Assessment of Transport's Impact on Health and Environment for Germany

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Abstract:

Transportation results in numerous pressures on the environment, among other effects. The nature of these pressures has been analysed and measurement methods, though partly imperfect, have been developed over past years. A broad consensus seems to have been reached on the enumeration or quantification of transport's environmental pressures. 'TERM – The transport and environment reporting mechanism' of the European Environment Agency is an important example for developments at the pan-European level. However its thirty environmental indicators and seventy in total is not easy to handle. Furthermore the data basis they provide – accepting their partly sketchy nature – is only one step for an assessment, which is the basis for any decision making.

This contribution proposes, first, to use only seven out of the thirty TERM indicators for a top level analysis of transport's environmental and health impact. This would both strongly reduce data demand and increase transparency. Second, these indicators are further submitted to a qualitative assessment that is derived from life cycle analysis. The indicators and the respective impacts they represent are ranked by the three criteria 'distance to target', 'specific contribution' and 'ecological relevance'. Third, by the so-called analytic hierarchy process transport's most important environmental and health impacts are identified including related target conflicts; this method is applied here to transport indicators and the assessment criteria for the first time.

The indicators, criteria and method are applied in a case study to transport in the South Western German state of Baden-Württemberg. A priority list of transport's most important environmental impacts is thus identified.

Keys-words*: Impact assessment, transport, environment, health, indicators, analytic hierarchy process.*

1. Indicators for environmental impact of transport

Transport undoubtedly exerts major pressures on human health and the natural environment, while being a valued service. Individual pressures and impacts have been measured for long in various ways, driven either by legal requirement or economic interest. Only recently one tries to summarise the individual results by means of so-called indicators that shall measure the impacts, monitor the policies, and establish a quantitative basis for an assessment. For the environmental impacts of transport a consensus on the scope and relevant indicators has been reached in recent years in the broad, e.g. represented by the 'Transport and Environment Reporting Mechanism - TERM' of the European Environment Agency (EEA 2002). They use about 30 indicators for the environmental impacts only[1], which can be regarded as a standard set. This approach can certainly be considered a step forward for a more comprehensive account of the environmental consequences of transport. However also when accepting the partly sketchy nature of the sometimes demanding data basis there are two further steps necessary for policy making, which will be outlined further in this paper:

- Reduce to a more manageable number of indicators by identifying the most pertinent environmental impacts of transport, and
- provide an overall assessment of the situation (or to come up with an applicable scheme).

This paper first presents a minimal set of seven top indicators for the most important environmental and health pressures of transport that are derived from TERM. Second, these indicators are submitted to a qualitative assessment that is derived from life cycle analysis. Third, the so-called analytic hierarchy process is applied in order to order the priorities in environmental and health impacts and to identify related target conflicts; this method is used for this task for the first time. While the method presented is general, all specific data relate to transport in Baden-Württemberg, the South-Western state of Germany.

2. Approach

The results presented here are for the first part based on a study commissioned by the Ministry of Transport and Environment of the South-western state of Baden-Württemberg/Germany, Borken & Höpfner (2001). Its government has consistently set targets for almost all environmental impact categories either in general or for transport specifically, MinUV (2001), MinV (1995). Without such objectives and targets, it would be vague to set up indicators; they provide a kind of bottom-up list of interests. The official transport plans provide the necessary historic and forecasting data on transport and environment, MinV (1995), IVT et al. (1995), IFEU (1999). While the data are calibrated to the state boundaries the method and indicators can readily be scaled up to other countries.

Life Cycle Analysis (ISO 14.040ff.) provides the scope of environmental impacts which the indicators need to represent, ensuring the necessary completeness in a top-down approach. The qualitative assessment criteria have been developed by the Federal Environment Agency of Germany for mandatory use in their life cycle assessments (UBA 1999b). The overall assessment by means of a pair-wise comparison (also known as analytic hierarchy process) has recently been proposed for project assessment in transport infrastructure planning (FGSV 2002). Both, the assessment criteria and analytic hierarchy process are adapted for our purposes here.

Definition of the transport system

Transport is considered as the movement of people and goods, here specifically within the borders of Baden-Württemberg, regardless of the transport means and national origin; i.e. a territorial principle is applied. Impacts from the provision of the energy for motorised transport are accounted

[1] TERM has in official counting 31 indicators that cover environmental pressures and impacts as well as transport developments, technological and institutional issues. However many sub-indicators are used; for the environmental aspects alone they sum up to a total of 30, which is the basis for comparison here.

for on a life cycle basis, i.e. all conversion steps and related pollutant emissions starting from the extraction of the primary energy carriers to their transportation, refinement and final use in the vehicles are accounted. Borken et al. (1999) provide detailed data on energy provision and on the life cycle method. Transport outside the state borders, among others air transport and maritime shipping, is not included as this was considered outside the ministry's reach.

3. Transport and environment indicators at the top level

For the state of Baden-Württemberg seven indicators, which are derived and adapted from the original TERM-set, have been proposed for monitoring transport's impact on health and the environment at the top level (Borken & Höpfner 2001), table 1.

General environmental impact category as used in life cycle assessments	Specific indicator proposed for transport
(1) Climate change (2) Consumption of (energy) resources	Emissions of (fossil) carbon dioxide (CO_2).
(3) Stratospheric ozone depletion	No indicator as transport with <4% share irrelevant.
(4) Protection of soil and landscape.	Size of settlement and transport infrastructure.
(5) Protection of nature and landscape.	Size of (un-)fragmented land.
(6) Acidification (7) Eutrophication (8) Ecosystem health	Emissions of nitrogen oxides (aggregated as NO_x).
(9) Human health	Concentration of particulate matter (PM_{10}).
(10) Photosmog	Concentration of ground-level ozone.
(11) Noise	Population exposed to noise levels > 65/55 $dB(A)_{day/night}$.
Personal accidents are not considered under the environmental focus here. Accidents with hazardous substances in land based transport were negligible (UBA 2000).	

Table 1: General categories of health and environmental impact as used in Life Cycle Analysis and top indicators proposed specifically for transport (Borken & Höpfner 2001).

The indicators have been derived by (cf. Borken (2003) for details):

a) taking the general list of environmental impact categories from life cycle analysis to ensure completeness (top-down),

b) taking the 30 indicators proposed by TERM to make the transport specific adaptation (bottom-up),

c) applying the state-specific objectives giving the regional political context, and

d) applying the following selection and exclusion criteria: Maximum one indicator per impact category; indicators only for environmental impacts, not for measures; indicators only for remaining problems, not for solved issues.

Consequently, the set of indicators is biased towards the problems, it records achievements only by the absence of problems, as is the case for many 'classical' air pollution issue, aims to avoid redundancy and double counting, and measures are judged by their effects rather than by their existence.

This top set represents a considerable concentration of information compared to the sets of 16, 30 or even 55 transport related environment and health indicators proposed elsewhere (Spillmann 1998, EEA 2002, UBA 1999a). However clearly it not intended to replace detailed analysis, but to provide overview and thus direct attention to the most urgent issues.

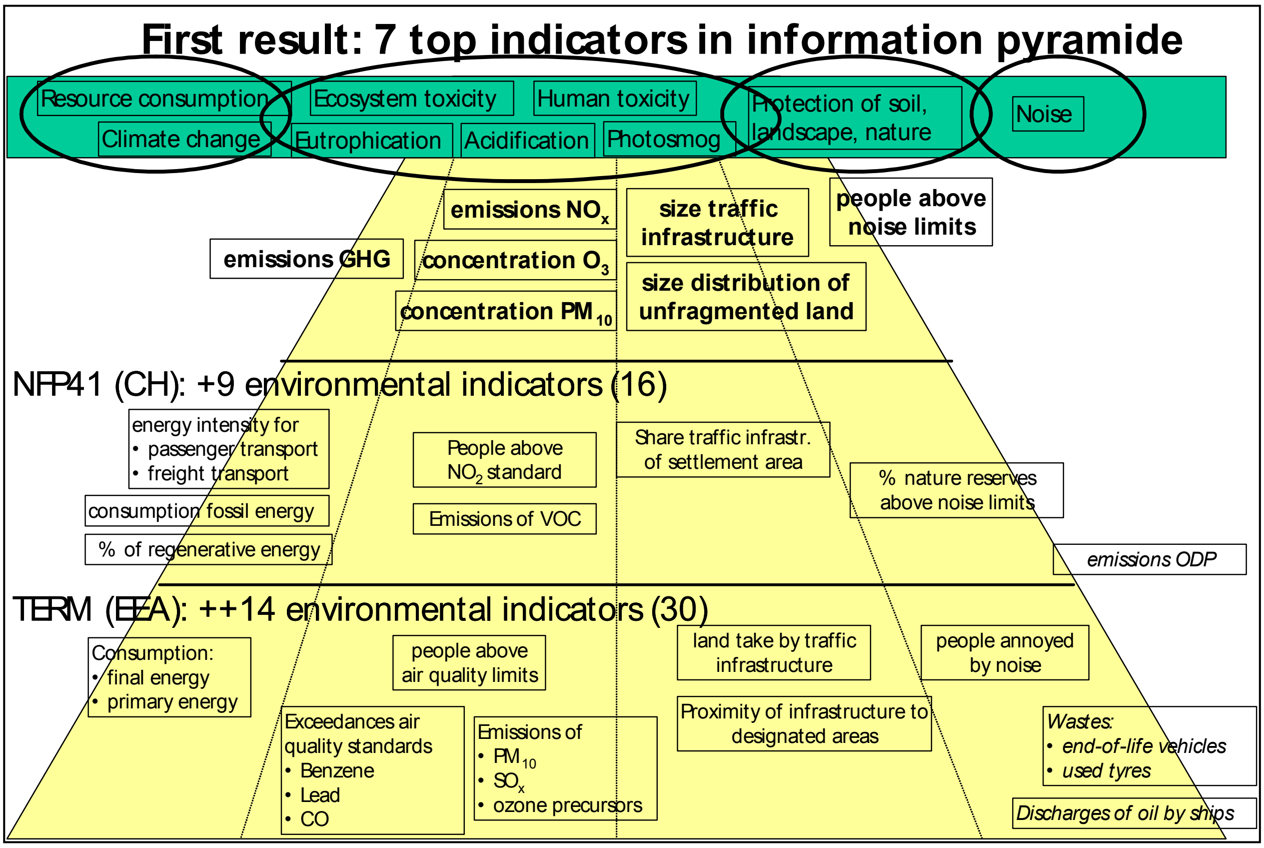

Figure 1: The seven environment and health indicators proposed here are intended to cover all important impacts and to represent the top level of an information hierarchy. They are standard also e.g. in Spillmann (1998) and EEA (2002).

4. Indicators applied to transport in Baden-Württemberg in 2010

The top set of indicators is applied to the official transport forecast of Baden-Württemberg. The traffic volumes are expected to rise until 2010 by about one third for passenger and by almost half for freight compared to 1990, mainly driven by road and air transport. Reduced specific emissions due to tightened European emission legislation for (road) vehicles are taken into account (MinV 1995, IVT et al. 1995, IFEU 1999). Table 2 summarises the target values set by the state government and the projected trend development until 2010 for each indicator.

Transport specific top indicator	Target value for Baden-Württemberg	Trend development until 2010
Sealing of land	<6,75 ha/day	Sealing ~11 ha/day (not all for traffic)
Fragmentation of land	Keep patches >100 km²	Further fragmentation
Emission of carbon dioxide (CO_2)	-10% (2005 to 1987)	+10% (to 1990)
PM_{10} concentration	<40 µg/m³ (annual av.)	Exceeded at urban main roads(?)
Emission of nitrogen oxides (NO_x)	-80% (2005 to 1987)	-60% (to 1990)
Ozone levels	<110 µg/m³ (8h average)	Levels in rural areas stagnant
Noise levels	<65/55 dB(A) day/night	~15% of population, stagnant
The target value for CO2 emissions is specifically set for the transport sector; targets for PM_{10} and ozone concentration are taken from EU legislation; all other are general environmental targets of the state government.		

Table 2: Transport top indicator, respective target value for Baden-Württemberg and officially projected trend development until 2010 (for details cf. Borken & Höpfner 2001).

Both, the condensed indicator list and the scenario calculations lay the basis for an overall assessment which is performed in the following.

5. Rating by distance to target, specific contribution and ecological relevance

The Federal Environment Agency of Germany (UBA 1999b) has mandated three criteria for the use in their life cycle assessments, which are applied to the transport sector here:

- The distance between the actual pressures exerted by transport and the target value, as well as the respective the rate of change;
- the specific contribution of the transport sector to the impact category, i.e. its strength relative to all other polluters;
- the overall ecological relevance of the impact category, i.e. the relative importance of the impact categories with respect to each other.

The overall ecological relevance of the impacts has been stipulated on environmental grounds for any assessment relating to Germany; hence it is independent of the specific investigation. The specific situation is reflected on the one hand by the target values that represent political priorities which can be specifically defined for the sector, process or region under investigation, and on the other hand by the specific contribution of the sector, process or region which reflects the actual situation.

These criteria are applied here for a non-monetary qualitative assessment. Each criterion is ranked on an ordinal scale from A to E, where A stands for the most and E the least important. Hence its natural unit, e.g. the share of emissions in case of the specific contribution or excess concentration in case of distance to target, has to be converted. This transformation from a continuous scale to an ordinal rating shall already account to some extent for the inherent inaccuracy or uncertainty of data and judgements. Furthermore it is essential to keep in mind that on any ordinal scale neither the interval between two values, e.g. the step from D to C, can be meaningfully compared to another interval, e.g. the step from B to A. Nor is an exchange value or weight between one criterion, e.g. distance to target, and another, e.g. ecological relevance, by itself given. This must be explicitly assigned and justified.

It is exactly this characteristic of any multi-criteria assessment not to be summed up to single value that distinguishes this approach fundamentally from e.g. a monetary assessment. Though it needs some more arguing in its application it much better helps to identify the fundamental conflicts of interests and targets instead of hiding them in an overall sum.

In the following we go through this process for each of the criteria proposed in order to identify the most important environmental problems to which transport contributes.

Distance to target and rate of change

None of the target values will be achieved under the assumed trend development[2] (table 2). However air pollutants, in particular NO_x emissions, display significant reductions and approach targets. Though primary particulate emissions might also decrease the resulting ambient concentration of particulate matter remains quite uncertain; hence its distance to target is rated C (medium). Noise and ozone levels are expected to stagnate affecting significant shares of the population and land; hence the distance to target is rated B. Trends for emissions of carbon dioxide, sealing and fragmentation of land are away from the target and hence they receive the highest rating (A) (table 3, first column).

Specific contribution of transport to the issue

The *'specific contribution'* represents the strength of transport relative to all other polluters. Here transport's share is estimated based on current data (table 3, second column); a projection until 2010 would need to model the entire society, which was beyond capacity. The rating is

[2] If the target would have been achieved this indicator would be excluded from further discussion as only remaining problems shall figure in this top level list of indicators, cf. chap. 3.

quantitative, where emission inventories exist (CO_2 and NO_x); it is qualitative for the PM_{10} and ozone indicators based on transport's share to the precursor substances. For noise the subjective perception of people that traffic is the dominant nuisance is taken over (UBA 2000); cf. Borken & Höpfner (2001) for details.

Ecological importance

The '*ecological importance'* of each impact category has been declared by the Federal Environment Agency for all its projects (UBA 1999b). Global, irreversible impacts affecting entire eco-systems with high uncertainty (precautionary principle) or lethal impact on human health are given highest rating while locally confined irritations whose mechanism is well understood and which can be remedied are given the lowest rating. In our case the impact of particulate matter and noise on human health is not well established. Due to its potentially lethal impact and the larger uncertainty involved, PM_{10} is given a higher rating than noise (Table 3, column 3).

Transport indicator	**Distance to target**	**Specific contribution**	**UBA: Ecological importance**
Emission of carbon dioxide (CO_2)	A	A (~100%, target transport specific)	A
Fragmentation of land	B	B (high)	B
PM_{10} concentration	C	B (high)	A-B
Sealing of land	B	C (medium)	B
Noise level	C	B (high)	C-B
Emission of nitrogen oxides (NO_x)	E	B (~66%)	B
Ozone levels	C	C (medium)	D

Ordinal scale from A to E, where A stands for the most and E for the least important.
Ecological importance according to UBA (1999b).

Table 3: For each impact category rating of the distance to target in 2010, transport's specific contribution and the ecological relevance of the impact category.

6. Assessment by pair-wise comparison (analytic hierarchy process)

The Federal Environment Agency has not defined a scheme for an overall assessment but only stipulated that the three criteria shall not simply be added up without explicit argumentation (UBA 1999b). To maintain the multi-criteria character and to identify the crucial aspects of the assessment in a transparent manner, we proceed by a pair-wise comparison, as has recently proposed as an alternative method for transport infrastructure planning (FGSV 2002 – in English also known as the analytic hierarchy process). In brief, each of the three criteria has to ordered according to its ranking (table 4) and where the relative orders differ the discrepancies are identified and decided after an explicit valuation of pros and cons.

Distance to target		**Specific contribution**		**Ecological importance**	
Emission of CO_2	A	Emission of CO_2	A	Emission of CO_2	A
Fragmentation	B	Fragmentation	B	PM_{10}	A-B
Sealing of land	B	PM_{10}	B	Fragmentation	B
PM_{10}	C	Emission of NO_x	B	Emission of NO_x	B
Noise	C	Noise	B	Sealing of land	B
Ozone levels	C	Sealing of land	C	Noise	C-B
Emission of NO_x	E	Ozone levels	C	Ozone levels	D

Table 4: Relative order of indicators/impacts for each criterion.

Unambiguous is the following ranking as all criteria display the same order:

- The emission of carbon dioxide (CO_2) is unquestioned the most important environmental impact of transport.
- Fragmentation is always considered more important than sealing of land, noise and NO_x emissions.
- PM_{10} levels are also always more important than noise and NO_x emissions, but not necessarily of sealing of land.

Ambiguous cases, where one impact is higher for one criterion and lower for another criterion compared to a second impact category are:
- The relative order of PM_{10} concentrations and fragmentation depends on whether the overall ecological importance, that is judged higher for PM_{10}, shall be given more weight or the distance to target, which would mean that fragmentation is the more urgent impact.
- The relative order between sealing of land and noise likewise depends on the relative weight that is attached to the distance to target (pointing then towards land sealing) and the specific contribution, which would give the priority to noise.
- Ozone levels can be seen more problematic than NO_x emissions only, if their larger distance to target is considered to outweigh both their lower specific contribution and lower ecological importance.

The order in these cases cannot be established from the outset but needs additional input on (political) priorities. This is exactly one of the merits of this pair-wise comparison to clearly identify the conflict of interests and to refer their solution to the political arena. When these conflicts are decided then the subsequent application of the principle of transitivity (in short: if $A > B$ and $B > C$ then follows necessarily $A > C$) ensures that the individual valuations are consistent overall.

Here we have identified three categories of
- *very high importance:* CO_2 emissions, fragmentation of ecosystems and concentration of PM_{10},
- *high importance:* sealing of land and noise levels, and
- *medium importance:* emissions of NO_x and ozone levels.

This is as far as the scientific approach goes. Instructive is a sensitivity analysis in order to check the robustness of this ranking and to highlight central assumptions.

Sensitivity analysis

If one accepts the ranking of the 'ecological importance' as given from the outset by scientific judgement then the remaining two criteria essentially represent two different kinds of uncertainties:
- The 'specific contribution' is broadly a physical entity measuring the share that (here) the transport sector contributes to each indicator and to the overall impact category in question. Hence, it is affected by measurement inaccuracies and data limitations (their spatial, temporal and/or factual coverage and representativeness) on the one hand and limited, insufficient or inaccurate knowledge about the causal chain between indicator and impact.

  Here in particular fragmentation can only be considered as a proxy until more relevant parameters for the impact on biodiversity and ecosystem stability have been identified. Likewise, due to the non-linear, multi-component and dynamic formation processes of both particulate matter (PM) and ozone it is very difficult to assess generally transport's specific contribution. Here, roughly its share of emissions of precursor substances has been taken as a measure (essentially primary particulate matter and NO_x), however, this is by no means accurate. In all cases, the ratings applied here might be lowered. In consequence this would not affect the overall assessment of ozone, which would remain in the category of medium environmental importance, but would bring the issue of fragmentation and PM_{10} closer to the noise assessment in the category of high environmental and health importance.
- While the 'distance to target' involves also potential inaccuracies related to the indicator measurement and causal impact chains it involves additionally the element of judgement, namely in the target setting. And often the target values set in a political process are lower then

values proposed e.g. by scientific advisory bodies.

In our case the indicative (EU) target value to protect against health damage from PM_{10} concentrations (annually 40 µg/m³) is discussed to be too high. And for CO2 emissions the (Baden-Württemberg) transport specific reduction target of only 10% can definitely only be considered a first step. In both cases the ratings assigned here would have to be increased. In consequence this only underlines the current high assessment and not changes the overall classification.

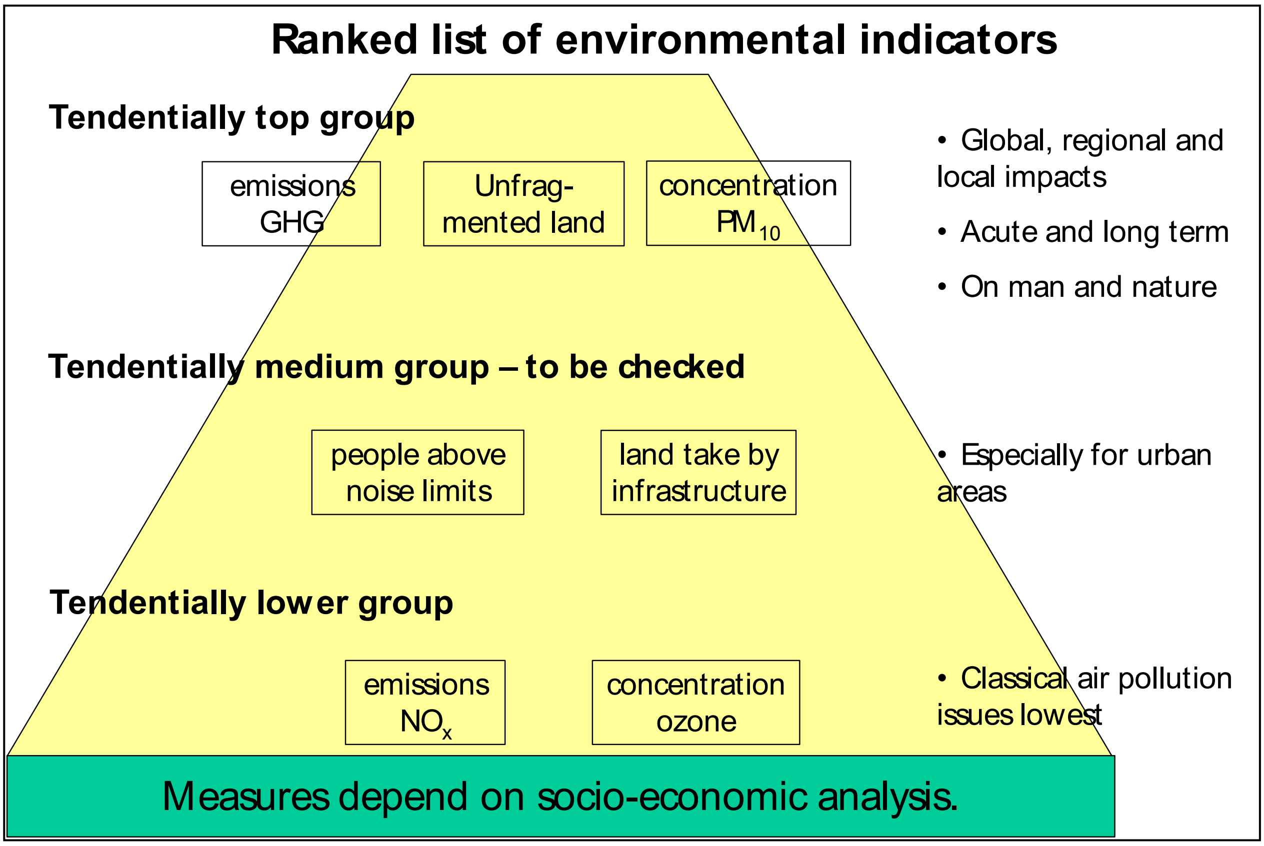

Figure 2: Classification of indicators and their related impacts by importance following an analytic hierarchy process applied to the criteria 'distance to target', 'specific contribution' and 'ecological importance'.

If one accepts the data basis then it is difficult to come up with very different individual ratings. Hence a strongly different overall assessment can only result if one individual criterion is given a dominant role; while this is possible its plausibility would have to be argued well. Following this (limited) sensitivity analysis at least the three broad classifications can be considered quite stable. This should give sufficient guidance to policy makers for priorities on mitigation and prevention measures: Particular emphasis should be given to all issues related to CO_2 emissions (impact: climate change), fragmentation (impact: nature, ecosystems and landscape) and PM_{10} concentrations (impact: human health).

7. Conclusions and outlook

Seven indicators are proposed to measure transport's most important environmental impacts. They are intended for prospective analysis at the highest level of aggregation. Three valuation criteria are adopted from life cycle analysis: The ecological importance of the impact, the specific contribution of transport and the distance to target. For an overall assessment, their ratings are submitted to a pair-wise comparison; this results in a qualitative order of importance on the one hand and an identification of conflicting priorities, which are referred to a further political assessment. A sensitivity analysis checks the validity of the results with respect to data uncertainty and different value judgements.

The method and indicators are applied here to transport trends in the state of Baden-Württemberg/Germany. Transport's carbon dioxide emissions, particulate matter concentrations induced and habitat fragmentation are found the most important environmental problems due to their large ecosystem and health importance and due to wrong or insufficient trend developments. Intermediate importance is seem for sealing of land and noise levels, where trends are stagnating away from the target but transport is only a co-factor among others. Environmental impacts related to NO_x-emissions and ground-level ozone are seen second place under the 2010-trend scenario as the target values adopted are approached though not quite a fast and stringent as desired. This classification is stable in the sensitivity analysis.

Given this analysis to reduce direct health impacts it will be necessary to reduce particulate matter concentrations and noise levels. This demands a coherent strategy including all sources as transport is only one important sector. While 'traditional' abatement policies have some considerable success in strongly reducing air pollutants from transport they are insufficient to reduce the long-term and largely irreversible ecosystem impacts. Rather transport's fundamentals, its land and (fossil) energy use, must be addressed which entails also tackle transport's driving forces. If the unsustainable trends shall be halted and reversed, then significant gains in technical and organisational efficiency and their clever implementation for simultaneous reduction of several impacts are needed. As much as the technical reductions then still fall short of the targets changes in today's production, consumption and transport behavioural patterns will then be on the agenda, which have always proven to be much more painful.

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