DEVELOPMENT OF AN ENVIRONMENTAL PERFORMANCE INDEX FOR THE GERMAN TRANSPORT SYSTEM (TEX)

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Abstract
This paper develops an environmental performance index for the German transport system: the Transport-Environment indeX - TEX. This index has two main aims: Firstly, to allow a holistic appraisal of the total environmental development of the transport sector over a specific time period by combining individual indicators into a single annual index; secondly, to allow for a comparison of different environmental impacts caused by the transport system, including as far as possible upstream and downstream processes. A distance-to-target approach is used to normalise and aggregate the indicators the TEX is composed of. An additional weighting step is included. The last section shows the exemplary application of the developed index for the German transport system. The data basis and methodology are explained; the empirical results are presented. The results show significant differences in the development of different environmental fields. A great deal of success has been achieved in reducing the number and severity of traffic accidents. However, energy consumption and greenhouse gas emissions have remained stable or even increased. The overall development of the index relies heavily on the weighting of the different indicators, and thus on the assumed environmental priorities.

Inhalt

1 BACKGROUND

Transport is responsible for a large number of environmental impacts. These include significant contributions to energy consumption, climate change, air pollution, noise pollution and habitat fragmentation. Some of these individual impacts are occasionally brought to the attention of politicians and the general public. The EU-legislation concerning air pollutants and noise, for example, forces many European cities to monitor air quality and noise exposure and to think about measures to reduce those effects. However, we are not aware of a systematic and comprehensive evaluation of the complete transport-related environmental impacts.

In order to overcome this deficiency, this paper discusses the development and implementation of an environmental performance index for the German transport system: the Transport-Environment indeX - TEX. This index has two main aims:

- Firstly, to allow a holistic appraisal of the total environmental development of the transport sector over a specific time period by combining individual indicators into a single annual index.
- Secondly, to allow for a comparison of different environmental impacts caused by the transport system, including as far as possible upstream and downstream processes.

We do not report the development of the different transport modes separately although separate numbers were computed for each mode. Shifts between the modes might be desirable, even increases in the environmental effects for example from waterborne or railway transport might be meaningful if at the same time environmental effects of other modes are decreased. In this paper, we are interested in the overall development in the field of transport and the environment.

The index is designed to be suitable as an information tool for decision makers and the general public. The goal is to develop a simple, traceable and understandable measure that is based on existing data and that can be updated easily. The TEX is made to give an overall impression of the environmental effects of transportation. It is not a suitable tool for actual policy design. For developing strategies to reduce the environmental effects of transportation it is necessary to look beyond the composite index, that is at the elements of the TEX – to look at specific environmental effects and at specific transport modes.

Besides the advantage of conveying messages that are easy to understand, the so-called composite indicators have several disadvantages (OECD, 2008): Reverse developments of different effects cannot be identified easily. They compensate each other in the aggregated index. Furthermore, composite indicators can be manipulated by the selection and weighting of indicators.

In this paper we develop a composite indicator, assuming that the problems of this approach are less disadvantageous than the information gain from one single index is advantageous.

To address the above mentioned two main goals, the paper is organised as follows: Section two provides an overview of existing indicator systems from the field of transport and the environment. Section three describes the aim and methodology of the indicator system presented in this paper. The criteria for selecting impact categories and indicators are discussed; the chosen indicators are briefly explained. Based on a discussion of the different methods available for aggregating and weighting individual indicators, a suitable approach for aggregation is presented. Section four shows the exemplary application of the developed index for the German transport system. The data basis and methodology are explained; the empirical results are presented. The paper ends with some final conclusions and an outlook for further research in section five.

2 OVERVIEW OF EXISTING INDICATOR SYSTEMS IN THE FIELD OF TRANSPORT AND THE ENVIRONMENT

The transport sector is an important sector of society for different reasons: It is an important production sector; it is one of the biggest consumers of energy and natural resources and one of the main environmental polluters; it is vital for the functioning of all sectors of society and thus for the overall societal well-being. As a result, transport indicators are included in almost all cross-sector indicator systems, for example in the systems of national accounts (SNA), the system of integrated environmental and economic accounting (SEEA) and within the reporting on sustainable development strategies (European Commission, 2009; Eurostat, 2009).

Various official institutions on different levels do comprehensive reporting for the environmental situation in different sectors and for different regions. This reporting is often done in the framework of sustainability monitoring. Important indicator systems are the EU sustainable development indicators (European Commission, 2009; Eurostat, 2009, Eurostat, 2007)[1], the CSD indicators of the United Nations (United Nations, 2007)[2] and the OECD reporting on sustainable development (OECD, 2008a)[3]. The European Environment Agency (EEA) runs a core set of indicators (EEA, 2005)[4] which aims at supporting EU policy priorities. The EEA additionally publishes the TERM indicators (Transport and the environment reporting mechanism) (EEA, 2009). Those indicators explicitly focus on the environmental effects of transportation. They are available for the years 2000 to 2008.

The German Federal Environment Agency runs a comprehensive set of indicators for all type of environmental effects[5]. This indicator system contains a separate section for transport. This section is mainly focused on transport as a driving force with indicators such as length of transport infrastructure, modal split, vehicles fleet, vehicle miles travelled. Additionally, fuel consumption, air pollutant emissions for road traffic (CO_2, PM, NO_x, VOC, SO_2) and climate impacts for all transport modes (CO_2) are reported. The freight and passenger transport intensity (in ton/passenger kilometres per GDP) and the energy consumption (in MJ) per ton/passenger kilometres are listed as efficiency indicators for the transport sector[6].

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1 For the German monitoring of sustainable development indicators see Bundesregierung (2008). For the American Discussion see Jeon (2005) and Litman (2008), for Swiss Indicators see Altwegg (2004), BFS (2009), Geiger (2004).

2 For more information see http://www.un.org/esa/dsd/dsd_aofw_ind/ind_index.shtml (21/01/2010).

3 See http://lysander.sourceoecd.org/vl=3865394/cl=32/nw=1/rpsv/factbook2009/index.htm (21/01/2010) for the OECD Factbook 2009.

4 See also http://themes.eea.europa.eu/IMS/CSI (21/01/2010).

5 See http://www.umweltbundesamt-daten-zur-umwelt.de/ (21/01/2010).

6 Indicator systems run by the German Federal Statistical Office (see http://www.destatis.de/) and by the German government within sustainability monitoring are also relevant for this paper (Bundesregierung,

Besides this official reporting, several scientific projects have developed indicator systems for the environmental effects of transportation (Ahvenharju, 2004; Borken, 2002, 2005; Kenworthy, 2008; Kolke, 2004; Litman, 2008; Wiederkehr, 2004). The COST-action 356 "EST - Towards the definition of a measurable environmentally sustainable transport" is specifically focused on developing indicators for the environmental effects of transportation (Joumard, 2010).

Some indicators such as green house gas emissions and energy consumption are included in all the above mentioned indicator systems. The relevance of those key indicators seems to be beyond doubt and consensual for all type of activities. The indicators that are included beyond those core indicators vary depending on the scope and goal of the indicator systems and of the data used.

Indicators are defined for different points in the impact pathway chain. Goedkoop (2009) works with indicators at the midpoint level (e.g. acidification, climate change, ecotoxicity) and additionally at the endpoint level (e.g. damage to human health and to ecosystem quality). The DSPIR is another approach to systemise indicators along the impact pathway chain (Smeets, 1999).

Hence, manifold indicators and indicator systems exist that we can build on for this paper. The task to be done is to compile a list of key indicators that are of special relevance for monitoring transport-related environmental effects, to add up- and downstream effects and to build a composite indicator.

In what follows, we give an overview of existing composite indicators[7].

We have found no composite indicator for quantifying the environmental effects of transportation. However, there are several aggregated indicators for monitoring societal environmental effects (United Nations, 2007). The Ecological footprint is a typical example for a proxy method. It translates human resource consumption and waste generation into a measure of biological productive land and relates this measure to biological capacity[8]. The Environmental Sustainability Index (ESI)[9] and the Environmental Performance Index (EPI)[10] use distance-to-target methods. Both were developed by the Center for Environmental Law and Policy at Yale Univer¬sity and the Center of International Earth Science Information Network (CIESIN) at Columbia University in collaboration with the World Economic Forum and others. The ESI integrates a diverse set of socioeconomic, environmental, and institutional indicators that characterize and influence environmental sustainability at the national scale into a single final index. The EPI emanated from the ESI and uses outcome-oriented indicators in order to be more easily understood by policy makers, environmental scientists, advocates and the general public. The "ecological scarcity" method is based on so-called eco-factors and permits impact assessment of life cycle inventories according to the "distance to target" principle (BAFU/Öbu, 2009).

Several EU-projects developed methods for monetising transport-related environmental effects and provide empirical results for EU25 (Ahvenharju, 2004; Nash, 2003, 2008). Maibach (2007) gives an overview of the state of the art in this field.

2008). However these indicator systems build mainly on the same database as the German Federal Environment Agency indicator system does.

7 See section 3.2 for a description of methods for weighting and aggregation.

8 See Browne (2008), Wackernagel (1996), http://www.footprintnetwork.org/ (21/01/2010).

9 See http://www.yale.edu/esi/, http://sedac.ciesin.columbia.edu/es/esi/ (21/01/2010).

10 See German Federal Environment Agency (2008), http://epi.yale.edu/ (21/01/2010).

3 METHODOLOGY OF THE TEX

3.1 Aim and scope

The aim of the TEX is to picture and to monitor the overall development of the transport-related environmental effects. All transport modes are included: road, rail, water and air. We decided to explicitly concentrate on the total effects of all transport modes. The main reason for this is the fact, that in the end, the total and combined effects of all environmental impacts of all modes determinde the total environmental pressure. Hence, the TEX is made for monitoring the environmental impacts of transportation on a highly aggregated level, for example for a whole country or region.

3.2 Selection of indicators

The impact pathway model is a suitable approach to describe the whole chain from the generation of environmental effects to their impacts. Transport-related environmental interventions (emission, resource extraction) lead via specific environmental pathways (transport, chemical transformation, deposition, concentration, reactions of receptors) to damages which can be assigned to different impact categories influencing certain areas of protections. According to Goedkoop (2009), these areas of protections are endpoints, which are themselves of value to society. Health of humans and ecosystems as well as resource protection are discussed in the literature of life cycle assessment as main areas of protection (Finnveden, 2009). Indicators can be defined for the whole impact-pathway-chain. Indicators at the end of the impact chain have the advantage to be close to the areas of protections and thus to the values that are relevant for political and societal discussion. Those indicators represent environmental damages caused by different sources and the link to a specific source such as the transport system is often not easy to establish. Indicators close to the beginning of the impact chain have lower uncertainties as they are closer to the origin. Additionally, they are more sensitive to measures.

For these reasons we decided to use indicators close to the origin: The intention of TEX is to monitor environmental effects of one specific sector, that is the transport sector, and to reflect changes in transport-related environmental effects mainly as a result of measures implemented in this sector and changing general framework conditions.

Additionally, the following requirements for the indicators to be used here can be derived from the aim of the TEX:

- Relevance: The indicators should describe environmental effects that can be attributed to the transport sector. The contribution of the transport sector should be relevant compared to the environmental effects of all sectors of society for the indicators chosen.
- Operational feasibility and data availability: The indicators should be measurable and based on readily and regularly updated data within the specified time scale. The data should be of known quality and representative for the whole Germany.

- Policy relevance: The indicators should respond rapidly to transport policy interventions and to changing general framework conditions (such as changing prices).
- Relation to targets: The indicators should monitor progress towards international or national commitments or targets.
- Comprehensibleness: The indicators should be easy to understand and to interpret. Their origin should be transparent (physical units are preferable to monetary values).

Based on these considerations we have chosen the following indicators for the TEX:

1. Energy consumption [MJ, all transport modes]: This indicator can be seen as a key indicator; the reduction of energy use is highly relevant seeing coming problems of resource scarcities. Energy consumption is highly correlated with greenhouse gas-emissions for conventional fuels.
2. Resource use [t, all transport modes]: We use the term resources here in the conventional sense for raw materials, that is for all necessary prerequisites to deliver transport services. In the literature different lines of argument can be found to consider resource use as an environmental effect (Hofstetter, 1997): Non-renewable resources can only be used once; we restrict the amount of available resources for future generations whenever we extract those resources. Possibly future generations are able to substitute resources thanks to technological progress; definitely they will only have resources of lower quality to their disposal. Another argument for considering resources as an environmental effect is about the intrinsic value of resources: Resources have an intrinsic value on their own; their extraction can be seen as a reduction of this value. For the TEX we include the weight of newly registered vehicles for all transport modes. For rail and inland ships, only proxy weights based on the newly registered vehicles could be estimated due to missing data. Up to now, recycling rates are not considered, although they might decrease the use of new ressources significantly. We do not consider resource use for transport infrastructure as no reliable data was available.
3. Greenhouse gas emissions [t CO_2-eq., all transport modes]: Greenhouse gas emissions are also a key indicator, transport is responsible for a significant share of the overall greenhouse gas emissions with a more rising than falling tendency. We consider CO_2, CH_4, N_2O for computing CO_2-equivalents.
4. Emissions of ozone precursors [NMVOC-eq., all transport modes]: Photochemical oxidants are substances such as hydrogen peroxide, ozone, peroxyacetyinitrate (PAN) and oxygen radicals that can be generated from air pollution under sunlight exposure. The underlying formation reactions are often multistage and complex but always include a stage that depends on sunlight, a so-called photolysis reaction. All photooxidants are powerful oxidising agents, thus causing oxidative stress and damages when getting in contact with tissue. WE include benzene, CO, NO_x, NMVOC, SO_2, Touene, CH_4 in the computation of this indicator.
5. Acidification [SO_2–eq., all transport modes]: The term acidification relates to a decrease of the pH-value down to a level that is harmful to an ecosystem. Both terrestrial and aquatic ecosystems can be affected by acidification. A substance's potential in contributing to acidification is called acidic potential (AP). Since sulfur dioxide is the reference substance for the concept of acidic potential, it is indicated in SO_2-equivalents. Its calculation is done by summing up the products of SO_2-equivalent and pollutant mass

for all involved substances (here: NO_x; NH_3; SO_2). The term eutrophication stems from the Greek word “eutraphein” (well nurtured) and is mainly used to describe over-fertilisation of habitats such as soils, watercourses, lakes and oceans by means of natural of artificial nutrients. It is closely linked to acidification as NO_x is an important pollutant for both effects. For the TEX we decided only to include acidification.

6. Land take [km^2, all transport modes]: This indicator is used as a proxy for all effects that are related to the existing infrastructure (sealing, functional separation, fragmentation) and its impacts on the areas of protection soil and water and on the overall ecosystems.
7. Noise exposure [measured via annoyance data, rail, road, air]: Noise is sometimes considered to be less important as it is a very local problem. EU-legislations shows that we have problems in this field; noise exposure exceeds critical values especially in urban areas. It has serious impacts on human health (e.g. cardiovascular diseases). Due to a lack of data, we had to approximate actual exposure by means of the share of people feeling strongly annoyed by transport noise.
8. Accidents [costs in Euro, all transport modes]: Traffic safety is an important indicator for protecting human health. Political discussion is often focused on fatalities. We decided to work with the accident cost in order to monitor also shifts from fatalities to accidents with severe and slight injuries. No statistics on accidents exist for inland waterways after 1996.
9. Human Health: Toxicity [t 1,4-Dichlorobenzen-eq., all transport modes]: The term human toxicity is derived from the greek words “human” and “toxin” and thus relates to all substances which are harmful to human health. In the current state of research, benzene, xyluoene and toluene are considered.
10. Human Health: Particle formation [PM_{10}-eq., all transport modes]: Particulate matters especially cause acute and chronic respiratory diseases and problems. $PM_{2.5}$ is directly emitted from transport activities, aditionally sulfur dioxide and nitrogen oxides form secundary particles in air.

Some of the considered air pollutants are included in several indicators. However, double counting seems to be no critical issue as the pollutant take their effects on different impact pathway chains. The following Table 1 gives an overview of the included effects. Up- and downstream effects were considered, when reliable data was available. No indicators for infrastructure supply, maintenance and disposal are considered due to lacking data availability. Table 2 describes the characterisation factors used.

Table 1: Overview of included effects.

		Material input	Energy consumption	Air pollutant emisssions	Land use	Noise	accidents
vehicle	Production	Yes					
	Use		Yes	yes	yes	yes	Yes
	Disposal						
fuels	Production		Yes	yes			
	Use		yes	Yes			
	Disposal						

Table 2: characterisation factors and units used

Impact category	Element included	Unit	Characterisation factor	Source for factor
Climate change	CO_2 CH_4 N_2O	t CO_2-eq.	1 25 298	IPPC (2007)
Ozone formation	NMVOC NO_x (as NO_2) CH_4 Benzene CO SO_2 Toluene	t NMVOC-eq.	1 1 0,01 0,37 0,047 0,02 1,08	Goedkoop et al (2008)
Acidification	SO_2 NO_x	t SO_2-eq.	1 0,56	Goedkoop et al (2008)
Human toxicity	Benzene Toluene Xyluene	t 1,4-Dichloro-benzene-eq.	0,4 0,81 1	Goedkoop et al (2008)
Accidents	Death Severe injuries Slight injuries	€/case	1.161.885 87269 3885	BaSt (2006)
Particle formation	NO_x Partikel SO_2	t PM_{10}-eq.	0,22 1 0,19	Goedkoop et al (2008)

3.2 Weighting and aggregation

Manifold methods exist for weighting and sometimes aggregation of indicitors within an indicator system. Four main groups can be distinguished (Finnveden et al, 2002, 2009):

1. Proxy methods focus on one or only a few quantitative measures, which are judged to be indicative for the total environmental impact of a given production system11. No explicit aggregation and weighting of indicators is necessary.
2. Monetisation methods convert environmental impacts into monetary units. Damage costs, avoidance costs, abatement costs and willingness-to-pay/-to-accept methods allow for monetising and thus comparing different environmental effects. No additional weighting is done.
3. Panel weighting methods: In panel methods, weighting factors are derived from the judgements made by some individuals or a group of people (e. g. experts). The panel participants are asked about the relative importance of damages or environmental impacts. The weighting of the effects is then derived from the answers given. In general,

[11] E.g. Cumulative Energy Demand (CED) or Material Intensity per Unit Service (MIPS), for a detailled description of these methods, see Ritthoff (2002).

no aggregation of the indicators is done, but a ranking of impact categories according to the stated prefences is possible.

4. Distance-to-target methods relate the indicators to some sort of target values and allow thus for comparing indicators even though these are measured in different units (Seppäla, 2001). These methods are mainly used for normalising and aggregating different indicators. Some sort of weighting is always included as not weighting means that all indicators are equally weighted. Distance-to-target methods do not quantify the damage itself. They are based on the assumption that the target values reflect the damage or rather the societal preferences for the damage.

The following Table 3 compares different weighting methods. No single method fulfills all criteria, all do have their special merrits and limitations. For this reason, it is especially important to understand and clearly communicate the underlying assumptions and limitations of any weighting method used.

Table 3: Comparison of different weighting methods (adapted from Finveden, 2002).

	Panel method	Monetisation	Distance to targets
Data availability and requirements	High amount of data necessary for providing an adequate desicion context	Impact data and monetisation factors (costs) necessary	Only data on impacts and target necessary, targets are sometimes missing
Transparency in the arguments behind the values expressed	Not given, since panel members state their preferences, not the arguments behind	Depends on monetisation method	Stated in background documents for the decisions in case of political target
Acceptable scientific practice in the sciences used	Scientific tradition exists, lack of formal requirements in many areas	Scientific tradition exists, lack of formal requirements in many areas	Scientific base unclear for political targets
Methods to determine social values	Stated preference	Stated preference/ revealed preference	Stated preference/ revealed preference
Inter-effect weighting	Yes	Yes	No

For the TEX, we decided to combine a distance-to-target approach with an additional weighting step. In our opinion, social values are best expressed through the decisions taken by society, that means through binding legislation and official targets. The standards and limits politics agreed upon, can be viewed as stated preferences and, if the goals are met, as revealed preferences of the society. In this sense, the TEX can be interpreted as a measure for the achievement of the objectives, a society has agreed upon.

For the calculation of the individual distance-to-target values, different formulas could be used (Ahbe 1990; Finnveden, 2002, 2009). In the simpliest approach, a linear reduction path from a given base value to the target value can be assumed; more complicated variants include log-shaped functions or squared terms to better reflect the higher importance of greater deviation from the proposed reduction path. For the TEX, we use a linear approach in order to keep the index simple.

We use a scale from 0 to 100 to measure the target achievement. Zero points are assigned to the environmental impact in the base year; 100 points are given if the target value is just met. The rate of target achievement and thus the TEX-points for impact i can then be calculated as follows:

TEX_i = (value reference year – value today) * 100 / (value reference year – target value)

The formula leads to negative values if the impact rises beyond the base year value and to values above 100 if the actual environmental impact is below the target values. For the TEX we allow for going beyond the targets in order to show and honour special advances.
Computing the overall TEX-value is then straightforward. The points computed by the above formula are summed up for all considered indicators.

Such a summation means equal weights for all effects. This assumption normally does not hold true for real legislation, where often some targets are considered to be more important than others and where targets are agreed upon in different points of time, by different stakeholders with different political and societal background (Finnveden, 2002). For this reason, an additional weighting step is applied for the TEX.
This weighting step is based on a methodology that was developed by the German Federal Environment Agency in the late 1990th (German Federal Environment Agency, 1999). This methodology uses three elements to derive weighting factors for the different impact categories. Firstly, the ecological hazard of the specific environmental effects is determined, secondly the distance-to-target and thirdly the share of the sector under consideration compared to the other contributors to the specific effect.
For the TEX, we only assess the ecological hazard. The distance-to-target is already used for normalizing and aggregating the indicators. We do not consider the specific contribution of the transport sector, since we only use effects with relevant contributions of the transport sector.
The ecological hazard is based on four elements: the severity of potential environmental damages, the reversibility, the spatial extension of an environmental impact and the uncertainty associated with the impact pathway. Table 4 shows the evaluations used for the impact categories and the derived categories.

Table 4: Weighting of impact categories (based on Becker, 2009; Borken 2005; German Federal Environment Agency 1999)

	Severity	Reversibility	Spatial extension	Uncertainty	Weight
Energy use	severe impact, only restricted to one area of protection (ressource use)	irreversible, can be substituted	global problem	stocks are well known, consequences can be modelled	C
Ressource consumption	impact on only one area of protection	irreversible, can be substituted	global problem	stocks are well known, consequences can be modelled	C
Climate change	severe impact on all ecosystems and humans	irreversible	global problem	high uncertainty about impact modelling and damages	A
Land use	severe impacts on biodiversity, on ecosystems	partly reversible	local problem, can have global consequences	high uncertainty in modelling effects of a loss of biodiversity	A
Noise	severe, on individual level	mostly reversible	local	empirical evidence has improved over the last years	B
Accidents	severe on indvidual level	partly irreversible	local	low uncertainty	B
Acidification	severe impacts on ecosystems	irreversible	Europe	effects are well known	B
Ozone precursors	direct impacts on human health and ecosystems	mostly reversible	Europe	effects are well known	D
Particles	severe impacts possible, direct influence on human health	irreversible	Europe	high uncertainty about dose-effect-curve	B
Human toxicity	severe impacts possible (carcinogenic substances)	acute reactions often reversible, others are irreversible	Relevant on national and European level	toxicity effects are only partly known	B

4 EXEMPLARY APPLICATION OF THE TEX TO THE GERMAN TRANSPORT SYSTEM FROM 1990 TO 2007

4.1 Data basis and targets

For obtaining the environmental impacts, a variety of data sources has been used:
Data on energy use and on limited pollutants have been taken from the newly updated Transport Emission Model (TREMOD, IFEU Institute), which now contains energy use and emissions data for all transport modes for the time period from 1960 to 2008. The model was developed in the early 1990th on behalf of the German Federal Environment Agency and has been updated regularly since then. It is used as a base of the national inventory reports of the emissions and greenhouse gas reporting schemes and is in our opinion the best model for this type of information in Germany. All data is available for the transport activities within Germany (inland principle) and includes the upstream chain of the energy supply and fuel production.
Registration data of new vehicles from the federal motor transport authority for all road vehicles was used for computing the resource consumption indicator. For some vehicle types (trucks and trailers) empty weights could be extracted from the broad range of statistical publications of the KBA, for others estimates are based on typical values published in literature and on manufacturers homepages. For inland waterway, we use the statistics of the central commission for vessel inspection (ZSUK) was used. The corresponding empty weights had to be estimated. For railway transport and aviation, no offical statistics about new registrations was available. For aviation, we use the data base at http://www.planespotters.net/.
Data on accidents and land use was provided by the federal statistical office. No data on noise exposure was available for the time period under consideration. Therefore, the results of a representative survey on annoyance due to transport-related noise emissions are used. This survey is conducted on behalf of the German Federal Environment Agency every two years (Federal Ministry for the Environment, 2008).

The targets used for the TEX are a highly sensitive parameter and have a great influence on the final index values. We use two scenarios:
The first one is a political scenario that is based on official political targets on national or EU level. The second scenario is called long-term scenario. It is based on long term requirements and target values which mainly come out of debates on sustainable development. The goal is here to keep the earth's long-term carrying capacity. The following Table 5 shows the targets we have used for our empirical application.

Table 5: Overview of target values used for the political and for the long-term scenario.

Impact category	Target values used	
	Political scenario	Long-term scenario
Energy consumption	On national level, an efficiency target has been formulated (Bundesregierung, 2002). We therefore use the European Energy saving target, as proposed in the European Directive 2006/32/EC on energy end-use efficiency and energy services (European Parliament, 2006) approved by the European Council in 2007 (European Commission, 2007). It states, that a 20% reduction in primary energy use compared with projected levels should be reached by 2020, this according to the Action plan corresponds to a 1,5% saving per year up to 2020.	According to the vision of the 2,000-Watt Society (Novatlantis, 2005) each person in the developed world would have to cut their over-all rate of energy use to an average of no more than 2,000 watts (i.e. 17,520 kilowatt-hours per year) by 2050. For the share, which can be attributed to the transport sector, it was assumed, that the relationship between transport related energy consumption and the consumption of other sectors remains unchanged.
Resource use	On national level, only an efficiency target exists. (Bundesregierung, 2002) We propose the use of the precautionary principle and suggest to use a longterm target value of zero.	Our proposal for a longterm vision is to reduce new ressource consumption to zero.
GHG-emissions	In the German Climate-and-Energy-Package a target value of minus 40 percent by 2020 (base 1990) is stated. (Bundesregierung, 2007)	In order to stabilize global warming to a maximum 2°C, industrialised countries need to reduce their CO_2-emissions by about 80 percent by 2050 (e. g. WBGU, 2009). This target is accepted by the European Council as well (European Council, 2007)
	The stated target values refer to total national CO_2-emissions. We assume that all sectors have to make the same contribution. This is ambitious for the transport sector and probably not meaningful from the economic viewpoint seeing that reductions in the transport sector seem to be more expensive compared to other sectors (Borken- Kleefeld, 2009). We nevertheless decided to use this assumption as concrete targets for the transport sector are missing or seem to be low compared to the high share of transport-related greenhouse gas emissions. The target value is applied to all included greenhouse gases.	
Land use	The German sustainability strategy aims at reducing the increase in settlement and traffic area to 30 ha/day by 2020. Currently, transport infrastructure accounts for about 20 percent of total settlement and traffic area, it was assumed, that this relationship remains unchanged (Bundesregierung 2002).	Land use and fragmentation nowadays present a serious hazard for biodiversity and the functionality of ecosystems. The German council for sustainable development supports the reduction targets stated in the German Sustainability strategy and suggests for the time period after 2020 a reduction of new land use to zero by 2050. This reducion path is used as target (SRU, 2005).

	For both targets, linear reduction paths have been assumed. Based on these reduction paths, it was calculated, how much land could be consumed between a base year and the actual year in order to remain on the reduction path.	
Noise	The German Federal Environment Agency suggests to reduce the share of people that are heavily annoyed by transport noise to less than 5 percent. (UBA, 2010)	Noise exposure and the resulting effects for human health are important problems. We suggest to reduce the share people that are heavily annoyed by transport noise to zero as a long-term objective
Accidents	The European Commission postulated the target to halve the number of traffic deaths between 2001 and 2010. (European Communities, 2009)	As a longterm target, the concept „vision zero“ was used. The target to organise traffic in a manner, that no deaths and severe injuries occur, is supported by different national governments (Sweden, Swiss, Austria) as well as German NGOs (VCD, 2009).
	In our opinion, a reduction of fatalities and severe injuries is necessary, so that we apply the stated targets to both. A weighting between these two is done by using the macroeconomic accident costs as calculated by the German Federal Highway Research Institute (BaSt, 2006).	
Acidification	For acidifying substances, the national Emission Ceilings Directive states a reduction target of 74% between 1990 and 2010 (emissions weighted with acidification potential) (European Communities, 2001)	Following the precautionary principle, a target value of zero is applied.
Formation of tropospheric ozone	For emissions of tropospheric ozone precursors, the National Emission Ceilings Directive states a reduction target of 68% between 1990 and 2010 (emissions weighted with ozone formation potential). (European Communities, 2001)	Following the precautionary principle, a target value of zero is applied.
	Both target values are applied on the emissions of all ozone precursors in the transport sector, for which characterisation factors exist (CH_4, Benzene, CO, NO_x, NMHC, SO_2, Toluol), the NECD restricts only NO_x, SO_2, VOC)	
Particle emissions	The national exposure reduction targets refer to maximum values for measured particle concentrations. Here, the pollution sources can no longer be identified, a target value for the transport sector cannot be derived. We propose the use of the precautionary principle and apply a target value of zero.	Following the precautionary principle, a target value of zero is applied.
Human toxicity	Following the precautionary principle, a target value of zero is applied.	Following the precautionary principle, a target value of zero is applied.

4.2 Empirical results

The following Figure 1 shows the TEX-results of the political scenario for the different areas of protection. Progress towards the goals can be seen for almost all indicators.

In the first panel we see that especially the emissions of limited air pollutants regulated under the National emission ceiling directive could be reduced. Land take, on the other hand could only slighty be reduced, leading to a target achievement near zero, for climate change, emissions even moved in the wrong direction until the beginning of this century.

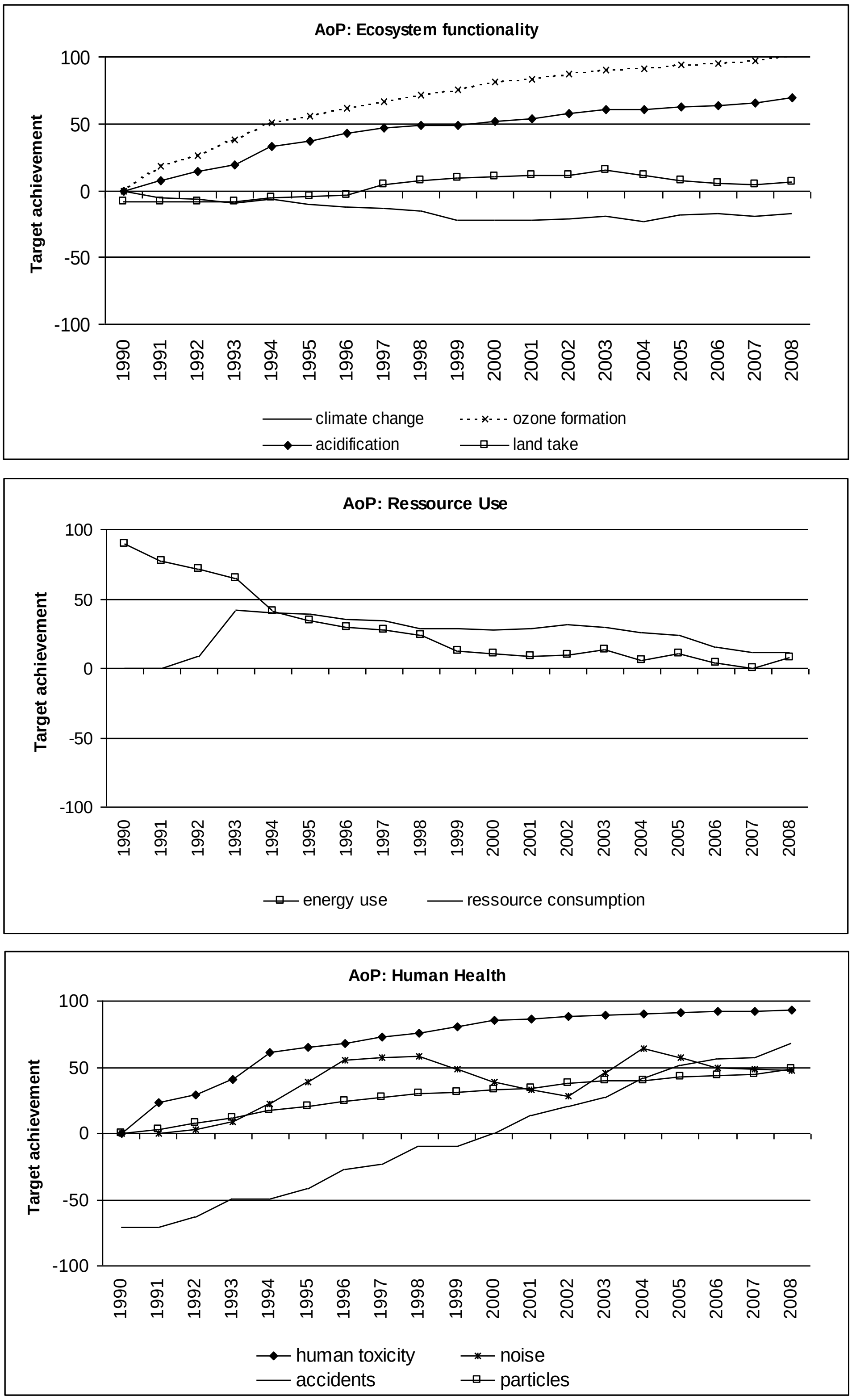
Special attention has to be paid to the second panel; the here depicted curves need some further explanation. The development of the energy use curve shows one of the methodological draw backs of a simple distance-to-target approach. The curve shows quite high values in the beginning, this is due to the fact, that the used political European reduction target was implemented in 2007, so that this year had to be used as base year. Depending on the development of the environmental impacts before the target formulation, negative or positive point values can occur.

The development of the ressource consumption reflects the high registration rates in 1991/1992 especially for cars and trucks and is probably in part attributable to the German reunification and formerly low motorisation rates in East Germany. In future applications, a modification of this indicator is planned to better reflect the overall development of ressource consumption. At present, vehicle weights and registration figures are included, aditionally, average fleet ages and recycling rates should be considered as well.

The third panel then pictures the indicator development for environmental impacts leading to damages to human health. Here, a positive trend exists for all indicator values. In the area of accident prevention, great progress could be achieved; the same is true for toxic substances and particle formation. The unsteady development of the noise indicator could not be clarified completely. In the main, it can surely be concluded, that noise annoyance has sunk since 1990. However, the here used results of regularly conducted noise surveys should be compared regularly to actual noise exposure data, which will be available in future due to European legislation.

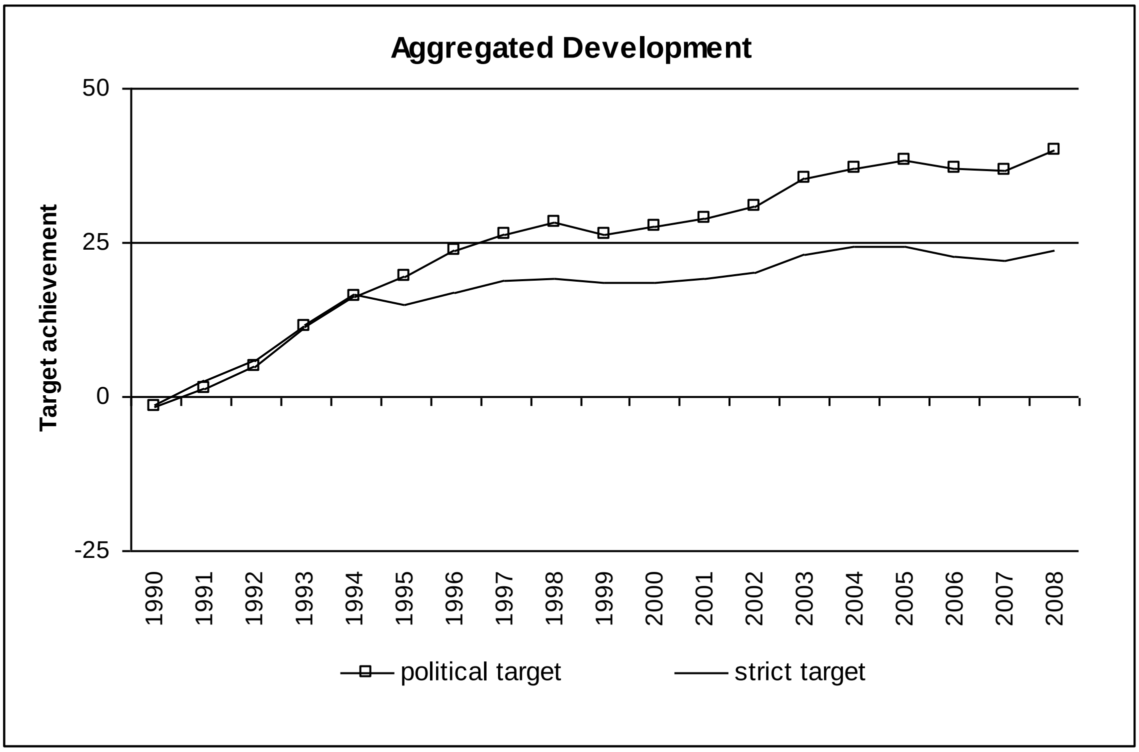
Figure 1: TEX-results for different areas of protection, political scenario.

a)



The following Figure 2 shows the TEX-results for the political and the long-term scenario. In general, it can be concluded, that the weighted environmental impact of the transport sector decreased since 1990, although the set targets could not be reached for any impact category so far. As expected, the TEX-values are lower for the long-term scenario. This is due to the stricter targets used. A methodological point to be addressed here is the fact, that the distance-to-target approach does not adress the different time spans associated with different targets. For the indicator value, it makes no difference, if a certain target has to be reached in one, five or even 10 years. In further improvements of the indicator system, it should be discussed, whether target deviations close to the target year can be priorisised over deviations for which still a long time for compensation exists.

Figure 2: Overall TEX-results for the political and the long-term scenario.



5 CONCLUSIONS AND OUTLOOK FOR FURTHER RESEARCH

This paper has shown that distance-to-target approaches are suitable for normalising and aggregating the different environmental effects of transportation. The results show significant differences in the development of different environmental fields. A great deal of success has been achieved in reducing the number and severity of traffic accidents. However, energy consumption and greenhouse gas emissions have remained stable or even increased. The overall development of the index relies heavily on the weighting of the different indicators, and thus on the assumed environmental priorities.

The overall decreasing trend for environmental effects of transportation can also be found in studies working with other methods for aggregating the effects. Schreyer (2007) computes

the external costs for Germany for the year 2005 and includes a qualitative discussion for the development of external costs of transport between 2000 and 2005. The trend is decreasing for accident costs and climate costs. For the other cost components no general trend can be seen, the transport modes show different developments.
The choice of the formula for weighting and normalising the indicators heavily influences the overall TEX-values. Additional formulas and sensitivities will be tested in the next steps of work. For some environmental effects no binding goals exist.
Data availability is always a problem, especially for up- and downstream effects and for noise exposure. Only a small share of aviation is included as we worked with the inland principle.

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