Emission scenarios for Bulgaria using the integrated model GAINS

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Abstract: The model GAINS is an integrated model for assessment of air pollution, developed by the International Institute for System Analysis (IIASA), Austria, as a tool to identify emission control strategies that achieve given targets on air quality and greenhouse gas emissions at least costs. It considers the following air pollutants - SO_2, NO_X, VOC, NH_3, PM and Greenhouse Gases (GHG) - CO_2, CH_4, N_2O and the F-gases HFC, PFC, SF_6, emitted from different economic sectors. In "scenario" mode GAINS focuses on individual abatement measures and considers the "multi-pollutant multi-effect" of a given measure simultaneously on air pollution and GHG. Thus, exploring synergies between measures for emissions reduction and GHG mitigation cost benefit results could be achieved. In "optimization" mode the model can be used to search for cost-minimal balances of controls of the pollutants considered that simultaneously achieve user-specified targets for human health and ecosystems impacts.

The model GAINS (Annex I version) is used in this work to realize some emission scenarios for Bulgaria till 2030 concerning the national emissions for the most of the above pollutants and GHG. For each scenario are calculated the costs for emissions reduction of some pollutants. Sensitivity analyses are carried out applying different control strategies. The results presented are compared and discussed. The use of this model approach in Bulgaria is at an early stage.

Keywords: integrated model, emission scenario, control strategy

1. INTRODUCTION

The Regional Air Pollution Information and Simulation (RAINS) model has been developed at the International Institute for Applied System Analysis (IIASA) as a tool for the integrated assessment of emission control strategies for reducing impacts of air pollution from the following pollutants: SO_2, NO_x, VOC, PM, NH_3, O_3. Since 2007 it has been replaced by the model GAINS (Greenhouse Gas Air Pollution Interactions and Synergies), which is used by the European Commission (EC) to develop, apprise, modify and set emission level ceilings for a range of transboundary air pollution under the National Emission Ceiling Directive (NECD) 2010. GAINS affords not only air quality modeling as does RAINS, but explores Greenhouse Gas (GHG) emissions of CO_2, CH_4, N_2O and the F-gases CFCs, HFC, SF_6, as well as additional abatement options. Thus, except impact on ecosystems, GAINS is used also for assessment of climate change options. Another innovative possibility of the model is focusing on the individual abatement measure for the level of associated economic activity and emissions and its impact on different pollutants and GHG simultaneously (multi-pollutant multi-effect approach). This allows identifying synergic effects of the control measures application, i.e. simultaneous change of emissions and GHG as a result of application of a single measure. More information about the model could be found at the web site of IIASA – www.iiasa.ac.at.

GAINS is an integrated model operating with a large number of input data for the different economic sectors, but at the same time it is simplified in a sufficient extent for easy use with sufficient accuracy. Nevertheless, it is recognized that many aspects that are presently not hard-wired into GAINS are important. That is why, instead of incorporating all complex relations that are relevant to these aspects into one super-model, a network of specialized models that address these aspects in more details has been created through the EC4MACS (European Consortium for the Modelling of Air pollution and Climate Strategies) project - www.ec4macs.eu. The EC4MACS model suite includes the GAINS integrated assessment model for air pollution, the PRIMES energy model, the TREMOVE transport model, the CAPRI agriculture model, the EMEP atmospheric dispersion model, the GAINS-Europe model for greenhouse gas mitigation, models for health and ecosystems impacts, the GEM-E3 macro-economic general equilibrium model and the Beta and ExternE benefit assessment approaches.

The Network for Integrated Assessment Modelling (NIAM - http://www.niam.scarp.se/) is established under the UNECE Convention on Long-Range Transboundary Air Pollution. The aims of the NIAM network is to encourage collaboration between national activities and with IIASA in integrated assessment modelling, to provide a forum for discussion, to facilitate communication and to enhance development of integrated assessment modelling complementing the work of IIASA as well as providing additional contributions to the work of the Task Force on Integrated Assessment Modelling. NIAM supports national activities in the use of GAINS and keeps close contacts with the working groups involved in the project EC4MACS. As a result of NIAM, national versions of the model GAINS are created, for example in Italy, the Netherlands, Ireland and some other countries.

The author of this work has experience with integrated modelling as a result of participation in the project DECADES of the International Atomic Energy Agency (IAEA) on case study for sustainable development of the Bulgarian power sector (using WASP model), participation in the FP5 project MERLIN (Multi-pollutant multi-effect assessment of European air quality – an integrated approach) and keeping contacts with IIASA and some of the NIAM members.

In the present work are considered 3 emission scenarios, concerning the national emissions and abatement costs for most of the above mentioned pollutants and GHG. The emissions from the power sector of Bulgaria are presented separately. The results are compared and discussed.

2. GAINS METHODOLOGY

GAINS considers the following traditional air pollutants: SO_2, NO_X, VOC, NH_3, PM and the 6 Kyoto GHG: CO_2, CH_4, N_2O and the F-gases CFCs, HFC, SF_6. The main important innovations in the model methodology, in comparison with RAINS, except addition of the GHG, are following.

The recent scientific insights open new opportunities for an integrated assessment that could potentially lead to a more systematic and cost-effective approach for managing traditional air pollutants simultaneously with greenhouse gases as they have common sources. That is why it is possible to carry out comprehensive and combined analysis of the common pollutants and GHGs, responsible for pollution and climate change and respectively, to combine measures for their reduction and mitigation (multi-pollutant, multi-effect approach). Important synergies of emission control measures, which could be of high policy relevance, reveal during this process. The synergic effects are based on the connections between measures for emissions reduction and mitigation of the GHG potential. This means that the application, for example, of one control measure (abatement measure) to reduce emission of one pollutant or GHG could reduces the emission also of one or more another pollutants or GHG and this leads to economic benefits. The model GAINS treats the multi-pollutant technologies (abatement measures) in a different way than RAINS. Costs of such measures are related to one pollutant in RAINS and to several pollutants in GAINS. This could lead to a different choice of technologies: measures that were not cost-effective in the single pollutant approach may become cost-effective in the multi-pollutant approach. Thus GAINS allows simulation of variety of flexible mechanisms for controlling GHG and air pollution emissions. The GAINS model operates with approximately 1500 end-of-pipe technologies to reduce emissions of SO_2, NO_x, NH_3, VOC and PM and several hundred options to reduce emissions of greenhouse gases.

The GAINS model quantifies the full DPSIR (demand-pressure-state-impact-response) chain for the emissions of air pollutants and greenhouse gases. It incorporates data and information on all different elements in the DPSIR chain and specifies connections between these different aspects. In particular, GAINS quantifies the DPSIR chain of air pollution from the driving forces (economic activities, energy combustion, agricultural production, etc.) to health and ecosystems effects, which procedure is similar to this of RAINS.

The GAINS model framework makes it possible to estimate, for a given energy and agricultural scenario, the costs and environmental effects of user-specified emission control policies (the "scenario analysis" mode). Furthermore, an optimisation mode can be used to identify the cost minimal combination of emission controls meeting user-supplied targets on air quality and/or greenhouse gas emissions, taking into account regional differences in emission control costs and atmospheric dispersion characteristics. The optimisation capability of GAINS enables the development of multi-pollutant, multi-effect pollution control strategies.

To summarise, in order to model the synergic effects of measures aimed at greenhouse gas emissions and air pollution, the RAINS model was extended and its optimization methodology was refined accordingly. The original RAINS model used single pollutant cost curves to find cost-effective emission reductions to attain environmental targets. The new GAINS model is based on individual measures that can reduce one or more pollutants, e.g. fuel substitution and structural changes in energy production as well as add-on control techniques that have an impact on one or several pollutants.

Methodology and theoretical basis of the model GAINS are well described by Amann M. et al., 2008, Klaassen G. et al., (2005). Information about the optimisation could be found in Wagner, F. et al., (2007).

3. EMISSION SCENARIOS

3.1. General principles

At this stage the GAINS model could be used only on line at the web site of IIASA after registration. Thus, the users obtain a possibility to interact directly with the GAINS database, to modify, create and/or update data and create their own scenarios. The basic principles for use of the database for calculating emissions and emission control costs in the model are following.

Emission = Activity * Emission factor * Technology implementation

Costs = Activity * Unit cost * Technology implementation

The exact formulae are given in Amman M. (2008). Components on the right side are organised into three data categories. Emission-generating economic **activities** are organised into **activity pathways**. Activity data are divided into five groups: Energy (ENE), Mobile sources (MOB), Agriculture (AGR), Process (PROC) and VOC-specific (VOC). **Emission factors and unit costs** of control technologies, together with all background information, form the so-called **emission vector**. Finally, **technology implementation** for each activity is specified in **control strategies**.

Each **emission scenario** is created through a combination of the following three data categories: **activity pathway, emission vectors and control strategies**. Activity pathway refers to the time-dependent evolution of economic activities and show the way how the activities (energy consumption, agriculture livestock, production of energy-intensive products, wastes etc.) will evolve in the future**. At this stage changes in emission vector, using GAINS on-line, are possible only with permission of the data administrator. Control strategy** is a data set that contains assumptions on the penetration of emission control technologies in a given emission scenario and includes information on controls applied in all sectors for all pollutants for the period considered. In general, this period is up to 2030 with a five years time interval. Additional input data, as macroeconomic parameters for example, also could be viewed as an element of the database. **In online use of GAINS the user has a permission to create/change only activity pathway and control strategy.**

GAINS energy database includes the following components of energy system:

- Electricity and district heat generation in the power plants and district heating sector (PP);
- Energy use for primary fuel production, conversion of primary to secondary energy other than conversion to

electricity and heat in the power and district heating plants, and for delivery of energy to final consumers (CON);

- Final energy use in: industry (IN), domestic sector (DOM), transport (TRA) and non-energy use of fuels (NONEN). The domestic sector covers residential and commercial sectors, as well as agriculture, forestry, fishing and services.

GAINS contains alternative pathways of energy use from national and international energy projections, e.g., scenarios developed for Europe by the PRIMES model, projections of the international Energy Agency (IEA) scenarios, based on national studies. Total energy consumption in a given country can be derived by summing up the fuel use in the conversion sector (CON), power sector (PP) and final demand sectors, i.e., IN, DOM, TRA and NONEN. Although this total is a sum of primary and secondary energy, it is equal to the total primary energy demand at a country level. Gains model includes rather detailed specifications of energy carriers. This is because emission factors for air pollutants and GHG heavily depend on the type and quality of fuel used. Consumptions of fuel in a given economic sector determine the level of energy-related activity used in emissions calculations. This consumption is measured in PJ.

3.2 Emission scenarios considered

The model GAINS exists in different versions: GAINS on Annex I countries, GAINS Europe, GAINS Souse Asia, GAINS China (GAINS Russia and GAINS Rest of World are not yet publicly available). The user's rights to manage (modify scenario or create a new one) could be given by the model administrator only for the version Annex I. **At this stage this means working only in scenario mode but not in optimisation one.** Each version contains a set of different emission scenarios. As it was mentioned above, each scenario consists of **activity pathway, emission vectors and control strategies** (emission vectors could be managed under special permission). It should be mentioned, that the model is being constantly improved. IIASA, as well as different users, also constantly increase the number of scenarios, stored in the database. This is the reason for the only possibility at present for on-line use of the model.

Three scenarios are considered in this work. They are as follows.

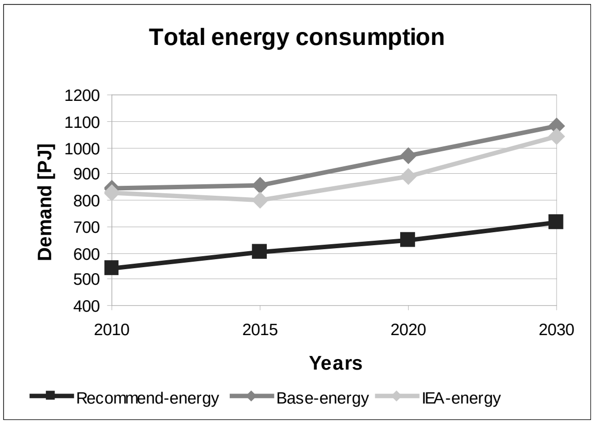
- Scenario 1: Scenario called "IEA WEO 2008; current policies" is created by IIASA and is recommended to be used as a source scenario. The reason is that this scenario was recently updated and used as a baseline (target) for Annex I countries. Energy activities for Annex I non-EU countries originate from the IEA World Energy Outlook 2008. For EU-27 PRIMES Baseline 2007 scenario has been used. Sources for agricultural activities are: for EU - CAPRI model scenarios; for other countries - FAO projections. The scenario includes "current policy" air pollution control measures in each country.

  One new created emission scenario and supporting pathway and control strategy is possible to be blank, i.e., all necessary input data to be introduced in them. But it is advisable the new scenario, pathway and control strategy to be existing ones, which further to be modified in order to create a unique scenario. The reason is that most of the existing data is relevant and the user should change only the rest according to his own projections.

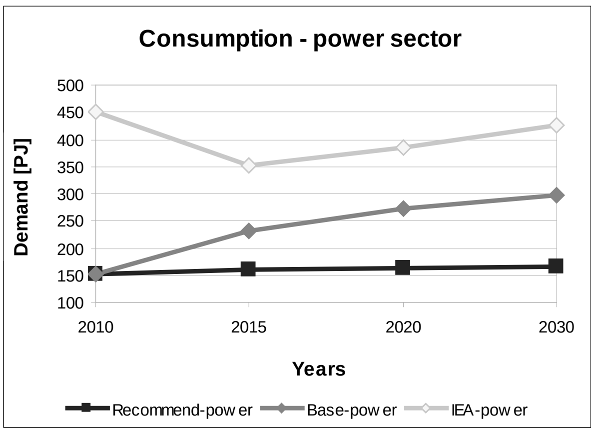
  Using this approach and scenario "IEA WEO 2008; current policies" and respective pathway and control strategy as sources two additional scenarios are created. They are as follows.

- Scenario 2: This scenario is called "baseline". The results from the project CASES for Bulgaria (Tzetanov P. et al., (2008)) are used as input data. These results concern the energy sector with preliminary accent of the power one. The scenario, presented in this work is a reasonable and actualised revision of all existing scenarios in Bulgaria about this sector. One further improvement of this scenario is presented by the same participants in the project CASES (Tzvetanov. P. (2009)) and practically this data is used for realisation of the above mentioned baseline scenario. The rest data are the same as these stored in IEA 2008, used as a source scenario. The control strategy used is the same as for scenario IEA 2008. Different sensitivity analyses are carried out in this control strategy, modifying some parameters, concerning emissions reduction of some pollutants. Finally, the results presented here are connected with the original control strategy for scenario IEA 2008.
- Scenario 3: This scenario is called "recommended". Practically, it is an extension of the work of the Bulgarian group participating in the project CASES, done after the project closing, and is described in Tzvetanov P., et al., (2009). It is actually one purifying vision for development of the Bulgarian energy sector, with a strong accent on the power sector. This scenario was proposed for implementation to the decision-making group of the Bulgarian Parliament. That is why it is considered here as one recent, actual and interesting national concept.

On Fig. 1a are presented the total country energy consumptions (demand) according to the above three scenarios and on Fig. 1b - this for the power sector.



1a



1b

Fig.1 Projections of the total energy consumption (1a) and consumption in power sector (1b) for Bulgaria in PJ

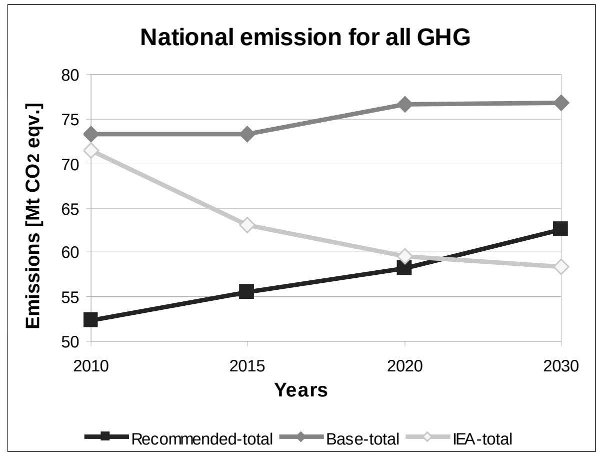
4. RESULTS

Emissions of the following pollutants are considered below: Total GHG, CO_2, NH_3, NO_x, PM2.5, PM10, PMtsp (total suspended particles), SO_2 and VOC. The control costs are presented for: total for the country control costs, NO_x, PMtsp, SO_2.

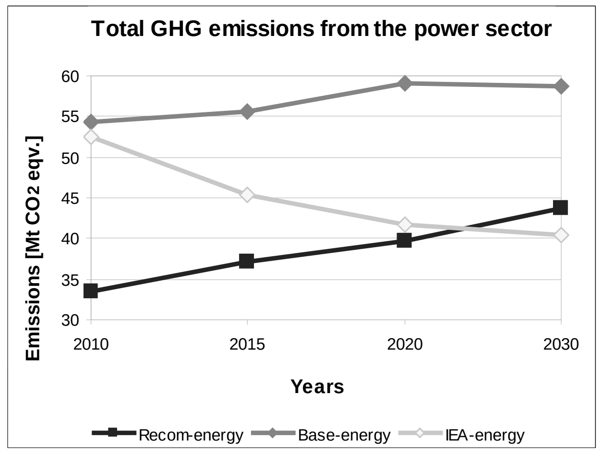
4.1. Emissions

Model GAINS allows obtaining the emissions of each GHG considered: CO_2, CH_4, N_2O and the F-gases. Here are presented only the total GHG emissions and CO_2 emissions.

On Fig. 2 are shown the total national emissions of all GHG (fig. 2a) and the total GHG emissions from the power sector only (Fig. 2b) (in CO_2eq./yr.). As it could be seen, the latter are 60-70% of the total GHG emissions. Lowest emissions are connected with the recommended scenario, where is stressed on the renewable energy sources.



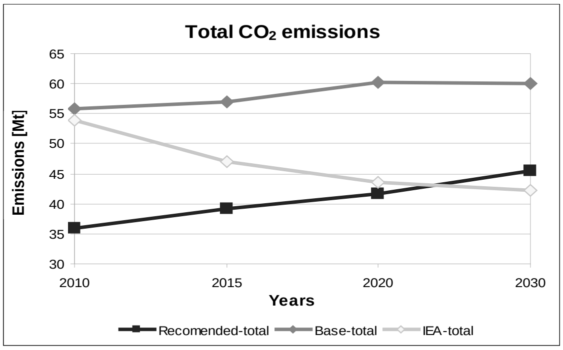
2a



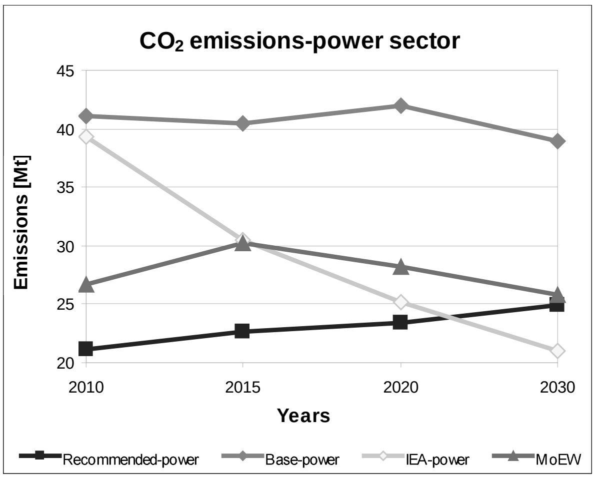
2b

Fig. 2 Total GHG emissions (fig 2a) and emissions from the power sector (Fig. 2b) (in Mt CO_2eqv.)

The CO_2 emissions are presented on Fig. 3. On Fig. 3a are shown the total CO_2 emissions and on Fig. 3b – these from the power sector only. As it could be seen, in comparison with the results on Fig. 2, the CO_2 emissions are significant part of the total GHG emissions and respectively the CO_2 emissions from the power sector are significant part of the total CO_2 emissions. On Fig. 3b are presented also results of the Ministry of Environment and Waters in Bulgaria (MoEW), presented in (Tzvetanov P., et al. (2009)).



3a



3b

Fig. 3 Total CO_2 emissions [Mt] (3a) and CO_2 emissions [Mt] from the Bulgarian power sector (3b)

The total NH_3emissions are presented on Fig. 4 and on Fig. 5 – the national NO_x emissions. As it could be seen, NH_3 emissions are very similar for all scenarios and keep a rising trend. The reason is that these emissions are mainly due to the agriculture sector where not many measures for reduction are foreseen.

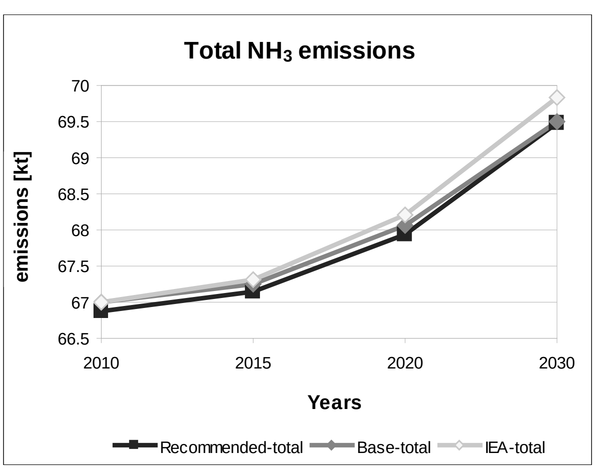


Fig. 4 National NH_3emissions [kt].

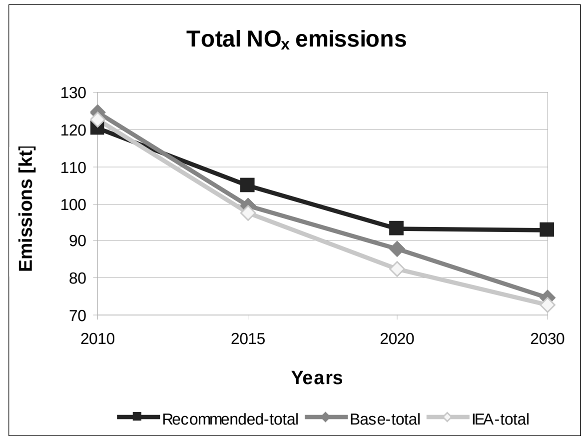


Fig. 5 National NO_x emissions [kt].

GAINS model divides the particular matter (PM) into 3 categories: fine particles PM2.5, bigger ones – PM10 and PMtsp – total suspended matter. Their total emissions for Bulgaria are down presented on Figs 6, 7 and 8.

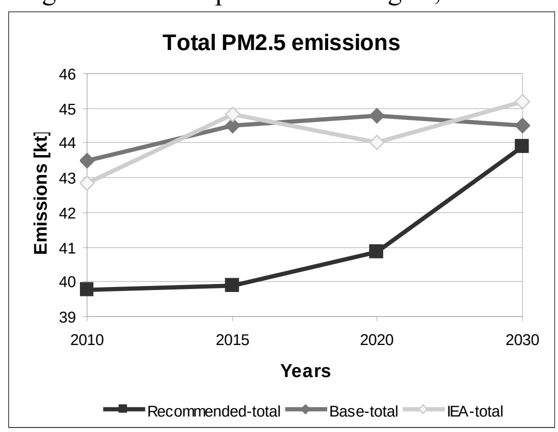


Fig. 6. Total PM2.5 emissions [kt].

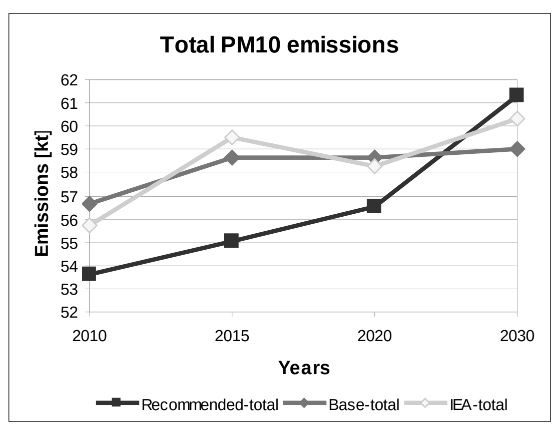


Fig.7. PM10 emissions [kt]

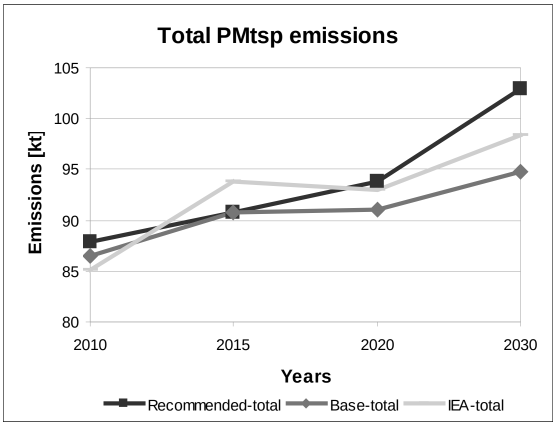


Fig. 8 Total PMtsp emissions [kt]

On Figs 9 and 10 are presented (in kt) the SO_2 and VOC emissions, respectively.

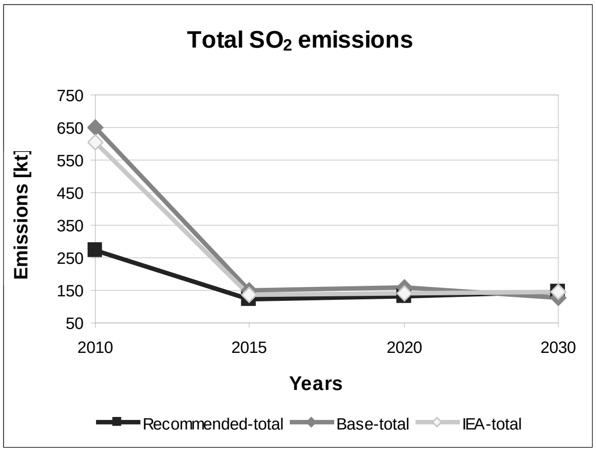


Fig. 9 Total SO_2 emissions [kt]

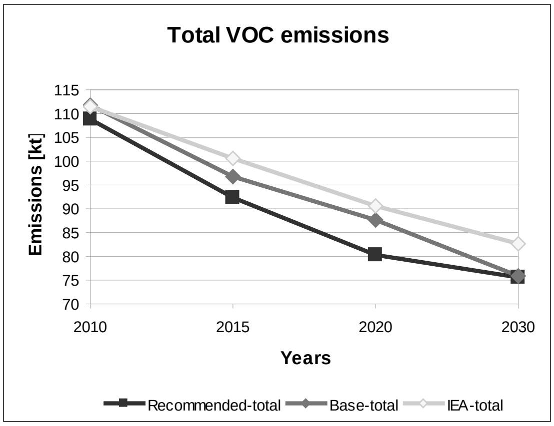


Fig. 10 Total VOC emissions [kt]

4.2. Costs of reducing emissions

This option displays emission control costs computed by the GAINS model for a selected emission scenario (= combination of energy pathway and emission control strategy), and provides details on the cost-relevant input data used for the calculations. Costs of reducing CO_2 emissions through implementation of energy system measures could be analyzed using the GAINS Mitigation Effort Calculator and are not discussed here.

For measures that influence more than one pollutant at the same time, the tables presented on the GAINS web site report their total costs under the main pollutant. In particular, if a measure reduces (inter alia) NO_x emissions, all costs of that measure are reported under NO_x. Second priority is given to PM, i.e., if a measure reduces PM and other pollutants (but not NO_x), all costs are reported under PM.

However, **these rules are only applied for the reporting of costs in the GAINS-online version. For the GAINS optimization, costs of multi-pollutant measures are not allocated to a single pollutant, but are associated with the particular measure, for which the simultaneous impacts on several pollutants are accounted (the “technology-based” approach of GAINS). GAINS optimisation is not available online at present.** For calculating emission control costs, GAINS relies on international operating experience of pollution control equipment and extrapolates it to country-specific conditions. The basic methodologies are described in model documentation for air pollutants and greenhouse gases.

Furthermore, recent information on emission control costs has been incorporated into GAINS on the basis of the reports prepared by the Expert Group on Techno-Economic Issues (EGTEI). Actual data that are used for the calculations can be extracted from the menus on this web site.

All input data for costs calculations are in Euro 2005. User can choose the cost level (Euro 2005 or Euro 2000) and the interest rate used for tables with calculation results. Here is used 10% interest rate. The results are presented in million euros per year.

On Fig. 11 are presented the control costs for all air pollutants (i.e., SO_2, NO_x, PM, NH_3 and VOC) for different scenarios. The values for the selected years do not double-count costs of measures that affect more than one pollutant at the same time. On Figs 12, 13 and 14 are presented the control costs for NO_x, PMtsp and SO_2, respectively.

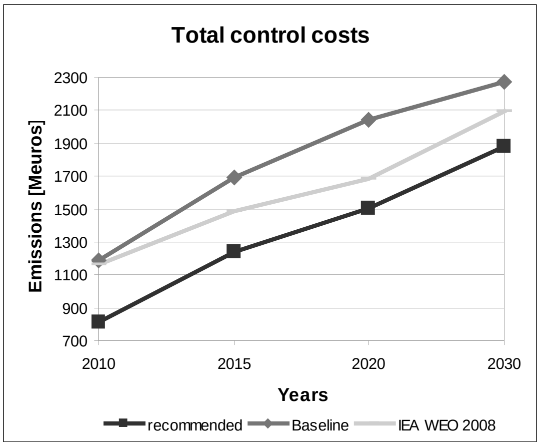


Fig. 11 Control costs for all air pollutants [Meuros]

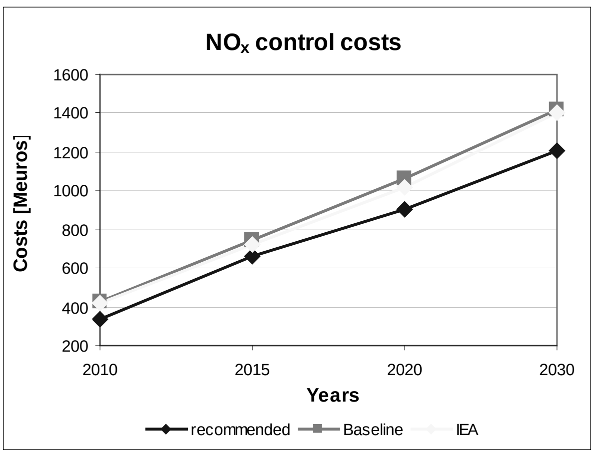


Fig. 12 Control costs for NO_X [Meuros]

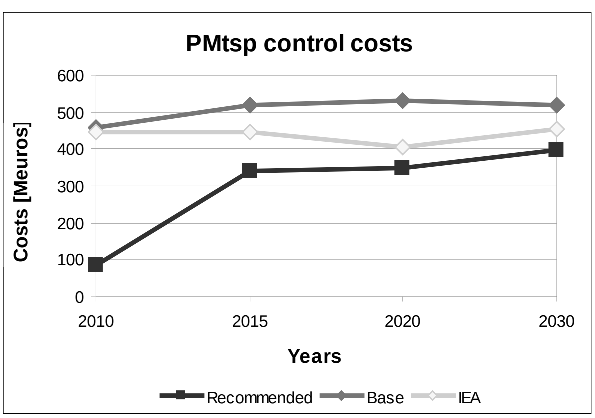


Fig. 13 Control costs for Total suspended particular matter [Meuros]

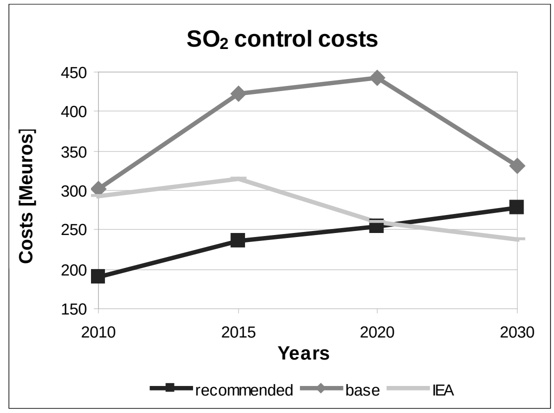


Fig. 14 Control costs for SO_2 [Meuros]

5. CONCLUSIONS

The present investigation should be considered as preliminary for Bulgaria, as the use of the model GAINS is at its beginning. The new scenarios – baseline and recommended are based on contemporary data and results, obtained by the Bulgarian participants in the project CASES. But they concern preliminary the power sector of Bulgaria. For more detailed description of the energy consumption from all economy additional data should be collected and their projections should be obtained for the selected scenarios.

Nevertheless, the results are interesting. Their comparison shows that the base scenario, which is a compilation and revision of the existing scenarios in Bulgaria, is not quite realistic. It is based on a too high demand forecast and commissioning of energy supply options that are not relevant very much. The respective emissions and reduction costs are biggest in comparison with the other scenarios. At the same time, the recommended scenario sounds more realistic. It is based on extended use of renewable energy sources, but excludes development of new nuclear options. The latter appears to be preliminary political decision, which in this case foresees building of such capacities. The emissions and reduction costs are lowest for this scenario. The referent scenario IEA WEO 2008, created by IIASA, is based on national and international input data. It is realistic, but some input options in it should be bring up-to-date.

Besides, it will be very interesting to compare the scenario considered, using the optimization module. This is not possible at present on-line. Such opportunity will give optimized results because in this case is used the "technology-based" (synergic) approach of GAINS – one measure is applied to more pollutants. This way allows achieving emission and impact targets at lowest costs. Impact assessment on human health and ecosystems is also not available on line at present.

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Сценарии Выбросов для Болгарии, Используя Интегрированную Модель GAINS

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Резюме: Модель GAINS (Greenhouse Gas Air Pollution Interactions and Synergies) представляет собой интегрированную модель для оценки загрязнения воздуха, разработанная Международным Институтом Системного Анализа (IIASA) в Австрии, в качестве инструмента для определения таких стратегий контроля выбросов, которые достигают данных целей в отношении качества воздуха и выбросов парниковых газов с наименьшими расходами. Модель рассматривает следующие загрязнители воздуха – SO_2, NO_X, VOC, NH_3, PM и парниковые газы (ПГ) – CO_2, CH_4, N_2O и F-газы (HFC, PFC, SF_6), выброшенными из разных секторах экономики. В режиме «сценарии» GAINS фокусируется на отдельных мерах по уменьшению выбросов и рассчитывает “мульти-эффект многих загрязнителей” данной меры одновременно для загрязнения воздуха и ПГ. Таким образом, исследуя синергию между мерами по сокращению выбросов и уменьшения парниковых газов, могут достигаться результы затраты-выгоды. В режиме “оптимизация” модель может быть использована для поиска баланса минимальной стоимости контроля загрязнителей рассчитивая что одновременно они достигают заданными пользователем целями для здоровья человека и воздействия на экосистемы. Модель GAINS (версия Annex I) используется в данной работе для реализации некоторых сценариев выбросов в Болгарии до 2030 года, касающихся национальных выбросов для большинства выше упомянутых загрязнителей и ПГ. Для каждого сценария рассчитываются затраты на сокращение выбросов некоторых загрязняющих веществ. Анализы чувствительности проведенны применяя разные контрольные стратегии. Представленные результаты сравниваются и обсуждаются. Использование этой модели в Болгарии находится на ранней стадии.

Ключевые слова: интегрированная модель, сценарий выбросов, контрольная стратегия