Evaluation of environmental indicators for transport with ELECTRE III

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1 Introduction

Environmental impact assessment (EIA) of transport infrastructure *projects* has been established for more than a decade (DIR 1985/337/EEC). For the strategic level of plans, programmes and policies it became mandatory in the EU in July 2004 (DIR 2001/42/EC). However, it not clear on what grounds to choose strategic indicators and, once chosen, how a diverging performance is to be aggregated in the final assessment?

The first question has been elaborated in some detail in recent publications of the author (Borken 2004, Borken 2005). This paper focuses on the evaluation and assessment method. We analyse to what extent a well-established qualitative multi-criteria decision aid method can be applied for strategic environmental assessment in the transport sector. We propose this method for a simple screening and identification of the most important issues, which then need to be investigated in detail.

For illustration and as test case we use the indicator set TERM of the European Environment Agency (EEA 1999, 2001, 2002, 2004). Key indicators for a strategic environmental assessment are identified, their reliability is judged, and the overall environmental performance of Europe’s road transport, as measured by these indicators, is evaluated.

1.1 Indicators for transport’s strategic environmental assessment

A strategic assessment differs in several ways from the longer established project assessments. For transport plans, programmes or policies (e.g. Pronello 2005, COST 350), typically the following constraints and demands condition the choice of the indicators:

– specific projects have not yet been defined, and hence data are not in the desired detail and quality available, if at all,
– time, resources and degree of elaboration do not allow more detail: Decisions have to be taken on the basis of limited knowledge and data,
– the assessment process shall help to identify the crucial elements and impacts, explore the different options and serve for communication.

In response to these demands and constraints, we propose to focus the *strategic* assessment as much as possible on the most important issues: This is adapted to the limited data or detail and helps to focus attention and communication.

The nature of the plan, programme or policy determines which impact will have priority. To proceed for transport we take the example to assess the development of the environmental performance of road transport in Europe, as it is described by the TERM indicators (EEA 1999, 2001, 2003, 2005). We are not concerned with proposing an *ideal* set of indicators; on the contrary, we analyse how to make the most of real-world indicators and data. As the focus of the TERM indicators is on the impacts of the traffic, not so much on the immediate infrastructure or construction impacts, they seem à priori well suited for a strategic impact assessment. We have verified that the indicators cover almost all impact categories enumerated in the SEA directive. To keep the number of indicators and thus the data needs as limited as possible, we propose to use only one representative indicator for each impact category. This approach has been studied in detail for the integrated assessment of the environmental impact of road traffic in Europe (Borken 2005).

Twenty-four indicators have originally been put forward for nine impact categories. For a strategic assessment we propose to focus on seven indicators, each representing an impact that is both relevant and pertinent to transport, and chosen on the following grounds (cf. Appendix):

– non-redundant; among several possible indicators we choose the one according to the precautionary principle;

– specific for transport as cause *as well as* pertinent for a relevant environmental impact,

– transport is considered a relevant source, if it contributes more than 5% to the total impact.

Each impact category and the respective indicators have been analysed in detail in (Borken 2005), but this is not part of this paper. Based on this analysis we propose seven key indicators for consideration in a Strategic Environmental Assessment of transport (Table 1).

Our proposal to focus on a few representative indicators is a response to the perceived demands and constraints of a strategic assessment: The need to decide while the planning is pending, hence without precision, detail and reliable data. These constraints are and must furthermore be matched by the assessment method. Indeed, both, the selection of the relevant impacts and indicators and of an appropriate evaluation method are interlinked and iterative.

Impact category associated indicator	Aggregation factor	Specif. contrib.	Reference year, comment, source
Climate change			
Emissions greenhouse gases	CO2-eq	21%	2001: excl. internat. bunkers, EEA 2003a:37.
Health protection: Air pollution			
pot. concentration of particles (PFP)	PM10-eq	38%	1999: tentative aggregation of particle precursors, EEA 2003:69; de Leeuw 2002.
pot. concentration of ozone (TOFP)	NMHC-eq	53%	1999: tentative aggregation of ozone precursors, EEA 2003:69; de Leeuw 2002.
Health protection: Noise			
Exposition to traffic noise	dB(A)	-/-	no European data provided.
Annoyance by traffic noise	#	50%	lower estimate based on (UBA 2001:321) for Germany
Health protection: Accidents			
Traffic fatalities	#, YOLL	40%	Share of all accident fatalities: 30-40%. Share of all years of life lost by accident: >50%, KUSS 2002:40.
Injured	#, treatment days	15%	Share of all accident hospital admissions: 10-20%. Share of hospital treatment days of all accidents: 10-20% KUSS 2002:40.
Protection of biodiversity (terrestr.)			
Unfragmented areas	%	50%	Assumption: Fragmentation caused equally by traffic infrastructure and settlement area.
pot. concentration of eutrophying compounds	N-pot	34%	1999: tentative aggregation, EEA 2003:69; de Leeuw 2002.
pot. concentration of acidifying compounds	H+-eq	25%	1999: tentative aggregation, EEA 2003:69; de Leeuw 2002.
Protection of biodiversity (marin)			
Discharge of oil at sea and	t oil	22%	In long-term average about 45.000 t oil are released annually, of which ~10.000 t in accidents und ~20.000 t from illegal discharges, Pavlakis et al. 2001:6f; REMPEC:16, 19; EEA 2002a:98.
discovered oil discharges	t oil	44%	
Energetic ressources			
Final energy consumption	mio toe	32%	2001: excl. internat. bunkers, EuroStat 2001:11. Share of primary energy lower.
End-of-life vehicles and tyres	mio toe	6%	max. 6% of transport's final energy consumption, Borken 2005:90f.
Land as ressource			
Land take by traffic infrastructure	%	ca. 40%	Traffics share of total traffic and settlement area in D, UBA 2001.
Disposal of end-of-life vehicles and of tyres	%	<2%	max. 1% and 0,6% of total waste disposal, banned from 2006; Borken 2005:90f.
Stratospheric ozone depletion			
Emission of ozone depleting substances	ODP-eq	<5%	2001: EEA 2003 02; EEA 2002a.
Abbreviations: PFP: Particle forming potential; TOFP: Total ozone forming potential; YOLL: Years of life lost. ODP: Ozone depletion potential.			

Table 1: Attribution of indicators to impact categories. Representative indicators proposed are highlighted.

2 Systematic evaluation of indicators

We propose for the strategic phase on an assessment a qualitative evaluation method, that is particularly well suited to a poor data situation. We analyse here to what extent the so-called ELECTRE III method can help with strategic environmental assessment. The following characteristics appear particularly promising in our context:

– It is designed to handle imprecise data and can also use qualitative input;

– the data can be used in their natural units without any need for conversion;

– compensation can be excluded and a maximal compromise is identified instead;

– it provides a hierarchy of the cases compared, if there is sufficient ground.

ELECTRE has already been proposed for use in the project PIE; its technical and mathematical details can be found elsewhere (Roy and Bouyssou 1993; Rousval 2005). We just highlight the following fundamental assumptions:

– A case A is preferred against a case B, if and only if two conditions are satisfied:
    - There are sufficiently strong arguments to favour A instead of B, and
    - there is no significant opposition nor veto against the preference of A over B.

  I.e. neither a maximisation of advantages nor a compensation of disadvantages are sufficient to decide on the comparison between two cases. Thus, ELECTRE III is compromise-oriented and highlights strong minority votes.

– The preferences between the cases under consideration are constructed in pairwise comparisons. I.e. it is assumed, that the preferences do not exist independently of the elaboration of the problem and hence cannot simply be revealed, but that they evolve dependent on context, actors and their system’s understanding.

– The assessment is ordinal: Only the differences between two indicators with respect to thresholds are important. Once these thresholds have been passed, neither its absolute value nor a potential improvement or deterioration of this indicator are taken into account.

The representative indicators identified above continue to serve as test case. The assessment result is – with ELECTRE - independent of the specific choice of the indicator representing the impact category. Other indicators with proportionally about the same development would return the same results, as only relative developments of the different indicators and not their absolute values are taken into account. The weights are directly allocated to the impact category; they are independent of the indicator, its value or measurement unit.

Data on the environmental performance of European road transport are derived for 1990 to 2010 (Borken 2005); the evaluation shall answer how the overall environmental impact, as measured by the TERM indicators and their related data, has or will develop(d).

2.1 Identification of important indicators

TERM has been developed by the European Environment Agency in cooperation with EuroStat and several dedicated European Topic Centres since 1998. However the Agency considers the comparability of many data over time and space as poor. Hence it is imperative to use an assessment method like ELECTRE III that systematically accounts for these uncertainties.

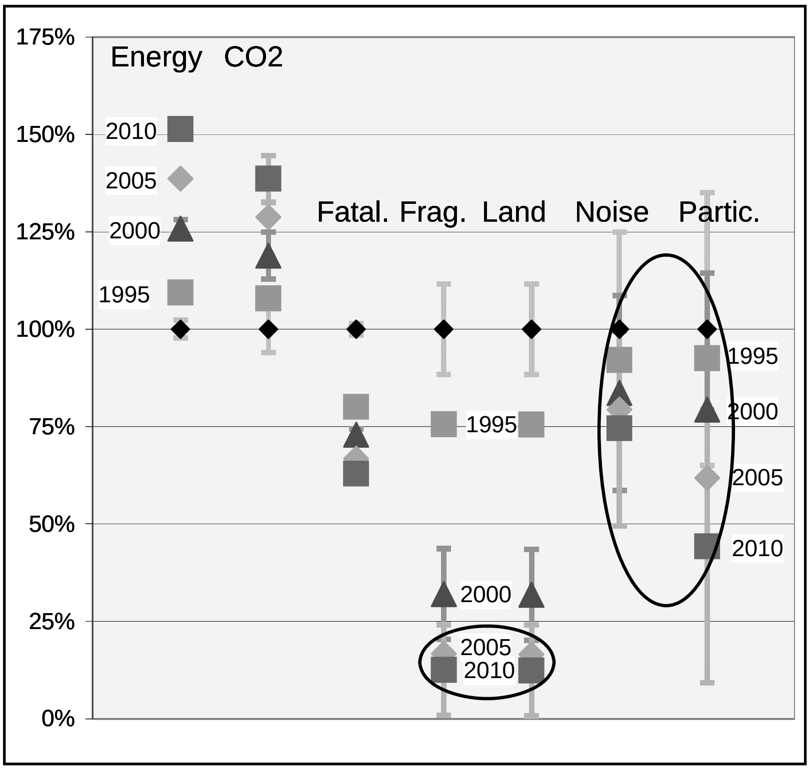


Figure 1: Graphical representation of the data for the key indicators relative to 1990 (=100%).
Note: The indicators for fragmentation and land take refer to the rate of change of the construction of extra-urban transport infrastructure, which is assumed decreasing.

For the representative indicators chosen from TERM, the data structure is relatively simple (Figure 1): The indicators ‘transport’s final energy consumption’ and ‘CO_2-emissions’ increase monotonously, and thus become worse, while all other indicators decrease monotonously, and thus become better. However, the uncertainty for noise exposure data or, likewise, for noise perception and for air pollutant emissions - here for emissions of particulate precursors - is significantly larger than their rate of change even over ten years.

Hence, two of the seven indicators chosen - or any other of the available representatives for the respective impacts – are too uncertain to found an assessment. The assessment in turn will depend, how the deterioration in the impact categories energy resources and climate change is judged compared to the ameliorations for accidents, biodiversity and land resources.

2.2 Overall assessment from the point of view of different values or actors

Having identifies the conflicting areas the following trade-off between heterogeneous and opposing impacts is the essential valuation phase. This is inherently subjective and usually gives rise to a lot of contentious, sometimes ideological discussions. Typically, different actors have different interests in transport plans, programmes and policies, and hence they attach different value to the same impact. This diversity of possible assessments needs to be taken into account for an overall result. This paper emulates different values by defining four profiles, which attach different weight to the three overall objectives: Protection of health, ecosystems or resources. Either, all objectives receive equal weight or, alternatively, one of the objectives is given with 50% a dominant weight and the other two objectives 25% each (Table 2).

Overall objective	Protection of human health		Protection of structure and function of ecosystems			Protection of resources	
Impact category	Accidents	Noise	Air pollution	Biodiversity	Climate change	Energy resources	Land resources
a) Equal weights	33/2	33/2	33/3	33/3	33/3	33/2	33/2
b) Health dom.	50/2	50/2	25/3	25/3	25/3	25/2	25/2
c) Ecosystems dom.	25/2	25/2	50/3	50/3	50/3	25/2	25/2
d) Resources dom.	25/2	25/2	25/3	25/3	25/3	50/2	50/2

Table 2: Weighting profiles depending on the overall protection target applied to the impact categories.

These different assessment schemes allow us to identify controversial results, but, not least, the converging issues despite different values. In the case of the TERM data with their simple monotonous structure, the rankings are strongly converging (Figure 2): The overall environmental impact does decrease from 1990 to 2010 but differences between 2000 and 1995 are not clearly discriminatory. I.e. a large number of actors with different priorities can agree to accept these improvements. They are clear enough that they do not depend on the details of the assessment.

However, the environmental state between five consecutive years cannot reliably discriminated. This reflects on the one hand the inertia of the transport system, on the other hand however also the imprecise data and insensitive indicators. These need therefore be improved in order to serve as a finer and more reliable instrument for analysis and assessment.

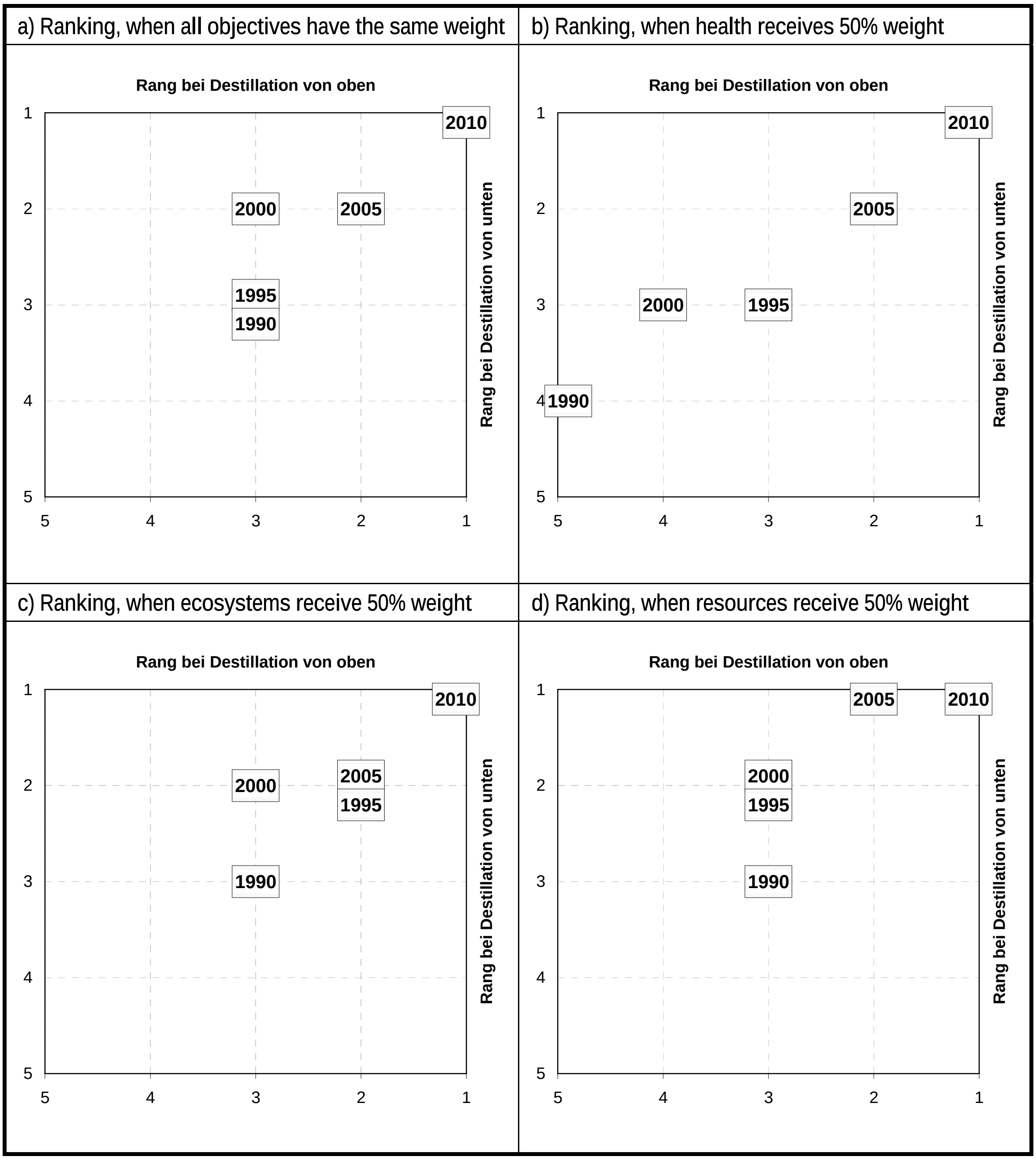


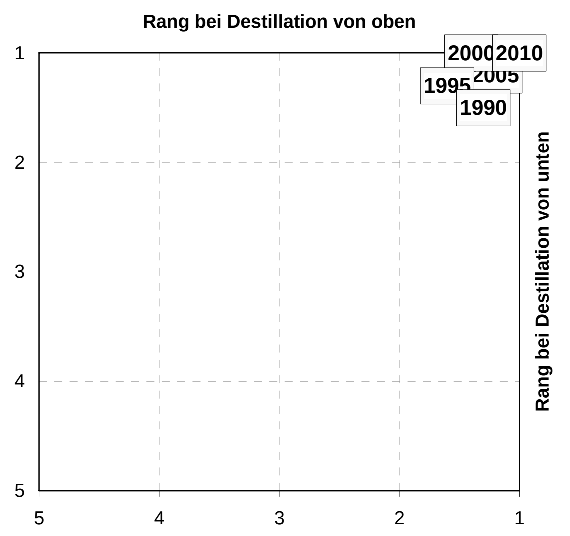
Figure 2: Ranking of Europe's road transport's environmental impact over time – as measured by TERM indicators – as a function of different weighting profiles a)-d).
Read: The rank from the top is given on the horizontal axis, the rank from the bottom on the vertical axis. When both coincide the ranking is unambiguous and the year is represented at the diagonal. Deviations from the diagonal indicate ambiguities.

2.3 Sensitivity analysis: When can the dominant assessment be inverted?

Having identified the convergence it is equally important to know, where the limits of the common assessment are. As there are only two impact categories, represented by the indicators energy consumption and CO_2-emissions, whose performance deteriorates over time, a rank reversal can only occur, when their relative weight is increased (Figure 3): As soon as 40% of the overall weight are allocated to the impact categories climate change and energy resources, the different years can no longer be discriminated: Advantages and disadvantages in the overall environmental performance of Europe's road transport balance each other and their changes are not decisive. As soon as 60% of the overall weight are allocated to these impact categories, their negative performance determines the overall negative assessment.

I.e. the generally positive assessment of the overall environmental performance of Europe's road transport can only be reversed if a relatively extreme assessment of the two counter-acting impact categories is accepted, given an ordinal assessment logic.

a) Ranking, when CO_2 and energy consumption have 40% weight	b) Ranking, when CO_2 and energy consumption have 60% weight



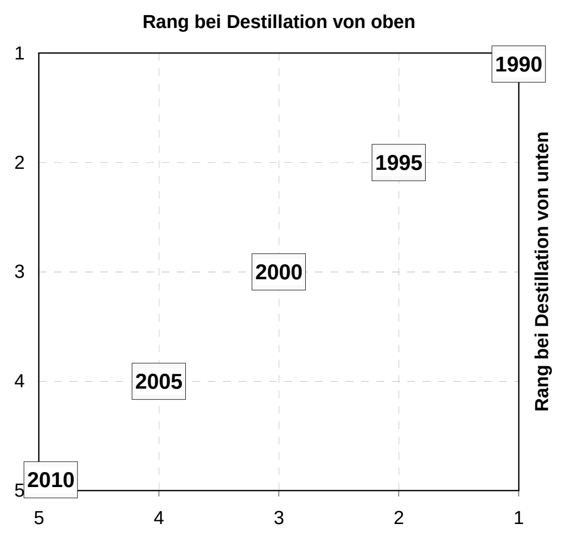


Figure 3: Sensitivity analysis: No ranking is possible when the impact categories energy consumption and climate change receive 40% of the total weight (a), when they receive 60% or more (b), the environmental impact from Europe's road transport is judged to deteriorate with time (rank inversion).

A systematic sensitivity analysis of the technical parameters of the assessment method - the indifference and significance thresholds, the distillation degree – excludes any significant influence (Borken 2005): The variation of these parameters influences the resolution between the overall performance in the different years but does not change their ranking. Hence, the method does not pre-determine this result, but the monotonous performance of the indicators.

2.4 Decisive indicators

As mentioned, of the original seven impact categories noise and air pollution do not play a great role in the assessment as their data are not reliable. The impact category 'accidents' can rely on highly precise fatalities data. But on its own this indicator will rarely receive enough weight – unless a veto power – to *decide* an assessment. The remaining reliable indicators can be split into two opposing groups: The indicators 'final energy consumption' and 'CO_2-emissions' can be referred to the fossil fuel consumption and, likewise, 'land use' and 'fragmentation' can both be referred to the length of the extra-urban traffic infrastructure. In consequence their weight is always allocated in pairs and thus has decisive power (Table 3). As a matter of fact, the multi-criteria problem can – for road traffics' impacts – be focused on two key parameters, fossil fuel consumption and extra-urban infrastructure construction!

Key indicator	Relevant for transport and pertinent for impact	Reliable data for EU15 1990 – 2010	Decisive
Final energy consumption	X	X	Fossil fuel consumption
Emissions greenhouse gases	X	X	
Unfragmented areas	X	X	Extra-urban infra-structure construction
Land take by traffic infrastructure	X	X	
Traffic fatalities	X	X	
pot. concentration of particles (PFP)	X	-	
Annoyance by traffic noise	X	-	

Table 3: Summary of selection steps and results for transport's environmental indicators.

Assuming continued reductions of traffic noise and pollutant emissions, the environmental performance of road transport in Europe can be further improved, if the fuel consumption is reduced and as much as possible decoupled from CO_2-emission; furthermore, extra-urban infrastructure construction should be kept minimal and decoupled from fragmentation.

3 Summary and outlook

This paper analysed to what extent a systematic, qualitative assessment can help to identify the most important parameters and provide a preliminary assessment that is stable for a wide range of value profiles. The main steps in the evaluation are a selection of representative indicators to focus attention and reduce all subsequent work significantly. Next, an inspection of the data uncertainties eliminates the non-reliable indicators. Subsequently, ELECTRE III identifies the converging assessments for a broad range of value schemes, and the sensitivity analysis identifies the limits of this agreement.

The ELECTRE III evaluation method is well suited when data are poor, when heterogeneous input shall be treated without potentially contentious conversions, and where strongly different value judgements occur. Its qualitative assessment logic seems particularly appropriate to reveal and facilitate compromise on the important issues, to identify its limits and thus to select for the relevant issues for a subsequent quantitative analysis.

4 Appendix

Detailed criteria for indicator selection

We are not concerned with proposing an *ideal* set of indicators; on the contrary, we analyse how to make the most of real-world indicators and data. Twenty-four indicators have originally been put forward for nine environmental impact categories (EEA 1999, 2002). A minimal set has been selected on the following grounds:

– The indicators must not be redundant, therefore choose
  - either final energy consumption or emissions of climate gases to represent the impact category climate change,
  - either exposition to or annoyance by traffic noise to represent the impact category noise;

  - either traffic's emission of air pollutants or the share of traffic to air pollutants ambient concentrations to represent air pollution impacts;
  - either fragmentation by traffic infrastructure or traffic's contribution to eutrophication and acidification to represent biodiversity impacts.

– The indicators must be specific for transport as cause *as well as* pertinent for a relevant environmental impact. As their environmental importance is not reasoned, the indicators
  - 'proximity of traffic infrastructure to nature reserves',
  - 'number of end-of-life vehicles and tyres', and
  - 'number of discovered oil slicks'

  are not included in the assessment.

– The road traffic must be a relevant cause. Here we demand at least 5% contribution to the total impact. Below this margin are
  - emissions of ozone-depleting substances, as measured in ODP-units, and
  - the share of waste from end-of-life vehicles and tyres.

Each impact category and the respective indicators have been analysed in detail in (Borken 2005) and are not part of this paper. The systematic analysis identifies, for road traffic's environmental impacts, seven key indicators out of initially twenty-four (Table 1). These indicators are proposed here also for consideration in a Strategic Environmental Assessment.

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5 References

Borken, J. 2003: Assessment of Transport's Impact on Health and Environment in Germany. In: Proceedings of the ECTRI-FERSI Young Researchers Seminar 16-18 Dec 2003, ECTRI-Report 2003-03. Bron/France.

Borken, J. 2005: Umweltindikatoren als ein Instrument der Technikfolgenabschätzung – Selektion, Aggregation und multi-kriterielle Bewertung am Beispiel des Verkehr. [Environmental indicators as a tool for technology impact assessment – Selection, aggregation and multi-criteria assessment for the example of transport.] PhD dissertation at the Faculty for Applied Sciences, University Freiburg/Breisgau. April 2005. 153 pp.

COST 350: Integrated Assessment of Environmental Impact of Traffic and Transport Infrastructure. European Cooperation in the field of scientific and technical research – Action 350. 2001-2005.

de Leeuw, F. 2002: A set of emission indicators for long-range transboundary air pollution. Environmental Science & Technology (5), 135-145.

DIR 1985/337/EEC: Council Directive of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment. OJ L 175/40 (05.07.1985).

DIR 2001/42/EC: Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment. OJ L 197/30 (21.07.2001).

EEA 1999: Are we moving in the right direction? Indicators on transport and environment integration in the EU. European Environment Agency, Copenhagen 1999. 155 pp.

EEA 2001: TERM 2001 - Indicators tracking transport and environment integration in the European Union. European Environment Agency, Environmental issue report No 23. Copenhagen 2001. ISBN 92-9167-307-2, 60 pp.

EEA 2002: Paving the way for EU enlargement - Indicators of transport and environment integration — TERM 2002. European Environment Agency, Environmental issue report No 32, Copenhagen 2002. ISBN 92-9167-517-2, 64 pp.

EEA 2002a: Environmental signals 2002 - Benchmarking the millennium. Environmental Assessment Report No 9. European Environment Agency, Copenhagen/Luxembourg 2002. ISBN: 92-9167-514-9, 149 pp.

EEA 2003: Air quality in Europe – State and trends 1990-99. European Environment Agency, Topic report 4/2002, Copenhagen 2003. ISBN: 92-9167-510-5, 82 pp.

EEA 2003a: Annual European Community greenhouse gas inventory 1990–2001 and inventory report 2003. European Environment Agency (Prepared by Bernd Gugele, Kati Huttunen and Manfred Ritter), Technical Report 95, Copenhagen 2003. ISBN 92-9167-521-0, 78 pp.

EEA 2003 02: TERM fact sheet — Transport emissions of greenhouse gases by mode (EEA-31). http://themes.eea.eu.int/Sectors_and_activities/transport/indicators (11/2004)

EEA 2004: Ten key transport and environment issues for policy-makers - TERM 2004: Indicators tracking transport and environment integration in the European Union. EEA Report No 3/2004. European Environment Agency, Copenhagen 2004. ISBN 92-9167-698-5, 32 pp.

EuroStat 2001: Transport and environment - Statistics for the transport and environment reporting mechanism (TERM) for the European Union. Data 1980-99. 2001 Edition. EuroStat, Luxembourg 2001. ISBN 92-894-1190-2. 198 pp.

Pavlakis, P., Tarchi, D., Sieber, A.J., Ferraro, G., Vincent, G. 2001: On the Monitoring of Illicit Vessel Discharges - A Reconnaissance Study in the Mediterranean Sea. European Commission 2001. 21 pp.

Pronello, C. 2005 : A set of indicators for Strategic Environmental Assessment of transport plans, programmes and policies. Séminaire PIE, Textes et résumés des interventions du séminaire du 16 juin 2005. INRETS Bron/France.

REMPEC o.J.: Protecting the Mediterranean against Maritime Accidents and Illegal Discharges from Ships. Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea. http://www.rempec.org/publications.asp?active=1:2&section=2&#top (12.11.2004).

Rousval, B. 2005 : Aide multi-critère à l'évaluation de l'impact des transports sur l'environnement. Thèse de doctorat en cours, INRETS Bron/Université de Paris – Dauphiné, LAMSADE, 2005.

Roy, B., Bouyssou, D. 1993: Aide Multicritère à la Décision : Méthodes et Cas. Ed. Economica, Paris 1993, 695 S. (ISBN 2-7178-2473-1).

UBA 2001: Daten zur Umwelt – Der Zustand der Umwelt in Deutschland, Ausgabe 2000. Umweltbundesamt (Hg.). 7. Ausgabe. Erich-Schmidt Verlag Berlin 2001. ISBN 3-503-05973-3, 392 S.