries $d^m_{c,i,jb} < 0$;

- those with non-negative consumption of balancing fuel before correction ($c \in C_2$). For those countries $d^m_{c,i,jb} \geq 0$).

Next, for the first group of countries the correction is done in two steps. In the first step the negative values for the balancing fuel are set to zero. In the second step consumption of other fuels is adjusted proportionally so that the total final energy demand remains unchanged.

Thus:

For $c \in C_1$:

$d^{m'}_{c,i,jb} = 0$ ('prim' means values after adjustments)

for $j \neq jb$:

$$d^{m'}_{c,i,j} = d^m_{c,i,j} * d^m_{c,i} / (d^m_{c,i} - d^m_{c,i,jb})$$

In order to keep the world region balance unchanged, it is necessary to adjust also energy consumption for other countries. Thus:

For $c \in C_2$ and each $j \neq j_b$:

$$d^{m'}_{c,i,j} = d^m_{c,i,j} * (D^m_{i,j} - \sum_{c \in C_1} d^{m'}_{c,i,j}) / \sum_{c \in C_2} d^m_{c,i,j})$$

This correction causes in some cases minor changes in the distribution of total final energy demand among countries belonging to the region. Thus after such a correction condition (1) might not be fully fulfilled. Differences are usually small enough to be neglected. In any case, total final demand for the whole world region remains unchanged.

It needs to be stressed that the corrections (if necessary at all) are done after calculations of fuel consumption for each economic sector. Thus the sectoral level balances are always kept consistent and the possible inconsistencies do not propagate on other sectors.

### *3.2. Rules for the power sector*

The power generation sector requires additional rules in order to ensure that electricity supply and demand match. Also the differences in electricity generation efficiencies which result from different assumptions on technical progress and fuel consumption structures in the power plant sector built into the "new" and the "old" scenarios must be taken into account. Calculations of fuel use in the power plant sector (PPL) of each country are done according to the following rules:

1. Calculate electricity and heat demand for each country. The demand for electricity has to be met by domestic production plus net imports. The demand for district heat has to be met exclusively by domestic production. In case the future electricity trade pattern is not known for the "new" scenario, the "old" trade pattern is adjusted proportionally to the change in electricity generation at the world region level[4]. Gross electricity and district heat generation for each country and for region totals is calculated as a sum of final demand, including CONversion sector, and net imports:

$$
\begin{aligned}
g^m_{c,ELE} &= -\sum_{i \neq PP} d^m_{c,i,ELE} + IEX^m_{c,ELE} \\
g^m_{c,HT} &= -\sum_{i \neq PP} d^m_{c,i,HT} \\
G^r_{ELE} &= \sum_c g^r_{c,ELE} \\
G^r_{HT} &= \sum_c g^r_{c,HT} \\
G^m_{ELE} &= \sum_c g^m_{c,ELE} \\
G^m_{HT} &= \sum_c g^m_{c,HT}
\end{aligned}
\tag{4}
$$

where:

g, G - gross electricity or district heat generation[5],

IEX - export-import balance of electricity and district heat.

---

[4] Alternatively, net imports of electricity for each country can be assumed to be the same as in the "old" scenario.

[5] Electricity and heat generation values are negative due to the convention adopted in the RAINS model.

2. Calculate fossil fuels based thermal electricity generation for the "old" scenario for each country as well as for both scenarios (i.e., for the "old" and the "new" scenario) for world region totals:

$$g^{r,th}_{c,ELE} = g^{r}_{c,ELE} + \sum_{j \in J_{NF}} d^{r}_{c,PP,j} * \eta_{NF}$$

$$G^{r,th}_{ELE} = G^{r}_{ELE} + \sum_{j \in J_{NF}} D^{r}_{PP,j} * \eta_{NF}$$

$$G^{m,th}_{ELE} = G^{m}_{ELE} + \sum_{j \in J_{NF}} D^{m}_{PP,j} * \eta_{NF}$$

where:

$J_{NF}$ - set of non-fossil fuels (nuclear, hydro and renewables)
$\eta_{NF}$ - assumed generation efficiency for non-fossil fuels (in our case 38 percent).
Superscript 'th' stands for thermal electricity generated from fossil fuels.

3. Adjust thermal electricity generation efficiencies for each country from the "old" scenario to the conditions of the "new" scenario.

This step is done in order to capture the differences in assumptions regarding technical progress in the power plant sector in the two scenarios. The generation efficiencies for each country in the "old" scenario as well as for region totals for both scenarios are calculated according to the following formula:

$$\eta^{r,th}_{c,ELE} = - g^{r,th}_{ELE} /( \sum_{j \in J_{FF}} d^{r}_{c,PP,j} + g^{r}_{c,HT}/\eta_{HT})$$

$$\eta^{r,th}_{ELE} = - G^{r,th}_{ELE} /( \sum_{j \in J_{FF}} D^{r}_{PP,j} + G^{r}_{HT}/\eta_{HT})$$

$$\eta^{m,th}_{ELE} = - G^{m,th}_{ELE} /( \sum_{j \in J_{FF}} D^{m}_{PP,j} + G^{m}_{HT}/\eta_{HT})$$

where:

$J_{FF}$ - set of fossil fuels

$\eta^{r,th}{}_{c,ELE}$ - thermal power generation efficiency for country c in the "old" reference RAINS scenario

$\eta^{r,th}{}_{ELE}$ - thermal power generation efficiency for the world region in the "old" reference (RAINS) scenario

$\eta^{m,th}{}_{ELE}$ - thermal power generation efficiency for the world region in the "new" (MESSAGE III) scenario

$d_{c,PP,j}$, $D_{PP,j}$ - fuel j consumption in the power plant sector in country c and in the whole world region.

$\eta_{HT}$ - (district) heat generation efficiency.

Note that fuel use for district heat generation is included through the second component in the formulas above.

Efficiencies of thermal power generation for each country in the "new" scenario are calculated from an assumption that relative changes in efficiencies for each country are the same as the changes for the whole world region:

$$\eta^{m,th}{}_{c,ELE} = \eta^{r,th}{}_{c,ELE} * \eta^{m,th}{}_{ELE} / \eta^{r,th}{}_{ELE} \qquad (5)$$

where:

$\eta^{m,th}{}_{c,ELE}$ - thermal power generation efficiency for country c in the "new" MESSAGE III scenario.

These new, adjusted efficiencies are then used for calculations of the demand for the balancing fuel in each country.

4. For all fuels except for the balancing fuel calculate new fuel demands assuming that fuel demand in a given country changes proportionally to the change in total use of a given fuel in the world region:

for $j \neq (jb, ELE, DH)$:

$$d^{m}{}_{c,PP,j} = d^{r}{}_{c,PP,j} * D^{m}{}_{PP,j} / D^{r}{}_{PP,j} \qquad (6)$$

5. Calculate the demand for the balancing fuel. Here two cases should be distinguished.

a) The balancing fuel belongs to a set of fossil fuels ($j_b \in J_{FF}$). Then the formulas are as follows:

$$g^{m,th}_{c,ELE} = g^{m}_{c,ELE} + \sum_{j \in JN_{NF}} d^{m}_{c,PP,j} * \eta_{NF}$$

$$d^{m}_{c,PP,jb} = - g^{m,th}_{c,ELE}/\eta^{m,th}_{c,ELE} - g^{m}_{c,HT}/\eta_{DH} - \sum_{j \in J_{FF},\, j \neq j_b} d^{m}_{c,PP,j} \tag{7a}$$

In the event when the calculated demand for the balancing fuel is negative, a correction as described in step 5 in the Section 3.1 is performed. This correction takes into account fossil fuels only (i.e., those with $j \in J_{FF}$). Such corrections involve always a small proportion of total demand for the balancing fuel.

b) If the balancing fuel belongs to a set of non-fossil fuels ($j_b \in J_{NF}$), then the following formulas should be used:

$$g^{m,th}_{c,ELE} = - \Big(\sum_{j \in J_{FF}} d^{m}_{c,PP,j} + g^{m}_{c,HT}/\eta_{DH}\Big) * \eta^{m,th}_{c,ELE}$$

$$d^{m}_{c,PP,jb} = (g^{m}_{c,ELE} - g^{m,th}_{c,ELE})/\eta_{NF} - \sum_{j \in J_{NF},\, j \neq j_b} d^{m}_{c,PP,j} \tag{7b}$$

Also in this case the demand for the balancing fuel might be negative for some countries. Again, a correction as in the step 5 from Section 3.1 needs to be performed. In this case, however, it takes the non-fossil fuels only ($j \in J_{FF}, j \neq ( ELE,HT)$).

6. Adjust the calculated demand for the balancing fuel to world region total.

Usually the calculated sum of the demand for the balancing fuel differs slightly from the world region total. This is because the generation efficiencies used for individual countries differ from the region average. Thus in the next step the difference is distributed among the countries proportionally to the total fuel demand in the power plant sector in each country. Necessary corrections are for majority of cases and countries well below 1 % of total sectoral fuel demand. The appropriate formula is as follows:

$$d^{m'}_{c,PP,jb} = d^{m}_{c,PP,jb} + (D^{m}_{PP,jb} - \sum_{c} d^{m}_{c,PP,jb}) * \sum_{j} d^{m}_{c,PP,j} / \sum_{j} D^{m}_{PP,j} \qquad (8)$$

According to the RAINS database format, information on consumption of certain fuels (e.g., nuclear, hydro, renewables) and on electricity and heat generation is available for sector aggregates only. Thus the calculations of fuel consumption in the "new" MESSAGE III scenario are performed for the whole power plant sector in each country and then split into existing and new plant consumption according to the pattern taken from the RAINS scenario. Of course, consumption of each fuel in the new power plant sector cannot be negative. In case negative numbers occur, fuel use in existing plant sector has to be adjusted accordingly, what is equivalent to earlier phase-out of existing capacities in the MESSAGE III scenario than assumed in the RAINS scenario.

### *3.3. Special rules*

Additional problems might occur in case when a new fuel type that did not appear in the "old" pattern scenario occurs in the "new" scenario. This might be for instance a case with renewable energy forms or (for some scenarios) with biomass fuels. For such fuels their shares in the pattern scenario are either zero or are close to zero. Thus the distribution of fuel consumption according to its distribution in the pattern scenario is not possible. Sometimes the distribution of consumption of a given fuel type in the pattern scenario cannot be regarded as representative[6]. In such cases the computer code provides the user with the option to distribute consumption of these fuels among countries proportionally to the total final energy demand in the pattern scenario. However, such an option is available only for a limited number of fuel/sector combinations where the problems are likely to occur. Calculations for other fuels are then performed as described in the section 3.1. This rule is applied not only in the final use sectors, but also in the power generation sector.

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[6] This is for instance the case when for some countries information on a consumption of certain fuels (e.g., non-commercial fuels or district heat supplied via local networks) is not available and thus not included in the pattern scenario.

### *3.4. Example of data transformation by the interface model*

Below an example is given which illustrates data transformations performed by the above algorithm.

Assume that a world region consists of two countries A and B. For a specific year in the future (e.g., the year 2000) available are energy scenarios for each of these countries. Country scenarios originate from the RAINS model energy database. An aggregated energy scenario for the world region as a whole is available from the MESSAGE III model. Assume further that energy demand is calculated for five fuel categories (solid, liquid, gas, other and electricity) and that energy system consists of two sectors: the final use sector and the power generation sector. Illustrative data set for this example is shown in Table 5. The upper part of the table displays data available from the RAINS model. The "new" aggregated balance for the world region is shown in the right bottom corner of the table. Parts of the table which include known data are grey shaded. Balances for countries A and B shown in the bottom part of the table are calculated by the discussed interface model.

In the first step the "new" total final demand for countries A and B is calculated. For instance, for country A the final demand is equal to 5400/6250*4510 = 3897 PJ. Final demands for electricity (ELECTR), coal (COAL) and oil (OIL) are calculated on a pure proportionality assumption. For instance, for country A the demand for electricity is equal to 500/900*600 = 333 PJ. In the "old" scenario total final demand for other fuels (OTHER) is very low ( less than 0.1 %). Thus the consumption of this fuel in the "new" scenario is calculated according to the rule specified in the Section 3.3., i.e. using the shares of countries in total final demand, instead of the shares for a given fuel. For instance, for country A the demand for other fuels (OTHER) is equal to 3897/5400*160 = 138 PJ. The demand for gas (GAS), which is assumed to be the balancing fuel, is calculated as a difference between the total final demand and the previously calculated demands for all other fuel categories.

In the next step electricity net imports for countries A and B are adjusted proportionally to the change in total electricity generation. Also electricity generation efficiencies are adjusted according to the formulas specified in Section 3.2. Then total primary fuel demand for electricity generation is calculated. Consumption of individual fuels is calculated in a similar way as for final demand sectors. Consumption of the balancing fuel (gas) is calculated from the requirement that the primary energy demand for electricity generation has to be met.

Energy demand patterns for the countries in the example are intrinsically different. Country A is coal dependent (more than 75 percent of primary energy demand is coal), for country B liquid fuels predominate. There are also substantial differences in energy demand patterns between the "old" and the "new" scenario. Total energy demand in the "new' scenario is by more than 20 percent lower. Electricity demand is only 56 percent of that in the "old" scenario. In turn, demand for gas is higher in the "new" scenario. In spite of these large differences, the "new" country level energy balances seem to be quite reasonable.

## 4. Description of Computer Procedure

Operations described in the previous sections are performed by a special interface model. It uses the output files produced by the MESSAGE III model and restores them, after appropriate transformation, as RAINS input dbase files. The output files from MESSAGE III are available in an ASCII format. The program code has been written in FOXPRO. The calculations are performed in an interactive mode in several steps. First, the user selects a MESSAGE III scenario to be processed together with a world region and a target year. Second, a year and a RAINS case which will be used as the reference (pattern) scenario are selected. After running the code for a given year the user has an opportunity to view the results and to compare - for each country - the balances for the "old" RAINS scenario with the balances for the newly created case consistent with the global MESSAGE III scenario. After the code is executed for all future years included in the RAINS scenario, the results can be stored as a new RAINS case.

Table 5. Example of data transformation by the interface model.

a.) Basic RAINS data ("old" data set)

| | Country A | | | Country B | | | Total world region | | |
|---|---|---|---|---|---|---|---|---|---|
| Fuel/sector | Final sector | Power pl. sector | Total | Final sector | Power pl. sector | Total | Final sector | Power pl. sector | Total |
| COAL | 3100 | 1200 | 4300 | 435 | 260 | 695 | 3535 | 1460 | 4995 |
| OIL | 710 | 70 | 780 | 900 | 260 | 1160 | 1610 | 330 | 1940 |
| GAS | 100 | 10 | 110 | 100 | 120 | 220 | 200 | 130 | 330 |
| OTHER | 0 | 500 | 500 | 5 | 180 | 185 | 5 | 680 | 685 |
| ELECTR | 600 | -597 | 3 | 300 | -303 | -3 | 900 | -900 | 0 |
| Total | 4510 | 1183 | 5693 | 1740 | 517 | 2257 | 6250 | 1700 | 7950 |
| | eff-cy | 0.34 | | eff-cy | 0.37 | | eff-cy | 0.35 | |

b.) Country data based on scenario for world region ("new" data set)

| | Country A | | | Country B | | | Total world region | | |
|---|---|---|---|---|---|---|---|---|---|
| FUEL | Final sector | Power pl. sector | Total | Final sector | Power pl. sector | Total | Final sector | Power pl. sector | Total |
| COAL | 2662 | 493 | 3155 | 378 | 107 | 485 | 3040 | 600 | 3640 |
| OIL | 617 | 28 | 645 | 783 | 102 | 885 | 1400 | 130 | 1530 |
| GAS | 147 | 109 | 256 | 153 | 111 | 264 | 300 | 220 | 520 |
| OTHER | 138 | 294 | 432 | 22 | 106 | 128 | 160 | 400 | 560 |
| ELE | 333 | -332 | 2 | 167 | -168 | -2 | 500 | -500 | 0 |
| Total | 3897 | 593 | 4489 | 1503 | 257 | 1761 | 5400 | 850 | 6250 |
| | eff-cy | 0.36 | | eff-cy | 0.40 | | eff-cy | 0.37 | |

Figure 1 shows the simplified flow chart of the interface model. Below the corresponding steps are discussed and explained.

1. Selection of the MESSAGE III scenario.
   In this step the user has to select a name and a code of the MESSAGE III scenario for which the aggregated balances are to be processed.

2. Selection of world region
   In this step a world region must be selected. The present version of the computer code permits the following choices:

   Central and Eastern Europe
   Western Europe
   Former Soviet Union

   or

   Centrally Planned Asia & China
   Other Pacific Asia
   South Asia
   Pacific OECD / Japan

3. Selection of RAINS pattern case
   The RAINS model energy database may contain several energy scenarios. In this step the user should select the scenario number (code) which will be used as a pattern for the distribution of MESSAGE III world region energy consumption into national energy balances. It is advisable to use the pattern scenario which is possibly close to the MESSAGE III aggregated scenario. However, experience has shown that the procedure is robust even in case when the RAINS pattern and the MESSAGE III scenarios are based on very different assumptions.

4. Selection of balancing fuel for the power plant sector.
   In this step the user has an opportunity to select a balancing fuel for the power plant sector which he regards as the most appropriate for data transformation from the pattern scenario to the new one. It is possible to use either natural gas or - for scenarios with high expansion of non-fossil fuels, one of these fuels (e.g., nuclear or renewable sources).

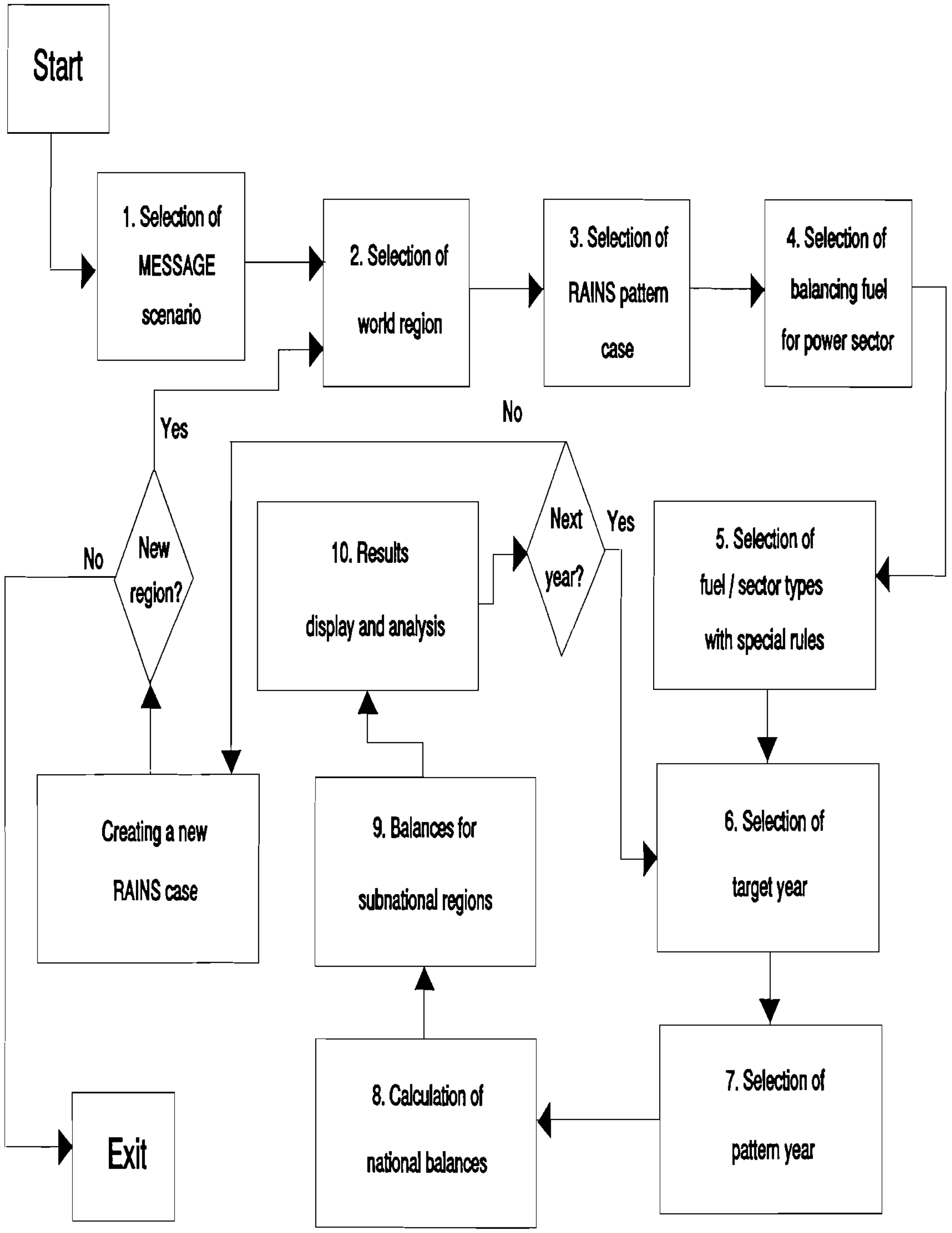

Figure 1. Flow chart of interface model

5. Selection of fuel/sector types with special rules

   In this step the user may select fuel/sector combinations, for which fuel consumption will be distributed among countries according to shares of individual countries in total sectoral consumption and not according to the contribution of a given country to consumption of a given fuel in the pattern scenario (compare Section 3.3.).

6. Selection of target year to be processed

   In this step the user should choose a target year for which the MESSAGE III aggregated balances are to be converted into national and sub-national balances. The user can choose among the years available in the MESSAGE III output file for the selected in the step 1 world region.

7. Selection of RAINS pattern year

   In order to distribute the global energy demand from the MESSAGE III scenario into national balances, a pattern year has to be selected. Fuel consumption for this year for each country and sub-national regions will be than taken as a pattern. The most common choice is to use the same pattern year as the target year. However, in case when energy consumption for the target year is not available in the pattern scenario[7] then a different year can be used. On the screen a list of the available years in the chosen pattern RAINS scenario will appear. The pattern year can be selected from this list.

8. Calculation of national energy balances

   Fulfilling the above described task specifications, the selected data sets are copied to a work area, and the calculations are carried out. First, this procedure creates world regional dbase files from the corresponding MESSAGE III output files and from adding up the RAINS country data. Next, country data sets are created utilizing the rules described in Section 3. Finally, a check is made whether country balances add up to the original balance determined by the MESSAGE III model.

9. Calculations of energy balances for sub-national regions

   In this step the national balances for countries additionally subdivided into regions are split into the sub-national balances for each region. The rules applied for this step are

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[7] For instance, the RAINS pattern scenarios generated on a basis of official energy pathways might be available only until the year 2010, whereas the MESSAGE scenario for the world region is available for 2020.

identical with those for the previous step.

10. Results display and analysis
    At the end of the calculations the user can look at the achieved results in a form of spreadsheets. The spreadsheets compare for each country/region energy demand by fuel and sector generated by the code with that for the pattern scenario. At this point there isn't any opportunity for user interaction. The user can only determine whether the results are satisfactory or not. If (for any reason) the user is not satisfied with the results, he might try to repeat the calculations with the use of a different type of balancing fuel for the power plant sector or change the selection of fuels/sectors combinations with special rules from the step 5.

11. Loop from step 6
    After processing the first chosen year, another year can be selected. The calculations will follow steps 7 to 10.

12. Creating a new RAINS case
    After processing the MESSAGE III output for all chosen years the user should save the results as a new RAINS case. The user has to define the new RAINS case code. The new RAINS scenario will be created for the selected world region from the recently generated country/sub-national regions data.

13. Start again from step 2 or exit
    In this step the user can select a new world region, or exit the program.

The FOXPRO computer procedure is a relatively user friendly program to prepare data for RAINS analysis. The user has flexibility in the task specification and in the result analysis. The algorithm seems to be robust enough as it doesn't fail in the case of minor data inconsistencies.

## 5. Illustrative results

In this Section the "real live" data for three countries belonging to the Western Europe have been used in order to demonstrate the results of the interface model. Western Europe has been chosen as an example for three different reasons:

- number of countries/regions (19) is high enough to test the robustness of the procedure,
- the sizes of the countries belonging to this world region are substantially different. Thus the differences in energy consumption among the countries are higher than a factor of 10. This enables to demonstrate the appropriateness of the procedure for countries of different sizes,
- the availability and consistency of both: statistical and forecast data is good. Such consistent set of input data should produce a consistent set of country scenarios. Any inconsistencies which might occur would be due to an unsatisfactory methodology.

Table 6 gives the aggregated energy balances for Western Europe for the year 2010 as available from the RAINS and the MESSAGE III models. Tables 7 to 9 show the country data for three countries of different sizes: Belgium, as a representative of a middle size country, France, as a big country and Ireland as a small country. For simplicity, the balances are presented for seven major economic sectors (compare Table 4) and seven major fuel types. In the bottom part of the table the differences in sectoral energy demand as well as relative difference in thermal electricity generation efficiency for the two scenarios are shown. The latter two types of differences were the main driving forces of the methodology and are helpful in the evaluation of the results.

The shaded cells in Tables 6-9 illustrate the behavior of fuel consumption in three cases. **Bold** numbers (DOMESTIC sector GAS consumption) represent the case when the aggregated value for the RAINS scenario is lower than the corresponding MESSAGE III value (the MESSAGE III consumption is 70 % higher than in the RAINS scenario). Underlined numbers (CONVERSION sector LIQUID fuel consumption) represent the case when the RAINS data is roughly two and a half times more than the MESSAGE III data. Finally the values put in *italics* (POWER PLANT sector SOLID fuel consumption) illustrate the case when the values from the two scenarios are more or less identical. Utilizing the procedure similar relations should be obtained for individual countries. The country data should also produce similar percentage differences by sectors and differences in thermal power generation efficiency. Looking at the tables one realizes that the criteria are fulfilled and the new scenarios are acceptable for each country.

Table 6. Energy demand for Western Europe: year 2010

RAINS (pattern) balance (sum of the country data), PJ

| Fuel/sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| SOLID | 1105 | 3260 | 0 | *10513* | 299 | 15177 |
| LIQUID | 4562 | 5508 | 12658 | 1792 | 1592 | 26112 |
| GAS | 5687 | 4790 | 7 | 5419 | 959 | 16862 |
| HYD,REN | 4 | 1 | 0 | 5730 | 0 | 5735 |
| NUCL | 0 | 0 | 0 | 8218 | 0 | 8218 |
| ELECTR | 5855 | 4564 | 249 | -12510 | 1836 | -6 |
| HEAT | 748 | 122 | 3 | -975 | 102 | 0 |
| TOTAL | 17961 | 18245 | 12917 | 18187 | 4788 | 72098 |

MESSAGE III world region balance, PJ

| Fuel/sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| SOLID | 726 | 2441 | 0 | *10220* | 430 | 13817 |
| LIQUID | 3333 | 5190 | 11933 | 1917 | 665 | 23038 |
| GAS | 9750 | 5215 | 739 | 2803 | 1074 | 19581 |
| HYD,REN | 0 | 0 | 0 | 5502 | 0 | 5502 |
| NUCL | 0 | 0 | 0 | 5943 | 0 | 5943 |
| ELECTR | 4546 | 3891 | 185 | -10264 | 1642 | 0 |
| HEAT | 187 | 88 | 0 | -307 | 32 | 0 |
| TOTAL | 18542 | 16825 | 12857 | 15814 | 3843 | 67881 |

Difference of energy demand between the two scenarios
By SECTORS in percentage of TOTAL fuel

| Sector | DOM | IND | TRANS | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| % difference | +3 | -8 | -1 | -13 | -20 | -6 |

Ratio of thermal power generation efficiency MESSAGE III/RAINS = 0.939

Table 7. Energy demand for Belgium: comparison of pattern and generated balances for the year 2010

RAINS (pattern) balance, PJ

| Fuel/sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| SOLID | 25 | 170 | 0 | *337* | 24 | 556 |
| LIQUID | 302 | 327 | 365 | 4 | 63 | 1061 |
| GAS | **218** | 229 | 0 | 154 | 22 | 623 |
| HYD,REN | 0 | 0 | 0 | 4 | 0 | 4 |
| NUCL | 0 | 0 | 0 | 332 | 0 | 332 |
| ELECTR | 126 | 185 | 5 | -350 | 49 | 15 |
| HEAT | 0 | 8 | 0 | -8 | 0 | 0 |
| TOTAL | 671 | 919 | 370 | 473 | 158 | 2591 |

Balance generated from MESSAGE III world region scenario, PJ

| Fuel/sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| SOLID | 17 | 132 | 0 | *328* | 30 | 507 |
| LIQUID | 221 | 300 | 338 | 4 | 25 | 888 |
| GAS | **357** | 246 | 21 | 128 | 27 | 779 |
| HYD,REN | 0 | 0 | 0 | 4 | 0 | 4 |
| NUCL | 0 | 0 | 0 | 240 | 0 | 240 |
| ELECTR | 98 | 158 | 4 | -287 | 44 | 17 |
| HEAT | 0 | 6 | 0 | -6 | 0 | 0 |
| TOTAL | 693 | 842 | 363 | 411 | 126 | 2435 |

Difference of energy demand between the two scenarios
By SECTORS in percentage of TOTAL fuel

| Sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| % difference | +2 | -8 | -2 | -13 | -19 | -6 |

Ratio of thermal power generation efficiency MESSAGE III/RAINS = 0.938

Table 8. Energy demand for France: comparison of pattern and generated balances for the year 2010

RAINS (pattern) balance, PJ

| Fuel/sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| SOLID | 67 | 270 | 0 | *175* | 13 | 525 |
| LIQUID | 512 | 823 | 2102 | 88 | 235 | 3760 |
| GAS | 811 | 679 | 0 | 178 | 42 | 1710 |
| HYD,REN | 0 | 0 | 0 | 697 | 0 | 697 |
| NUCL | 0 | 0 | 0 | 4542 | 0 | 4542 |
| ELECTR | 983 | 601 | 38 | -2239 | 365 | -252 |
| HEAT | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 2373 | 2373 | 2140 | 3441 | 655 | 10982 |

Balance generated from MESSAGE III world region scenario, PJ

| Fuel/sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| SOLID | 44 | 202 | 0 | *170* | 19 | 435 |
| LIQUID | 374 | 775 | 1950 | 94 | 99 | 3292 |
| GAS | 1269 | 699 | 122 | 393 | 96 | 2579 |
| HYD,REN | 0 | 0 | 0 | 669 | 0 | 669 |
| NUCL | 0 | 0 | 0 | 3285 | 0 | 3285 |
| ELECTR | 763 | 512 | 28 | -1837 | 326 | -208 |
| HEAT | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 2450 | 2188 | 2100 | 2774 | 540 | 10052 |

Difference of energy demand between the two scenarios
By SECTORS in percentage of TOTAL fuel

| Sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| % difference | +3 | -8 | -2 | -19 | -18 | -8 |

Ratio of thermal power generation efficiency MESSAGE III/RAINS = 0.939

Table 9. Energy demand for Ireland: comparison of pattern and generated balances for the year 2010

RAINS (pattern) balance, PJ

| Fuel/sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| SOLID | 34 | 8 | 0 | 157 | 0 | 199 |
| LIQUID | 50 | 51 | 94 | 50 | 0 | 77 |
| GAS | **22** | 36 | 0 | 15 | 1 | 74 |
| HYD,REN | 0 | 0 | 0 | 10 | 0 | 10 |
| NUCL | 0 | 0 | 0 | 0 | 0 | 0 |
| ELECTR | 47 | 28 | 0 | -91 | 16 | 0 |
| HEAT | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 153 | 123 | 94 | 141 | 17 | 528 |

Balance generated from MESSAGE III world region scenario, PJ

| Fuel/sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| SOLID | 23 | 6 | 0 | *143* | 0 | 172 |
| LIQUID | 37 | 48 | 87 | 50 | 0 | 222 |
| GAS | **62** | 36 | 5 | 1 | 0 | 104 |
| HYD,REN | 0 | 0 | 0 | 10 | 0 | 10 |
| NUCL | 0 | 0 | 0 | 0 | 0 | 0 |
| ELECTR | 36 | 24 | 0 | -75 | 14 | -1 |
| HEAT | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 158 | 114 | 92 | 130 | 15 | 507 |

Difference of energy demand between the two sectors
By SECTORS in percentage of TOTAL fuel

| Sector | DOM | IND | TRA | PPL | CON | TOTAL |
|---|---|---|---|---|---|---|
| % difference | +3 | -7 | -2 | -9 | -12 | -4 |

Ratio of thermal power generation efficiency MESSAGE III/RAINS = 0.934

The procedure has been utilized for six world regions belonging to Europe and South-East Asia and the results have been used for the analysis of the impact of global energy scenarios on regional acidification (compare de Jánosi et al., 1994, Amann et al., 1995). The procedure has turned out to be robust even in cases when the internal consistency of the RAINS pattern scenarios or of the MESSAGE III global scenarios was not as high as in the case of Western Europe. Thus the approach is reliable enough to be used in the integrated assessment of regional impacts of global energy scenarios.

## 6. Summary and final remarks

The paper describes the interface model that links the studies on the future development of global energy systems with the assessment of the possible impacts on regional air pollution, especially on acidification. In this way an integrated assessment of global energy strategies is facilitated.

For the regional impacts analysis national energy demand scenarios or even scenarios for sub-national regions consistent with the global scenarios are required. The interface model distributes energy consumption calculated by global energy models (in our case the 11R-MESSAGE III model) into a set of national energy balances taking into account a distribution by fuels and sectors from the pattern scenarios available in the IIASA RAINS model of acidification.

Such a top-down approach is characterized by a great number of degrees of freedom. In other words, number of national energy balances that sum up to a given world region balance is very large. The interface model starts from the pattern energy scenario for each country and aims at the development of a reasonable set of national energy balances consistent with the global balance through the application of a set of simple rules and consistency conditions which must be fulfilled while developing the new set of energy balances.

The proposed approach adopts strong assumptions regarding relative changes of activity levels and energy intensities at a sectoral level in each country. Implicitly, it assumes that the changes between the "old" pattern scenario and the "new" global scenario are the same for each country belonging to the same world region. In reality the development in individual countries might be different. However, across-the-board assumptions are necessary for the top-down approach used in this paper. Any other approach would have required additional information about the development in individual countries consistent with the global scenario. Because in-depth studies of national energy systems using the same set of assumptions as for the global model are not feasible with the available resources, it was necessary to use simple rules as described above.

It has to be mentioned that the interface model produces one possible set of national energy scenarios. By no means this set is the only possible one. Its major advantages are its simplicity and the preservation of internal consistency while maintaining the world region energy balance resulting from the global model.

The interface model creates not only national energy balances but also the balances for country regions derived from aggregated national balances. It is also possible to use the model to generate national/regional projections from the aggregated projections even if the detailed country level scenarios are not available for a given year. In such cases, the historic balances for the base year from the statistics or the available balances for a year closest to the target year can be used as pattern data.

The interface model can also be used to check the consistency of the base year data used by the global and regional models. Data sources utilized by the two types of models are different and sometimes discrepancies exist due to wrong initial classification of countries, sectors or fuels or just due to numerical errors. Linking the two models, each of them has been designed for stand-alone usage, makes it possible to discover data inconsistencies and to remove them in subsequent iterations.

The interface model has been used for Europe and South-East Asia for the analysis of the impact of global energy scenarios on regional acidification. The procedure has turned out to be robust even in cases when minor inconsistencies of the processed scenarios existed. Thus the approach is reliable enough to be used in the integrated assessment of regional impacts of global energy scenarios.

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