MEASURES AND INSTRUMENTS FOR EMISSION REDUCTION IN TRANSPORT– FINDINGS FROM THE OTELLO PROJECT

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ABSTRACT

In 2007 the German Federal Ministry for Science and Education (BMBF) launched the research project otello (Development of an Integrated Assessment for National Air Emission Management). The objective of the research is to develop a simulation model for assessing measures and instruments to reduce emissions of air pollutant and CO_2 from transport, industry, electricity and heat supply and residential buildings in Germany until 2020 and their compliance with the EC-directive on National Emission Ceilings (NEC).
This paper concentrates on the transport sector, for which the assessment of emission reduction policies is approached by the integrated system-dynamics model ASTRA, capturing the various relationships between demand and supply segments. 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 a national level. The model application is supported by a detailed technology database going into the emission reduction potentials of single technical measures by transport mode and sector. For each mode several independent measure and instrument groups have been defined and prioritised by cost effectiveness, where the major challenge was the quantification of inter-relations between the different measures. The database then was applied to generate time-variant emission reduction curves, feeding into the ASTRA model.
The paper will discuss the methodology applied to model air and greenhouse gas emissions within the transport sector for Germany. As the research is still on-going, research results of previous exercises using a very similar approach for the transport sector are presented.

Keywords: transport, electric vehicles, consumer behaviour, user behaviour

1. INTRODUCTION

In 2007 the German Federal Ministry for Science and Education (BMBF) launched the research project otello (Development of an Integrated Assessment for National Air Emission Management). The objective is to develop a simulation model for assessing measures and instruments to reduce emissions of the air pollutants NO_x, SO_x, VOC and particulate matter as well as of CO_2 from transport, industry, heat and electricity supply, as well as residential buildings in Germany until 2020. The otello model application will be able to assess measures and instruments with respect to emission reductions and to aspects of sustainability. It supports thus the development of integrated strategies to meet the requirements of the EC-directive on National Emission Ceilings (NEC) for Germany. The paper will present the overall approach developed in the otello project and will discuss the methodology applied to the transportation sector. Current results of assessing technical and non-technical measures in the transport sector with specific emphasis on CO_2 emissions are presented. Eventually, these findings will be discussed in the light of previous findings for emission reduction and climate abatement measures in Germany.

2. OVERVIEW OF THE OTELLO APPROACH

The UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) adopted in 1979 has been extended by now eight protocols identifying specific measures for emission reduction. The 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg protocol) sets national emission ceilings for SO_x, NO_x, NH_3 and VOC in 2010. Even though the technical annexes of the Gothenburg protocol contain for example emission limit values (ELVs) for mobile and stationary sources, large flexibility—also with respect to the ELVs—is given to the parties of the convention if only the emission ceilings are met. The EU—like many EU countries party to the convention—set in turn national emission ceilings (NEC) for the EU member states in the NEC Directive (2001/81/EC). The NEC directive leaves it also to the countries to decide how to achieve the NECs in the best way within the EU regulatory clean air framework. In 2008 reporting under the NEC directive 14 out of 27 member states anticipated that they will miss at least for one pollutant their NECs with 12 countries having problems meeting their NO_x NEC, 4 their NMVOC NEC, 2 their NH_3 NEC and one country its SO_2 NEC (EEA 2009). Currently, the NEC directive like the Gothenburg protocol is under revision and new emission ceilings, including for dust, for 2020 are expected. Ceilings are negotiated based on pollution effects and abatement costs derived from the integrated assessment models (IAM) RAINS/GAINS developed and run by IIASA, Laxenburg.

Several member states, e.g. Finland, Ireland, Italy, the Netherlands, Sweden, and the United Kingdom, started initiatives for national IAMs to support national clean air policy but also the negotiation process of NECs and therefore use mostly national versions of RAINS/GAINS.

The otello model is an independent approach to develop a national IAM 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 the NECs. Otello considers besides the pollutants SO_x, NO_x, NH_3, VOC and dust also CO_2. The model covers the areas *industry and energy supply*, *residential buildings,* and *transport* and has a planning horizon of 10 to 20 years. In the following, the general modelling concept, the area modules as well as the *decision support module* are briefly presented (cf. Comes et al. (2010) for more details).

The otello model is a simulation model integrating a macro-economic 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* (see Figure 1). 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.

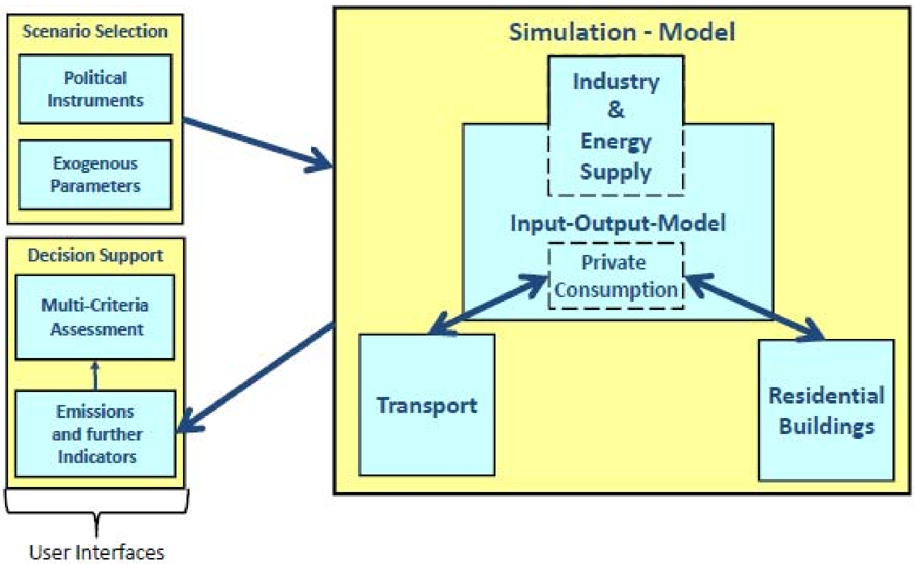

Figure 1: Model structure

Important drivers for emissions, especially for *industry and energy supply*, are consumption levels. 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. Thereby, effects of behavioural changes of consumers on industrial production and the corresponding emissions can be included into the model.

The diffusion of emission abatement measures in the considered sectors results from the individual decisions of the actors. 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. The IOM is based on the IO-Table of the Federal Statistical Office of

Germany[1]. 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 GDP or employment.
In the following the modelling approach of the transport sector will be described in more detail and available research results will be presented. The other sectors considered by the otello approach, namely the areas industry, energy supply and residential buildings are described in more detail in Comes et al. (2010).

3. MODELLING TRANSPORT EMISSIONS

Methodology: In contrast to the areas industry, energy supply and residential buildings, the transport sector 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 model ASTRA. The 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 a national level.
The ASTRA model application is supported by a detailed technology database going into the emission reduction potentials of single technical measures by transport mode and sector. The database has been set up by making use of engineering journals, research reports, existing data bases and interviews with industry representatives. The major challenge was the quantification of inter-relations between the different measures. For each mode several independent measure and instrument groups have been defined and prioritised by cost effectiveness. Out of that four implementation stages have been defined.
The database then was applied to generate time-variant emission reduction curves, feeding into the ASTRA model. This procedure enables the model to take into account detailed technology knowledge. Finally, the transport module is inter-connected to the area modules industry, energy supply, residential buildings and a macroeconomics module by standardised data exchanges. This extended modelling instrument was then applied to a series of scenarios, which are characterised by different intensities of technology development, pricing, regulation, incentives, etc. The scenarios made consistent across all economic sectors considered in the Otello project.

The ASTRA System Dynamics Model

ASTRA is a strategic System Dynamics model based on a hybrid structure of European countries and regions. The current version of ASTRA comprises 29 European countries (EU27 plus Norway and Switzerland). Each country is subdivided into up to four functional zones representing their degree of urbanisation. The ASTRA model consists of nine integrated thematic modules on population, macro-economy, regional economy, international

1 Statistisches Bundesamt, 2009

trade, transport, transport infrastructure, vehicle fleet, environment and welfare measurement. These modules and their relevance for the otello assessment approach are briefly described in turn. A detailed description of the ASTRA model is provided by Schade (2005).

The *Population Module* (POP) provides the population development for the 29 European countries with one-year age cohorts. The model depends on fertility rates, death rates and immigration into the EU29 countries and is calibrated to EUROSTAT population predictions. Population size and structure of the regions are an important trigger for their transport and economic activities and thus impact the level of air emissions.

The *Macroeconomics Module (MAC)* provides the national economic framework, which imbeds the other modules. The MAC could not be categorised explicitly into one economic category of models for instance a neo-classical model. Instead it incorporates neo-classical elements like production functions. Keynesian elements are considered like the dependency of investments on national income extended by some further influences on investments like exports or government debt. Or elements of endogenous growth theory are incorporated like the implementation of endogenous technical progress as one important driver for the long-term economic development. The latter also is a decisive determinant of air emission rates of the various transport and economic sectors.

The *Regional Economics Module (REM)* mainly calculates the generation and distribution of freight transport volume and passenger trips. The number of passenger trips is driven by employment situation, car-ownership development and number of people in different age classes. Trip generation is performed individually for each of the 76 zones of the ASTRA model. Distribution splits trips of each zone into three distance categories of trips within the zone and two distance categories crossing the zonal borders and generating OD-trip matrices with 76x76 elements for three trip purposes. As opposed to the classical static 4-stage transport modelling approach, the distribution in ASTRA is performed without carrying out the trip attraction. Freight transport is driven by two mechanisms: Firstly, national transport depends on sectoral production value of the 15 goods producing. Secondly, international freight transport i.e. freight transport flows that are crossing national borders are generated from monetary Intra-European trade flows of the 15 goods producing sectors. In both cases transfer into volume of tons is performed by applying value-to-volume ratios. The REM is thus another decisive determinant of total air emissions as it finally generates traffic demand by regions.

The *Foreign Trade Module (FOT)* is divided into two parts: trade between the EU29 countries (INTRA-EU model) and trade between the EU29 countries and the rest-of-the world (RoW) that is divided into 12 regions (EU-RoW model). The resulting sectoral export-import flows of the two trade models are fed back into the macroeconomic module as part of final demand and national final use respectively. Secondly, the INTRA-EU model provides the input for international freight generation and distribution within the REM module.

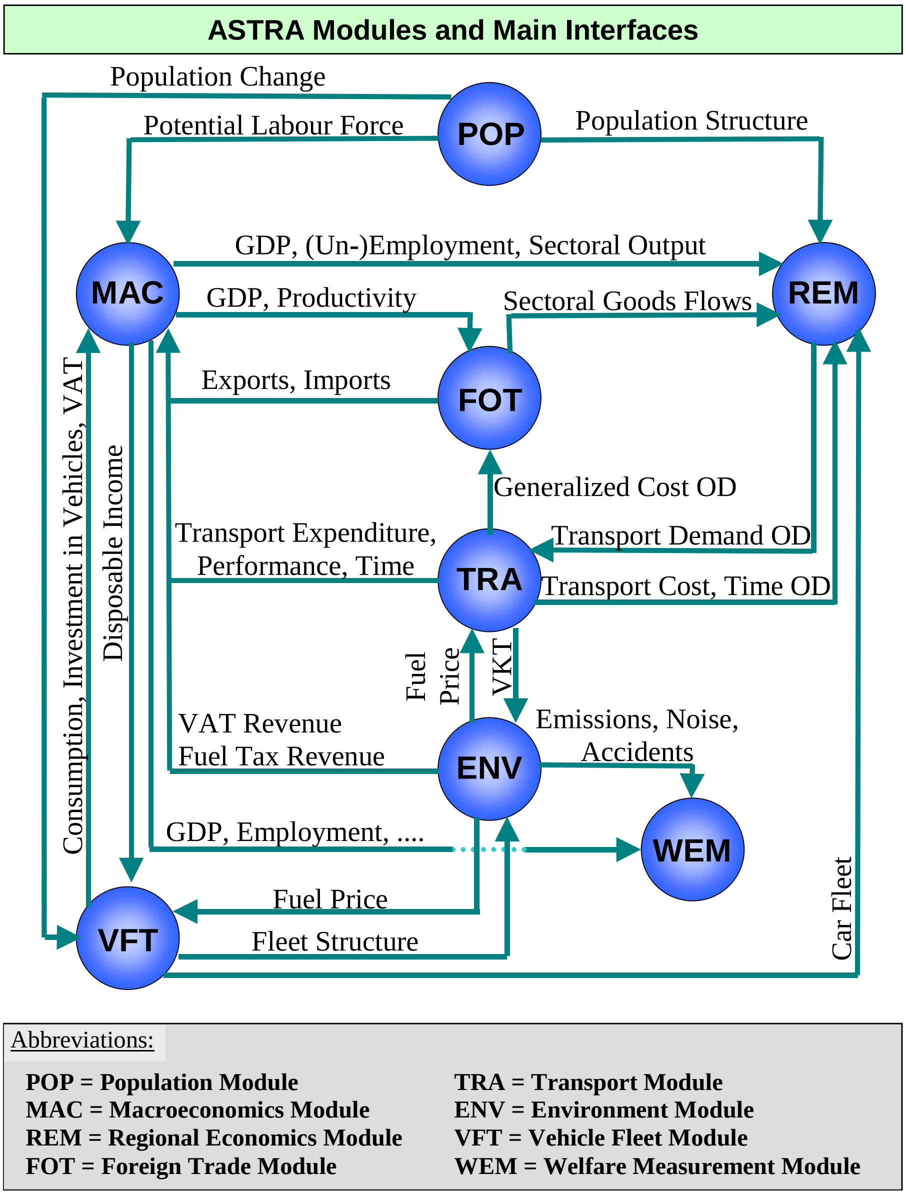

Figure 2: ASTA model structure (source: Fraunhofer-ISI)

Major input of the *Transport Module (TRA)* constitutes the demand for passenger and freight transport that is provided by the REM in form of OD-matrices. Using transport cost and transport time matrices the transport module is performing the modal-split for five passenger modes and three freight modes. Cost and time matrices depend on influencing factors like infrastructure investments, structure of vehicle fleets, transport charges, fuel price or fuel tax changes. For road transport network capacity and network loads are considered for four different road types such that congestion effects may affect the road transport time matrices in a simplified way. For other modes rough capacity models and capacity constraint functions are developed such that interactions between load and travel times can also be taken into account. Depending on the modal choices, transport expenditures are calculated and provided to the macro-economic module. Changes in freight transport times are also transferred to the macro-economic module such that they may influence total factor productivity. Considering load factors and occupancy rates respectively, vehicle-km are calculated. These represent an important input for the ENV module where emissions or accidents are calculated and for the VFT module, which estimates the new purchase of road vehicles besides cars.

Major output of the TRA provided to the *Environment Module (ENV)* is the number of vehicle-kilometres-travelled (VKT) per mode, distance band and traffic situation respectively. Based on these traffic flows and the information from the vehicle fleet model on the different vehicle fleet compositions and hence on the emission factors, the environmental module is calculating the emissions from transport. Besides emissions, fuel consumption and, based on this, fuel tax revenues from transport are estimated by the ENV. Traffic flows and accident rates for each mode form the input to calculate the number of accidents in the European countries. Expenditures for fuel, revenues from fuel taxes and value-added-tax (VAT) on fuel consumption are transferred to the macroeconomics module and provide input to the economic sectors producing fuel products and to the government model. The ENV module is the most relevant element of the ASTRA model for the purpose of the otello assessment framework.

The Vehicle Fleet Module (VFT) is describing the vehicle fleet composition for all road modes. Vehicle fleets are differentiated into different age classes based on one-year-age cohorts and into different emission standard categories. Additionally, car vehicle fleet is differentiated into gasoline and diesel powered cars with different cubic capacity categories. Car vehicle fleet is developing according to income changes, development of population and of fuel prices. Vehicle fleet composition of bus, light-duty vehicles and heavy-duty vehicles mainly depends on driven kilometres and the development of average annual mileages per vehicle of these modes. The purchase of vehicles is translated into value terms and forms an input of the economic sectors in the MAC that cover the vehicle production. Driven by detailed car purchase functions the VFT module thus provides an important trigger to the ENV module, and through functions of technological progress it takes direct impact on the otello modelling framework.

Finally, in the Welfare Measurement Module (WEM) major macroeconomic, environmental and social indicators can be compared and analysed. Also different assessment schemes that combine indicators into aggregated welfare indicators for instance an investment multiplier are provided in the WEM. In some cases e.g. to undertake a cost-benefit analysis (CBA) the functionality is separated into further tools to avoid excessive growth of the core ASTRA model by including the assessment scheme directly within the model.

The integrated modular approach of ASTRA has the advantage that feedback loops, which commence on the micro- or meso-level in one of the modules (e.g. transport expenditures for one mode and one OD-pair in one distance band in the TRA) and then end up with an effect on the national level (e.g. changes in sectoral consumption and gross-value-added), can influence the originating module such that the feedback loop is closed e.g. in this case by the integration of the MAC module. Closing the feedback loop then implies to establish either macro-micro-bridges (e.g. from GDP and sectoral output to goods flows) or vice versa micro-macro-bridges (e.g. from transport investments into vehicle fleets to overall investments).

The Measures and Instruments Database

The ASTRA system dynamics model provides the functionality to model the inter-relationships between different sectors within transportation as well as between transport and other economic sectors. The model also deals with technical change by a set of learning curves and elasticity of factor productivity, costs or emissions with respect to market factors including prices, demand or economic activity. However, in the framework of the otello research a more detailed analysis of technical options and measures influencing behavioural change to judge the compliance of the transport sector with national emission limits is needed.

To meet this requirement we have set up a database on “Measures and Instruments for Reducing Emissions in Transport” (MIRET). The database concentrates on technical measures for energy, CO_2, air emission and noise reduction in all transport modes. Besides these, MIRET also treats soft measures, i.e. behavioural change, and policy instruments. For each measure and instrument the following parameters are recorded:

- Classification of the measure or instrument by technology field, organisational level and its market segment (passenger / freight, long / short distance)
- State of development, expected market entry, full unfolding and its potential contribution to energy saving and emission reduction of CO_2, NO_x, particles (PM) and noise.
- Costs of implementation and operation as fixed investment costs and variable operating costs in terms of full market penetration per year.
- Detailed description, sources, internet links and comments.

The classification of data entries according to technology areas appeared necessary for two reasons: to get a more structured insight into the drivers of emission reduction per mode and to uncover possible mutual interferences between measures and instruments. We have used the following classification:

- Propulsion system: all measures reducing emissions due to more efficient engines or engine control systems.
- Fuels: potential of alternative fuels, such as biodiesel or hydrogen.
- Vehicle technology: power train, aerodynamics, light weight construction, on-board energy systems and storage, including brake energy recuperation systems.
- Operations: vehicle / train operation standards, including the management of air conditioning or optimised driving cycles.
- Infrastructures: way-side energy supply, IT facilities or infrastructure construction standards and operation procedures.
- Policy instruments: pricing, taxation, regulation, information, research funding or mobility management

Currently the database contains 203 entries, which are the result of multiple data searches, assessment and filtering of emission reduction concepts in road, rail, air and waterborne transport. Data sources used for filling the database included existing studies in the field of climate mitigation and environmental management of transport, journals, community gazettes and the websites of manufacturers, transport operators and their associations. A large number of contemporary studies deal with technical options to increase fuel economy and to

avoid CO_2 emissions of passenger cars, such as the King Review (King 2007) for the UK department of transport, McKinsey (2008) for the German Association of Industries (BDI) or TNO et al. (2008) for the EU. In previous work we have conducted an economic assessment of technological and behavioural trends and scenarios within the national integrated climate and energy program Fraunhofer-ISI et al. (2008) on behalf of the German Environment Agency, or within the German technology foresight process (Cuhls et al., 2009). Specific reviews of technological innovations in single modes include Appel et al. (2008) for trucks, Raper (2008) for aviation or House of Commons (2009) for the shipping sector.
A specific information source was provided by the Energy Efficiency Database of the International Union of Railways dating back to 2003. For the otello study we have updated the entries using contemporary studies (e.g. Kollamptodi (2006) on Diesel engines) and by interviews with industry representatives. Due to this valuable point of departure the MIRET dataset holds slightly more than half of all entries, 103 out of 203, for the railway industry. Thus, we analyse technology implications for the railways in more detail than we do for the remaining modes. The consequences of this bias will be discussed below. The number of database entries my mode and technology area is as follows:

Table 1: MIRET database entries by mode and technology area

	Rail	Road	Aviation	Shipping	TOTAL
Propulsion systems	11	17	1	5	34
Fuels	3	2	2	2	9
Vehicle technologies	53	16	6	12	87
Operations	15	3	5	4	27
Infrastructures	18	0	3	1	22
Policy instruments	3	2	10	9	24
TOTAL	103	40	27	33	203

One of the main challenges of composing the MIRET database was to address the manifold inter-relationships between the several measures on the one hand and between measures and instruments on the other hand. In the first case we must admit that technical measures applied to a particular transport segment may impact the effectiveness of other measures. In the case of speed reduction and aerodynamics for instance we need to consider that the impact of more streamlined vehicles or better surface materials and structures is increasing with rising air (or water) resistance. Another example is the coincidence of more fuel efficient or clean engines on the one hand and light weight constructions and behavioural measures on the other hand. In these cases the absolute reductions in emissions must not be simply added up.
We have checked several solution concepts.

- The most sophisticated way of dealing with mutual inter-relationships is to create a cross reference table describing the effectiveness of one measure (or instrument) in case other instruments are in place. As in most cases only vague information on cross-effects are available and as the complexity of the database would rise exponentially with this direct modelling we have discarded the option.

- In a more simple case we can pre-define implementation pathways. This implies that for each option we have an idea which other measures or instruments had been implemented before. The emission reduction potential encoded in the MIRET system then corresponds to the respective marginal abatement potential. We have chosen this approach by grouping measures and instruments according to specific technological areas.
- A very simple general solution to the problem is to multiply emission reduction potentials rather than to add them up. We apply this rule to the marginal abatement potentials within each mode of transport in order to make sure not to exceed 100% emission reduction with certain combinations of measures. Across transport modes we add up absolute emission reductions as we can assume these to be rather independent of each other.

A further methodological problem concerns the treatment of behavioural (soft) measures and policy instruments in the MIRET dataset. Policy actions and soft measures do not reduce emissions themselves, but trigger the use of particular transport options or foster the implementation of certain technologies. Their impact strongly depends on (a) the availability of low emission options and technologies and (b) on their intensity and design. Further, we may face considerable feedback loops and cross-sector relations, which can hardly be covered by a simple database system. We thus transfer these complex measures to the ASTRA model. For reasons of information we just report the emission reduction potential of soft measures and policy instruments in the MIRET database assessment.

In the subsequent sections we will briefly describe the results of the database for the four modes. The presentation is restricted to CO_2 emission reduction potentials as the data availability on air emission reduction potentials and on implementation costs currently contained in MIRET is not of sufficient quality.

Emission reduction scenarios

Within the otello approach policy packages for complying with the several requirements of the NEC directive are generated via implementation scenarios of policy instruments. This method is chosen because a numerical optimisation of all possible options is hardly feasible because many technical and policy measures may be scaled across various intensity levels and may have mutual impacts on other measures and thus creates a continuous solution space.

We thus go for a rather simple setting of scenarios. Using qualifiers like “weak” or “strong” for several policy instruments we define policy packages targeted to specific modes or policy orientations. The areas of policy instruments considered in the scenario process are:

- Regulation – emission standards, speed limits, access control
- Market-based instruments – prices, emission trading, fiscal policy
- Incentives – research funding, mobility management, investment strategies

Out of these areas and the respective subsequent policy options two basic scenarios are developed for the transport sector: moderate and sharp increase of pressure on the transport modes to reduce climate gas and air emissions.

4. RESULTS

Results from the MIRET database

In the following paragraphs we present first results of the Measures and Instruments for Emission Reduction in Transport (MIRET) database. This is the result of on-going research, which implies that the values presented may be adopted throughout the further course of the otello project. Final results will be available in autumn 2010. Due to missing or incomplete data on emission reduction potentials for some air pollutants and in particular for implementation costs we have to restrict the presentation of results to climate gas abatement potentials.
Mode by mode we discuss the slope of unit CO_2 emission function relative to 2005 within the time period 2010 to 2030. These abatement curves are the result of technologies and procedures which are known today and which can be expected to be implemented without a major change of the transport policy environment. With respect to the scenarios drafted above this means a mean intensity of policy measures. With softer or harder policies we will finally scale the emission functions. These will finally be fed into the ASTRA system dynamics model to compute overall reduction potentials and further sustainability indicators.

a) Results for rail transport
We start the discussion of the MIRET results with the sector having the most entries, namely rail. Even under consideration of mutual impact of measures and no drastic change in transport, energy and environmental policy we receive a reduction in CO_2-emissions of 27% in 2020 and of 42% in 2030 against the 2005 reference level. Within the rail sector vehicle technologies constitute the largest technology area with 53 entries and a CO_2 reduction potential of 16% until 2020 and 25% until 2030. Out of these the most relevant sub-areas are:

- Aerodynamics: 8 entries, 4.8% reduction until 2030
- On-board energy systems: 18 entries, 1.7% reduction until 2030
- Energy re-generation: 7 entries, 8.3% reduction until 2030
- Driver assistance systems: 4 entries, 3.4% reduction until 2030
- Light weight technologies: 4 entries, 5.6% reduction until 2030
- Wheel-track system: 7 entries, 2.2% reduction until 2030
- Others: 5 entries, 2.0% reduction until 2030

This short listing demonstrates, that the number of measures is not necessarily decisive for the reduction potential of a technology area. Energy re-generation, i.e. through the recuperation of brake energy or the use of waste heat from engines and air conditioning are the most relevant drivers of potential railway energy saving strategies. But also the aerodynamics of locomotives and entire trains, as well as light weight construction can play a significant role in the railways' climate strategy.
Infrastructures take the second position in rail climate abatement areas. In the MIRET database this area contains classical measures to improve infrastructures, e.g. by grinding and adjusting tracks for better train operations, wayside energy facilities or information and IT

networks. But the item infrastructures also contains novel transport systems like inter-city tubes following the SwissMetro approach, or maglev trains. Here we have not attached any market share until 2030 to these measures as their implementation now is more questionable than ever. The projected climate gas saving potentials for the technology areas in rail transport from 2010 to 2030 are presented by Figure 3. The numbers in brackets denote the number of database entries.

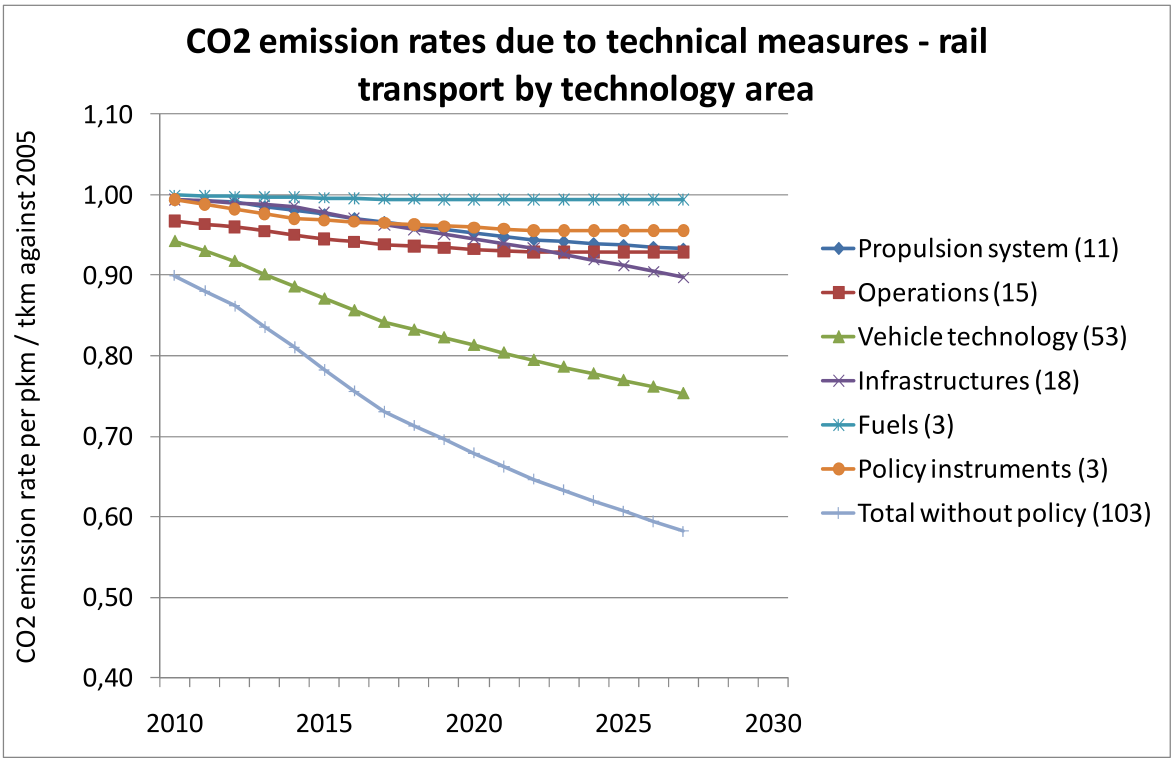

Figure 3: MIRET database results for rail by technology area

Given the database structure we cannot subdivide the results by transport market, i.e. passenger versus freight or long versus short distance. The reason for this is that many measures are not specific to one of these segments and would have to be artificially subdivided for a more differentiated assessment of the MIRET content.

b) Results for road transport

We estimate the potential reduction in road traffic related CO_2 emission rates amounting to 33% in 2020 and 49% in 2030 against 2005 levels. Astonishingly, this is only slightly above the results for rail transport. The reason for this cautious result is that we took rather conservative assumptions on the market penetration of alternative propulsion technologies. In passenger transport we assume the car and public transport fleet being composed of 6% electric cars, 5% fuel cell vehicles, 5% plug-in hybrids, 10% full and 25 mild hybrid vehicles. In other words, about half of all road passenger vehicles will still be running on gasoline or diesel, of which we assume 30% running on bio-fuels.

In total propulsion technologies contribute the most to road emission savings with 27% reduction in 2030, followed by vehicle technologies reducing by 17%. Among these light weight constructions are the most important single component reducing emissions by 5%. Biofuels finally contribute 10% and operations, namely logistics concepts, have the potential to reduce all road CO_2 emissions by another 6%.

Results for aviation:
Aviation is found to be muss less capable in reducing its climate gas emissions than road and rail. We find values of only 15% until 2020 and 21% until 2030. The most important technology area is aircraft technology reducing emissions by 11% until 2030. Most of this reduction potential is attributable to the use and research support of open rotor fans. With 6% reduction potential improved operations, in which the use of wide body aircrafts on medium distances and taxi / pushback without aircraft engines have the biggest effect. Policy measures, namely emission trading, fuel taxation and environmental airport charges could contribute another 6% to the climate gas emission potential in 2030.

Results for waterborne transport
With a CO_2 emission reduction potential of 13% maritime shipping and inland navigation takes the least position of the four modes. The biggest single contribution is made by the technology area of propulsion technologies. Total reductions in this area of 6% are driven by several wind power technologies. More efficient ship bodies and other vehicle technologies for ships contribute another 3% to the emission reduction potential of waterborne transport. As for air, policy instruments pushing new technologies are an important factor as investments in ships and aircrafts are extremely expensive and may not always be borne by the market without regulations or economic instruments.

Total effects:
A comparison of the MIRET database results across modes is given by Figure 4. Total CO_2 emission rates of the transport sector as a whole are computed by the weighted sum of the modal results. The weights are set according to total CO_2 emissions of the modes in 2005. In total all measures (excluding policy instruments) which are encoded in the MIRET database lead to a reduction in CO_2 emission rates per transport unit of 27% in 2020 and of 42% in 2030 against 2005 levels.
The difference between road and rail on the one hand and shipping and aviation on the other hand is remarkable. To some extent this can be explained by the bias of database entries and by external studies towards rail and road transport. But as we have tried to compensate for this bias by giving road and rail measures very cautious market entry probabilities, we assume these partly reflecting the real situation. Shipping and aviation are both caracterised by high vehicle stock investment costs. Moreover, in aviation much has been done in the past to get cleaner and more efficient, i.e. the low hanging fruits have been picked to a large extent.

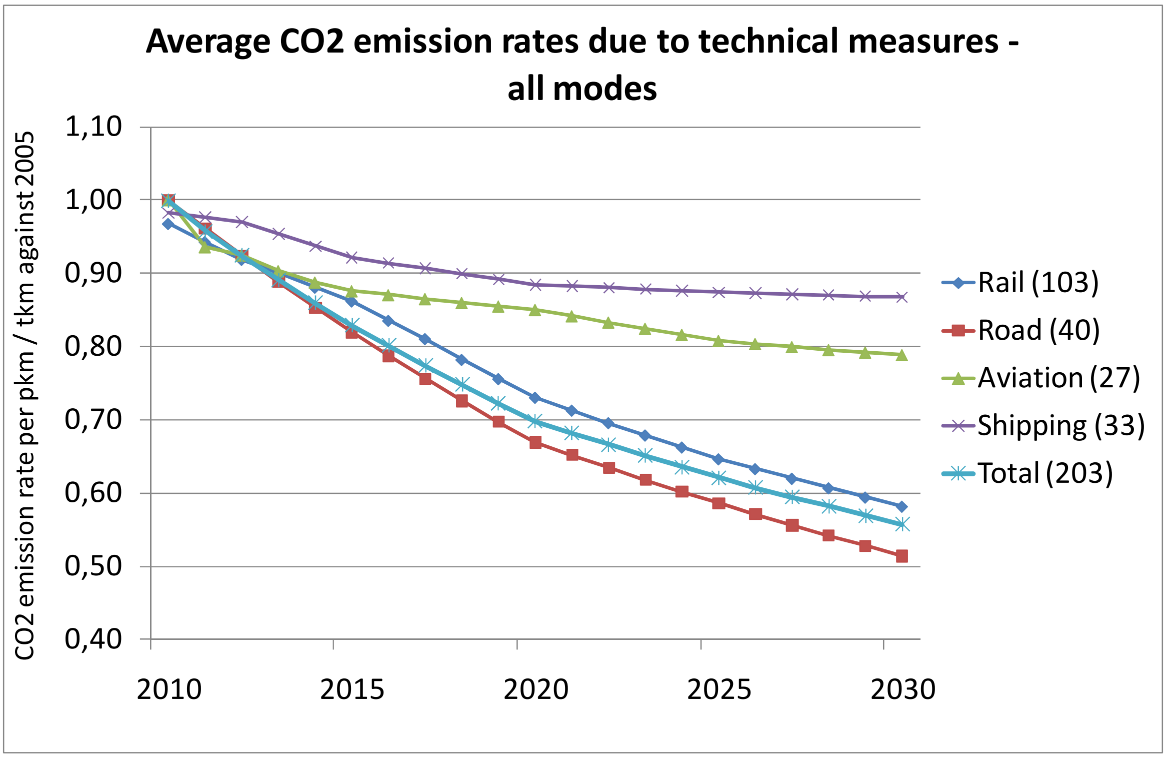

Figure 4: MIRET database results for rail by technology area

Results with ASTRA application

In this section we will briefly introduce results of earlier studies on GHG mitigation measures using the ASTRA system dynamics model. This serves two purposes: first, the type of output which can be expected with this tool shall be demonstrated and second, the results shall validate the above results of the MIRET database. For these purposes we present the findings of the study series "policy scenarios for climate protection" funded by the German Environment Agency (UBA). Currently, volume V has been published and volume VI is in preparation. In the following paragraphs we will refer to volume V (Öko-Institut et al., 2009). The study distinguishes between two cases:

- "Additional measures", where additional refers to current policy plans. Measures:
  - VAT on flight tickets
  - Enlargement of the HGV motorway toll
  - Abatement of electricity tax for rail
  - More stringent CO_2 strategy for cars
  - Adaptation of the taxation of company cars
  - Tax on kerosene
  - Speed limit on motorways.
- "Structural change" referring to a re-orientation of national transport policy: Considered are the same measures as above, but under the framework of a drastically sharpened cap for the EU's Emission Trading System. This has implications on energy prices in all sectors, but possibly with varying degree.

The resulting CO_2 emissions absolute and relative to 2005 are presented in Table 2. When comparing these figures to the MIRET results it is to be considered that Öko-Institut et al. (2009) work with total emission figures including demand changes. Further, the number of measures applied in the study represents only a small fraction of the measures implemented in the otello project.

Table 2: Policy scenarios V: transport sector results on CO_2 emissions

Scenarios	2005	2010	2020	2030
Total climate gas emissions (Mt CO_2 equivalents)				
With additional measures				
National transport	165.5	166.3	157.7	136.6
Int. air and sea transport	29.3	32.8	39.6	46
Structural change scenario				
National transport	165.5	156.2	128.5	102.4
Int. air and sea transport	29.3	31.2	21.5	24
Comparison total CO_2 emissions to 2005				
With additional measures				
National transport	100%	100%	95%	83%
Int. air and sea transport	100%	112%	135%	157%
Structural change scenario				
National transport	100%	94%	78%	62%
Int. air and sea transport	100%	106%	73%	82%

The measures investigated in Öko-Institut et al. (2009) in the additional scenarios case and without considering international air and maritime transport lead to a reduction in total CO_2 emissions against 2005 of 17%, including technological and demand based effects. In contrast, the MIRET database arrives at a reduction level of 42% abstracting from demand effects. Considering the large number of measures investigated in the otello research this relation appears justified. One could only argue that the difference in cases considered should lead to a much higher difference between the two studies. For a clearer picture we need to do the comparison on the basis of individual measures. This check will be carried out in the remaining course of the project.

CONCLUSIONS

The paper has presented the basic methodology for assessing the emission levels of the various transport sectors as a consequence of the introduction of various technical as well as non-technical measures in transport. The methodology of coupling a database on measures and instruments to the ASTRA system dynamics model in this context allows modelling these emissions on two very different levels: the coarse regional and economic sector based structure of the ASTRA model and a very fine technology based level. Despite the demonstration that the basic elements of this approach work, meeting the objectives of the otello project still requires to carry out a number of working steps. These include:

- Shifting from emission rates to total emissions. This will be done within the ASTRA model and thus does not require any adaptation of the MIRET database.
- Include other than CO_2 emissions. This is rather a problem of data mining than of the database technology.
- Incorporate cost data for each measure. Even more than the collection of data on other pollutants this task will be strongly limited by data availability.
- Assess the costs and the effectiveness of policy instruments on each measure. Some measures will be more reactive on prices, while others can best be adjusted by regulation or information.

The composition of CO_2 reduction measures in the MIRET dataset indicates that a clear cut of GHG gas emissions even with today's technologies is well possible. Without serious cost figures in the database we do not have an idea of the market conditions which would help realising these potentials. But we can suspect that there are still some rather low hanging fruits. The serious consideration of multi-national energy companies and big automotive manufacturers with alternative fuels and propulsion technologies in the past years indicates that we may be in between a technological break. This idea is supported by studies on young peoples' attitudes towards cars, saying that since a few years their interest turns more towards communication and consumer electronics, and that mobility is regarded more pragmatically in the sense that multi-modal travel options are chosen according to actual needs, rather than to go for a own car at the earliest possible occasion (Bratzel, 2009).

As concerns the emission of air pollutants we can suspect that their overall reduction potential is much stronger than that for CO_2. In most circumstances, GHG emission reduction means saving fuel and thus to reduce the basis for harmful air emissions. On top of that air emissions can be filtered or can be avoided by changing the chemical composition of fuels. In particular through electric or hydrogen vehicles air pollution is shifted from mobile combustion engines to stationary power plants. These can be reduced much more effectively by modern process integrated measures and abatement techniques. Further aspects of sustainability are noise emissions, traffic safety, equity, or income issues. We acknowledge this, but the mandate of the otello research was targeted on air emissions.

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