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A national integrated assessment model for Germany

Challenges for national clean air policy

Clean air policy faces not only the classical problems like multi-pollutant aspects but also complex consequences of instruments on production costs, competition and consumption. A new model can support clean air policy in Germany. By Tina Comes, Claus Doll, Magnus Fröhling, Michael Hiete, Rebecca Ilsen, Michael Krail, Thomas Lützkendorf, Frank Schultmann, Julian Stengel and Matthias Unholzer

In spite of large efforts and progress which have been made in the field of clean air policy in the last decades, in large areas of the European Union (EU) air pollution is still a problem. Air pollution causes acute and chronic health effects, considerable ecosystem damages through exceedance of critical loads and concentrations and major economic effects due to medical costs and loss of earnings, reduced crop yields or damage to materials. Main problems include acidification (e.g. SO_x, NO_x, NH_3), eutrophication (e.g. NO_x, NH_3), ground level ozone (e.g. NO_x, VOC), health issues (e.g. primary and secondary aerosols, heavy metals as well as VOC and NO_x directly and via ozone) and climate change (e.g. CO_2, CH_4, N_2O).

Clean air strategies are developed from the local up to the EU level and to the level of the United Nations Economic Commission for Europe (UNECE). These strategies are making use of cost-effectiveness and cost-benefit analyses which compare emission abatement costs with their effects respectively the monetarily valued effects. Cost curves in which total abatement costs are compared with abated emissions have been used to identify cost-effective measures.

Necessity for decision support

However, these approaches show difficulties to account for the simultaneous abatement of several pollutants (multi-pollutant) and different effects caused by a single pollutant (multi-effect), e.g. acidification, eutrophication and ground level ozone formation by NO_x. Furthermore, in contrast to end-of-pipe measures costs for process-integrated measures and non-technical measures are more difficult to determine. Finally, effects not only comprise abatement costs but also macro-economic effects like higher product prices resulting in lower competitiveness of industry and jobs created in companies offering abatement techniques.

To reduce transboundary air pollution the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) was adopted in 1979 covering now eight protocols of which the 1999 Protocol to Abate Acidification, Eutrophication and ground level ozone (Gothenburg protocol) sets emission ceilings for parties to the convention for SO_x, NO_x, NH_3 and VOC in 2010. Ceilings have been negotiated based on pollution effects and abatement costs derived from integrated assessment models (IAM). Such models, in particular the Regional Air Pollution Information and Simulation model (RAINS) and its successor, the GAINS model (Greenhouse Gas and Air Pollution Interactions and Synergies), have been applied to relate abated emissions with costs for their abatement. Combined with atmospheric transport and dispersion as well as air pollution effects modelling, abatement options with a high cost-effectiveness respectively cost-benefit ratio have been identified on a multi-national level.

The EU, itself party to the CLRTAP, has set national emission ceilings (NEC) for EU member states in the NEC Directive (2001/81/EC). Currently, the NEC Directive is under revision and new emission ceilings, including dust, for 2020 are expected.

As emission ceilings are given in mass of a pollutant emitted per year and country it is left open to the member states how to achieve this best, that is in which sector by which instrument. To solve this allocation problem member states have a high interest in decision support to identify best measures and instruments. Best here means measures and instruments that guarantee to achieve the emission levels of all the pollutants at lowest total costs with maximum benefit highlighting the need for decision support at the national level. Therefore, several countries started initiatives for national integrated assessment models. Among these countries are Finland, Ireland, Italy, the Netherlands, Sweden, and United Kingdom.

National integrated assessment modelling

Most of these initiatives make use of adaptations of the RAINS/GAINS model to the national level to evaluate the RAINS/GAINS results for their country, for example by increasing the spatial resolution of atmospheric transport and dispersion modelling. Additional models for including for example sea transport (Italy) or a more complex modelling of transport as a whole (Ireland) are linked. Methodologically, the core of RAINS/GAINS is preserved in these national models with the advantage of direct exchangeability and comparability of data and results. However, the abilities to account for country specifics and methodological refinements in integrated assessment methodology, which become possible with the reduced focus on the national level compared to the UNECE level in RAINS/GAINS, remain to a large extent unused.

Abilities and challenges on the national level are not only a spatial and temporal disaggregation but also a more realistic and detailed modelling of technical and non-technical measures and their consequences with regard to sustainability, the consideration of uncertainties and cross-media effects to avoid problem shifts and of interrelations between societal needs, activities and abatement measures. The otello model, a German national IAM, aims to address these issues.

The otello model is an independent approach to develop a national integrated assessment model for Germany. It aims at providing decision support for decision makers in national ministries and agencies in identifying and assessing instruments and thus elaborating strategies for effective and sustainable compliance with emission targets such as the NECs. Otello covers besides the pollutants SO_x, NO_x, NH_3, VOC, which are addressed by the Gothenburg protocol and the NEC directive, also dust and CO_2. The model covers the areas industry and energy supply, residential buildings, and transport and has a planning horizon of ten to 20 years. In the following, the general modelling concept, the area modules as well as the decision support module are presented.

General modelling concept

The otello model is a simulation model integrating a macroeconomic input-output-model (IOM), describing the interdependencies between different areas, with technology based bottom-up-approaches for the three areas industry and energy supply, residential buildings and transport. The IOM simulates macroeconomic parameters used by the area models and ensures the consistency of the results. The main task of the area models is estimating emissions by simulating the development and diffusion of relevant technology. Results of each simulation run are evaluated by a multi-criteria decision support module for better interpretation by potential users.

Important drivers for emissions, especially for industry and energy supply, are consumption levels. Final consumption includes private and public consumption as well as private and public investments and exports. While public consumption, public investments and exports are given exogenously, the consumption of private households is modelled endogenously by a linear expenditure system. The two area models for residential buildings and transport estimate the consumption of certain goods in more detail, with energy being the most important one. Thereby, effects of behavioural changes of consumers on industrial production and the corresponding emissions (for example fuel switching for space heating) can be included into the model. Investments of the industry (that is private investments) are regarded within the area model for industry and energy supply.

The diffusion of emission abatement measures in the considered sectors results from the individual decisions of the actors, that is the plants. In addition to direct responses to political instruments, such as emission limit values, technology standards and emission trading systems, these decisions are influenced also indirectly by instruments that change the cost or demand structure of a good. Examples are green taxes or the German Renewable Energy Sources Act (EEG) both affecting the costs and prices of input-factors. Effects of such instruments may accumulate along the value chain. The IOM is based on the IO-Table of the Federal Statistical Office of Germany and contains supply relationships between all production sectors of the German economy. Thus, it allows the user to account for any of these effects. Further on, an aggregation of effects resulting from the detailed area models at a national scale is possible, which enables to estimate the influence on economic indicators, such as gross domestic product or employment.

Area industry and energy supply

Industrial production processes and corresponding emissions are simulated at the level of individual plants. Data about individual plants is derived from the European Pollutant Emission Register (EPER) and its successor the Pollutant Release and Transfer Register (PRTR) database. Reference processes are defined to represent the technical process steps of a technology, based on data from the Expert Group on Techno-Economic Issues (Ball et al. 2005), BAT-Reference Documents and sector specific literature. They simulate the multi-stage input-output relations of a plant. The differentiation of several process steps per technology enables to model changes in production processes (for example conversion of steel production from blast furnace to electric arc furnace) as well as additve (end-of-pipe) or integrated abatement measures. Furthermore, effects of each measure can be calculated simultaneously for all pollutants.

The implementation of innovative environmental technologies is modelled by simulating individual decisions for each plant. Decisions are based on the discounted cash flow method using price and demand expectancies derived from economic parameters given by the input-output-model. Political instruments are regarded in the investment decision as a cost factor (for example emission trading schemes or green taxes) or via expected price and demand development. There are several discrete decision options including 'doing nothing' which is only possible if environmental standards are met. The environmental performance is evaluated in the light of process specific technology standards and emission limits.

The implementation of an emission abatement measure causes some changes in production technology and in most cases has an influence on up- and downstream stages of the value chain, too (for example each improvement in terms of energy efficiency results in a decline in demand for the energy sector). A feedback from these individual changes in production technology into the input-output-model leads to a consideration ➜

of the aggregated effects on the cost and demand structure of other sectors and areas.

Area residential buildings

To simulate the effects of clean air policy instruments on air emissions and final energy consumption of residential buildings a residential building stock model has been developed. The stock model makes use of the IWU building typology (IWU 2003). The typology distinguishes between building types and construction periods and differentiates in addition between quality of thermal insulation as well as systems for heating and hot water preparation, characterised by energy carrier, centrality and system type and age. The stock model takes into account new construction, demolition and refurbishment of residential buildings and allows simulating the residential building stock until 2030 including indicators representing the aspects mentioned above as well as the economic interaction with the areas represented by the input-output model and the area industry and energy supply in particular. Air emissions and final energy demand are calculated in a high temporal and spatial resolution that is per month and down to the municipal level.

In modelling the dynamics of air emissions from residential buildings the energy refurbishment of existing buildings plays a decisive role. The corresponding decision of building owners can be characterized by the thermal insulation, by the system for heating and hot water preparation as well as by the date the refurbishment takes place. In consideration of refurbishment inactivity of building owners the latter one is determined by typical lifetimes of the technical components. The choice of the alternatives is simulated by the discounted cash flow method taking into account the different objective functions in the case of owner-occupied and rented dwellings, which are caused by the German legislation (Amstalden et al. 2007). Thus, effects of several instruments as energy taxes, incentive programs as well as the Energy Saving Regulation (EnEV) and the 1st Federal Immission Control Ordinance (1. BImSchV) can be analysed.

Area transport

In contrast to the areas industry and energy supply, and residential buildings, the area transport is characterised by a heterogeneous set of users, activity patterns and potential technical and policy measures for emission reduction. The proper assessment of reduction policies thus demands for the application of a full scale integrated assessment model capturing the various relationships between demand and supply segments. This part of the analysis is carried out by the system dynamics sub-model ASTRA. This model consists of a detailed vehicle fleet module, containing classical and innovative propulsion technologies. The core contribution of ASTRA is to quantify the costs and impacts of non-technical and general technical emission reduction policies by transport sector and field of technology on the national level.

The ASTRA model application is supported by a detailed technology database going into the emission saving potentials of single technical measures by transport modes and sectors. Its content is composed of up-to-date information from engineering journals, research reports, existing data bases and interviews with industry representatives. To meet the major challenge of quantifying the inter-relations between the different options for emission reduction, for each mode several independent measure and instrument groups are defined and prioritised by cost efficiency.

The database is applied to generate time-variant emission reduction curves, feeding into the ASTRA model. This procedure enables the model to take into account detailed technology information sources. Finally, the transport module is inter-connected to the overall otello model system by standardised data exchange procedures to be applied to a series of different assumptions about uncertain parameters (for example different intensities of technology development, pricing, regulation or incentives structures).

Decision support

The otello model analyses the consequences of instruments, for example on competitiveness of industry and consumption, and assesses the instruments not only with respect to cost (as for example measures in IAMs like RAINS/GAINS) but with respect to all dimensions of sustainability. This increases the problem's complexity: different possible instruments, conflicting objectives, a plethora of perspectives and value judgements, and uncertainties entail supporting decision maker.

In the otello model both Multi-Criteria Decision Analysis (MCDA) and scenario-based decision support are integrated. The latter explores multiple plausible developments of a situation. A major drawback of scenarios is that they lack a method for systematically evaluating different alternatives with respect to multiple, potentially conflicting, goals. Yet, the essentially multidimensional nature of sustainable development (comprising economic, environmental and social aspects) requires simultaneous consideration of different goals. In MCDA goals are operationalised by an attribute tree hierarchically structuring the problem.

The combined MCDA and scenario-based approach facilitates evaluating different instruments considering the preferences of experts and decision makers involved and taking into account uncertainties. For each decision alternative this approach evaluates a set of scenarios by means of an attribute tree. When the set of generated scenarios is large, an additional aggregation step taking into account the relative importance of each scenario can support the decision makers further.

Application potentials

The utilisation potentials of the developed national IAM otello comprise application-orientated and methodological aspects.

The model can be used by decision makers in ministries and governmental agencies for the assessment and allocation of instruments respectively emission reductions. Setting story lines for scenarios they can analyse the impacts of instruments, measures and bundles of these and thus derive strategies of how to allocate ‘best’ the emission reductions necessary to comply with the NECs or even more ambitious reduction targets. The analysed scenarios will allow deriving recommendations for national clean air strategies. Moreover, also the negotiations on further national and international emission targets in clean air policy can be supported. Besides the use of the model as a whole, the modules for the single areas can be used independently to answer sector-specific questions. The database of the model comprises a comprehensive set of techno- and socio-economic data of emission abatement techniques and therefore can serve as a source of information in clean air policy.

As the otello model follows a novel approach besides the lines of integrated assessment models on the multi-national and other IAMs on the national level it is also interesting from a methodological point of view. Here especially the actor-orientated modelling in the area industry and energy supply, the model for the residential building stock and the assessment of non-technical and technical emission reduction measures and their interrelations in the area transport as well as the decision support module are noteworthy. Overall, the model thrives towards simulation whereas other IAMs are restricted to cost-effectiveness and cost-benefit analysis. The findings are discussed with national experts, for example in the group of national integrated assessment modelling initiatives (NIAM) and thus support the scientific discussion in the field of national IAM (NIAM 2010). Furthermore, the modular character of the model allows integrating further modules in future, for example for agriculture. The temporal and spatial resolution of emission sources, for example from point sources in the industry and energy supply module and of the building stock and the detailed vehicle fleet module allow for a later combination with an atmospheric transport and dispersion model as well as further disaggregation for example in regional models.

Conclusions

Clean air policy faces the challenge, which instruments and measures should be implemented to achieve clean air or comply with emission targets for air pollutants and greenhouse gases in the ‘best’ way. Challenges are not only the classical problems like multi-pollutant, cross-media and multi-effect aspects but also complex consequences of instruments on production costs, competition and consumption.

The national integrated assessment model otello aims at providing a tool for the assessment of instruments for control of SO_x, NO_x, NH_3, dust and CO_2 emissions from industrial production, energy supply, transport and residential buildings with respect to the sustainability objective. To provide decision support for political deciders different policy instruments and measures are evaluated considering the dimensions of sustainability. To take into account uncertainties each instrument is evaluated under a set of different assumptions about the further economic and demographic development. To account for the complex consequences of control instruments on the economy, the otello model simulates positive and negative interdependencies along supply chains and effects of behavioural changes on the consumer side via a dynamic input-output-model. A feedback loop from individual investment decisions to the input-output-model allows taking into account the effects of investments on the cost and demand structure of up- and downstream chain links of the value chain.

Application-orientated potentials of the model lie in the identification and assessment of instruments and measures for achieving emission reduction targets and the support in the development of clean air policy strategies, as well as in the provision of a comprehensive database on measures and instruments. Methodologically, the independent and new approach will enrich the scientific discussion in the field of integrated assessment modelling.

Annotations

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