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Indicators for sustainable mobility – a policy oriented approach

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Abstract:
Seven indicators are derived to measure transport's most important environmental impacts. They are proposed for prospective analysis at the highest level of aggregation. With the aid of three valuation criteria adopted from life cycle analysis a transparent ranking and overall assessment can be established. A sensitivity analysis checks the validity of the results with respect to data uncertainty and different value judgements. These elements can equally be applied as indicators for environmental sustainability or for strategic environmental assessment.

The method and indicators are applied to transport trends in the state of Baden-Württemberg/Germany. Transport's land use, carbon dioxide emissions and related particulate matter concentrations are found the most important environmental problems. Impacts related to noise, NO_x-emissions and ground-level ozone are seen second place under the 2010-trend scenario. This ranking is stable in the sensitivity analysis.

To reduce direct health impacts from transport it will be necessary to reduce particulate matter concentrations and noise levels. This demands a coherent strategy including sources outside the transport sector. However 'traditional' abatement policies are insufficient to reduce long-term ecosystem impacts. Rather transport's fundamentals, its land and (fossil) energy use, must be addressed. Still large gains in efficiency need to be accomplished to reverse the unsustainable trends and to achieve the targets. This will require significant technological progress, clever implementation for simultaneous reduction of impacts but also changing consumers and producers.

Keys-words*: Sustainable transport indicators, environment, health, impact assessment, life cycle methods.*

1. Sustainable development, transport and environmental indicators

Sustainable Development – meeting the needs of the present generation without compromising those of future generations - was proclaimed a guiding political concept at the United Nations' World Summit on Environment and Development in 1992. The European Union as well as Germany, among other member states, have since adopted strategies to implement the concept in their policies. Transport has been identified as a priority area for action not least because of its impact on the environment, EC (2001a, §27), COM (2001, p.4), DE (2002, p.177ff).

Sustainable transport strategies call for indicators that measure the impacts, monitor the policies, and establish a quantitative basis for assessments balancing environmental concerns with human needs. This paper focuses on the environmental side and has four objectives:

- Identify the most important environmental issues pertinent to transport,
- propose a set of indicators which is comprehensive in scope, minimal in number, and applicable

for state or national policy;
- apply these indicators to transport, here to the state of Baden-Württemberg/Germany, and
- thereby identify transport's most important future environmental problems.

The indicators proposed here are intended to support decision makers at the state or national level in prospective analysis. Only the most relevant indicators shall be selected. They can also easily by applied in strategic environmental assessment of transport plans and programmes, soon mandatory (EC 2001b). Finally a contribution to the assessment of environmentally sustainable transport is intended.

The paper begins with a definition of the system. Thereafter I select the impact categories relevant for transport and a minimal set of indicators. These indicators are then applied to transport. The paper closes with an overall assessment of the impacts identified, including sensitivity analysis, and concluding remarks.

2. Approach

The selection criteria and assessment method are essentially inspired from Life Cycle Analysis (ISO 14.040ff.). The analysis is based on scientific understanding of environmental impacts. The explicit goal is to take *every important* environmental aspect into account. The importance and the target values, which both involve judgement, are taken from politically sanctioned regulations or declarations, and complemented by values proposed by scientific advisory boards, wherever possible. As the state Ministry of Transport and Environment commissioned the underlying investigation, Borken & Höpfner (2001), all objectives and target values refer to the state of Baden-Württemberg/Germany (MinUV 2001). Likewise all historic and forecasting transport and environment data are taken from the official transport planning, 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.

Definition of the system

Here I consider any movement of people and goods, regardless of the transport means, within the borders of Baden-Württemberg. Impacts from the provision of the energy for motorised transport is accounted for on a life cycle basis, i.e. from the extraction of the primary energy carriers to their transportation, refinement and final use. Borken et al. (1999) provide details of the data on energy provision used and on the life cycle method. Transport outside the state borders, among others air transport and maritime shipping, is not included as this is considered outside the ministry's scope.

3. Selection of impact categories and indicators specific for transport

To ensure the desired completeness I start with the general list of environmental impact categories standardised for life cycle analysis (ISO 14.040ff). The work on environmental impact in general is rather extended and general indicators are – more or less – well known and quantified. The problem is to define indicators that capture adequately transport's contribution and specific importance. While explicitly acknowledging that this process is iterative, I present here only the very final and minimal indicator set, chosen as follows.

Selection criteria for indicators

The indicators proposed here are intended to support decision makers by pointing towards the (remaining) problems for environmentally sustainable transport. Existing transport indicator sets comprising 30 (EEA 2002) or 55 (UBA 1999a) indicators were considered too large. To make the set more manageable but without sacrificing comprehensiveness about 10 core indicators had to be selected and partly redefined. In addition to the general criteria for selection – scientific soundness, representativeness, unambigouity and data availability – a few *exclusion criteria* had to be applied:
- Only one indicator per impact category is proposed.

- Where the environmental objectives are already today attained and will safely be maintained in the future, no monitoring is necessary; consequently no indicator at the top level is proposed.
- The indicator shall represent the desired target as closely as possibly, here the protection of health or environment. However, transport is only one among many polluters and its exact share of the impact is difficult to establish. Therefore it is often easier and less speculative to monitor the source, e.g. the emission of a polluting substance from vehicles; in a way this also reflects the precautionary principle.
- No indicators are assigned to measures like the enforcement of traffic regulations, the modal share itself, financial investments or taxation, etc.

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 minimum set is hence not intended to replace detailed analysis, but to guide efforts to the most urgent issues by providing overview. Table 1 names the standard environmental impact categories of life cycle assessment and assigns transport specific indicators. For details on impact categories, conventions and other possible aggregation parameter cf. Borken et al. (1999) or UBA (1999b).

General environmental impact categories of life cycle assessment	**Transport indicators proposed**
(1) Climate change (2) Consumption of (energy) resources	Emissions of (fossil) carbon dioxide (CO_2).
(3) Stratospheric ozone depletion	No indicator proposed as transport an irrelevant source.
(4) Protection of soil and landscape. (5) Protection of nature and landscape.	Size of settlement and transport infrastructure. 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 $dB(A)_{day/night}$.
Accidents are not considered under the environmental focus here. Accidents with hazardous substances have been small.	

Table 1: General categories of health and environmental impact as used in Life Cycle Analysis and minimal indicators proposed for transport.

Table 1: Categories des impacts sur l'environnement et la santé selon l'analyse de cycle de vie et indicateurs spécifique au transport.

The proposed minimal set of indicators resulted from an iterative process that lead to the elimination of other potential indicators:

- As transport runs almost exclusively on mineral oil products, the emission of carbon dioxide is a direct measure of the consumption of fossil energy resources. Hence this indicator is taken as a measure for both impact category.
- The stratospheric ozone layer is depleted under the catalytic action mainly of chloro-fluoro hydrocarbons. Older air conditioners are filled with such a substances however their share of the total is estimated at below 5% (Schwarz 2001). Due to a phase out under the Montreal Protocol this share is even falling and therefore no indicator is proposed.
- Transport and settlement infrastructure are closely linked with each other, and the one is cause and driver for the other. Therefore the total sealed size shall be measured. Furthermore

fragmentation due to transport infrastructure is cutting habitats into pieces, affecting landscape as well as nature.

- Nitrogen oxides are key substances for eutrophication and acidification impacts, above certain concentrations also for direct health impacts and indirectly as precursors for ozone and secondary particulate matter. Moreover it is predominantly emitted by transport and well monitored for long. Hence it is proposed as lead substance for monitoring
- Health impacts appear to be mainly related to particulate matter (PM_{10}). At least given Baden-Württemberg's concentrations and if the dose-response-correlations are valid they seem to be an order of magnitude more severe than the second category, carcinogenic impacts essentially from soot and to a falling degree benzene, Lambrecht et al (1999). Therefore only PM_{10} concentration are proposed as indicator, also accounting for the fact that a large mass fraction is soot, which is thus indirectly measured.
- Due to its non-linear formation process, the ground-level ozone concentration is proposed as an indicator; complementary the emissions of the precursor substance nitrogen oxides are monitored anyway.
- Some indicators serve as an approximation to describe the impact category, as for example the size of unfragmented land is a proxy for natural land potentially rich in biodiversity. On the other hand only the area of built land appears unsatisfactory with respect to habitat impacts and landscape. Better indicators need to be developed and the proposal reviewed to incorporate progress and shifts of importance.
- Aggregation is most important here. If detail is demanded, e.g. for an analysis of causes and possible measures, a differentiation of the indicators by transport mode and region would be natural extensions.

Individual indicators are interpreted for several impact categories, thus strengthening the self-reference of the set.

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

The minimal set of indicators proposed above is now applied to transport in the state of Baden-Württemberg. Its government has consistently set targets for almost all impact categories, either in general or for transport specifically (MinUV 2001, MinV 1995). I take over these values only noting in passing that they have different quality: Some targets are legally binding by national law or international agreements, like reduction targets for NO_x-emissions or ozone levels, others are rather indicative values as for sealing of land. The official trend data is analysed for the prospective development of the respective indicators. According to the scenario calculations 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.

Transport indicator	Target value for Baden-Württemberg	Trend development until 2010
Sealing of land	<6,75 ha/day	Sealing ~11 ha/day
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
Targets for PM_{10} and ozone concentration from EU legislation.		

Table 2: Minimal transport indicators, target values for Baden-Württemberg and officially projected trend development until 2010 (for details cf. Borken & Höpfner 2001).

Table 2: Indicateurs minimales propose pour transport, objectives de land de Bade-Wurtemberg et développement selon trend jusqu'à l'année 2010 (voir Borken & Höpfner 2001 pour détails).

5. Valuation and final assessment: The most pertinent environment and health impacts

The minimal set of transport indicators proposed represents a considerable reduction of information. Nonetheless it is often demanded to arrive at a further overall ranking and priority list. Herefore I apply the three criteria proposed by the Federal Environmental Agency of Germany (UBA 1999b) for a valuation: i) The distance between the actual and the target value, here adapted for the transport targets; ii) the specific contribution of the source investigated, i.e. its strength relative to all other polluters; iii) the overall ecological relevance of the impact category. Each criterion is given a rating on an ordinal scale from A to E, where A stands for the most important and E the least.

Distance to target

None of the target values will be achieved under the assumed trend development (table 2). However air pollutants, in particular NO_x emissions, display significant reductions and approach targets; as the calculation for particulate matter concentrations is quite uncertain, it is rated C. Noise and ozone levels are expected to stagnate affecting significant shares of the population and land; hence the distance to target is rated B. Highest rating (A) is assigned to those indicators whose trend is away from the target, i.e. to emissions of carbon dioxide, sealing and fragmentation of land (table 3, first column).

Specific contribution

The *'specific contribution'* represents the strength of transport relative to all other polluters. Here transport's share is estimated based on current data ; a projection until 2010 would need to model the entire society. The rating is quantitative, where emission inventories exist (CO_2 and NO_x); traffic is perceived as the dominant nuisance with respect to noise (UBA 2000), i.e. a subjective rating is taken over; transport's contribution to PM_{10} and ozone concentrations – or more precisely: their exceedances – is only roughly judged on the basis of the elemental composition of samples and transport's significant share of precursor emissions (table 3, second column; cf. Borken & Höpfner (2001, pp. 26, 36) for details).

Ecological relevance

The ecological relevance of each impact category has been declared by the Federal Environmental Agency for all its projects (UBA 1999b). Global, irreversible impacts affecting entire eco-systems with high uncertainty or lethal impact on human health are given highest rating. 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. The ratings applied are given in table 3, column 3.

Transport indicator	Distance to target	Spec. contribution	UBA: Ecol. relevance	My overall assessment
Sealing of land	A	A (100%)	B	**A**
Fragmentation of land	A	A (100%)	B	**A**
Emission of carbon dioxide (CO_2)	A	C (~25%)	A	**B**
PM_{10} concentration	B	B (high)	A-B	**B**
Noise level	B	B (high)	C-B	**B**
Emission of nitrogen oxides (NO_x)	D	B (~66%)	B	**C**
Ozone levels	B	C (medium)	D	**C**

Ordinal scale from A to E, where A stands for the most and E for the least important.
Ecological relevance according to UBA (1999b).
For the results of the sensitivity analysis compare the respective paragraph below.

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

Table 3: Pour chaque catégorie d'impact le pondération du distance à l'objective, de la contribution spécifique du transport et de l'importance général d'impact avec mon évaluation totale.

Overall assessment

Finally, the overall assessment is the most subjective phase. Here I apply equal weight to each rating, i.e. an arithmetic mean is produced: Following this valuation scheme transport's the most pertinent problems in Baden-Württemberg are sealing and fragmentation of land due to its large distance to target, the transport's dominant contribution and the irreversible ecosystem impact. The emission of carbon dioxide, i.e. transport's impact on climate change and consumption of energy resources, is given second priority, together with transport's direct health impact from air pollutants, as measured by PM_{10} concentrations, and from noise. Transport's impact on eutrophication and acidification, which is related to classical air pollutants and measured here by the NO_x-indicator, and ground-level ozone is assessed third place, either because target values are approached or because the general ecological relevance is assumed lowest.

Sensitivity analysis

A sensitivity analysis is essential to check the stability of the overall assessment against a different rating, which might result either because of progress in scientific understanding and changed data or because different values are assigned.

Already the transformation of the continuous inventory data in rating on an ordinal scale accounts to some extent for the uncertainty of data and individual valuations. Now I shift one of the three criteria by one mark up or down (more or less importance).

> For instance assume that the distance-to-target for the PM_{10} concentration would be judged larger than here, i.e. A instead of B. Then the ratings would read A.A.A-B, resulting in overall A (instead of B right now). If however the respective rating would be set to C, then the ratings would read C.A.A-B, still resulting in overall B. Hence the overall assessment of this indicator for severe health effects stays the same if one criterion would be given less importance, but would increase if one criterion would be assigned a higher importance than assumed here. These variations are executed for all other impact categories (and criteria) and the results given in table 4.

A number of conclusion can be drawn from the results (table 4):

- The relative order of the impact categories remains the same for any of the ratings applied. Hence the priorities for future (political) action stay the same, namely reduce land take and fragmentation, CO_2-emissions and PM_{10}-concentrations.

- Furthermore a set of second place impacts can clearly be distinguished: Impact from noise, NO_x-emissions and ground-level ozone. In none of the ratings they could take first importance.
- A strongly different overall assessment or even a different order of importance can only result if individual ratings would differ strongly from my valuation here or if the criteria would not be given equal weight. This would have to be argued well, but could result from the combined effect of uncertain data and different valuation.
- The sensitivity analysis helps to identify weak or critical aspects. Thus its results are even more important than the original assessment as it allows to encompass (scientific) uncertainty as well as different judgements. As happens here, the overall judgement might still remain valid.

Hereby the method presented can contribute to increased transparency in assessment and ranking and finally policy making.

Transport indicator	**- Sensitivity of assessment -** Higher	My assessment	Lower
Sealing of land	**A**	**A**	**B**
Fragmentation of land	**A**	**A**	**B**
Emission of carbon dioxide (CO_2)	**A**	**B**	**B**
PM_{10} concentration	**A**	**B**	**B**
Noise level	**B**	**B**	**C**
Emission of nitrogen oxides (NO_x)	**B**	**C**	**C**
Ozone levels	**C**	**C**	**C**

Table 4: Results of sensitivity analysis: Higher/lower, i.e. one of three criteria is given a higher/lower rating (more/less importance) than by me.

Table 4: Résultats d'analyse de sensitivité : Pondération plus/moins grave d'une critère individuelle par rapport de mon pondération.

Conclusions and outlook

Seven indicators are derived to measure transport's most important environmental impacts. They are proposed for prospective analysis at the highest level of aggregation. With the aid of three valuation criteria adopted from life cycle analysis a transparent ranking and overall assessment can be established. A sensitivity analysis checks the validity of the results with respect to data uncertainty and different value judgements. These elements can well be also applied for strategic environmental assessment and sustainability indicators.

The method and indicators are applied to transport trends in the state of Baden-Württemberg/Germany. Transport's land use, carbon dioxide emissions and related particulate matter concentrations are found the most important environmental problems. Impacts related to noise, NO_x-emissions and ground-level ozone are seen second place under the 2010-trend scenario. This ranking 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 sources outside the transport sector. However 'traditional' abatement policies are insufficient to reduce the long-term ecosystem impacts. Rather transport's fundamentals, its land and (fossil) energy use, must be addressed. Significant gains in efficiency need to be accomplished to reverse the unsustainable trend and to achieve the targets. This will require significant technological progress, clever implementation to reduce several impacts simultaneously but likely also significant change in today's production, consumption and transport patterns.

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