Executive summary

Environmental issues figure still more prominently in the decision-making processes concerning transport policies, plans, programmes, projects, or transport technologies. The environmental impacts to be considered increase in complexity and relevance, as do the decisions to be taken.

This report contributes to the development of methods to efficiently integrate complex environmental issues into the assessment and decision processes regarding transport. The main objective is to help to design harmonised methods for building better environmental impact indicators based on the existing knowledge, and to integrate these indicators into decision-making processes. Key elements to fulfill those objectives are criteria for indicator selection and methods for joint consideration of impacts through aggregation or multi-criteria analysis.

The authors of this report are thus concerned with how environmental impacts of transport can be measured, how measurements can be transformed into operational indicators, how several indicators can be jointly considered, and how indicators are used in planning and decision making.

We do not propose one new harmonised method. The work has included a wide state-of-the-art review, an assessment of existing methods and tools, and finally proposed improvements to the methodological elements mentioned above.

The research should be useful for persons involved in the selection and building of indicators, especially environmental impact indicators. It should also serve those using sets of such indicators, for problem identification, monitoring, planning, decision making, evaluation, or benchmarking of transport policies, plans, programmes, projects, or transport technologies.

This volume is the final report of the action COST 356 'EST - Towards the definition of a measurable environmentally sustainable transport' (http://cost356.inrets.fr). COST 356 was a collaboration among a network of scientists specialized in some environmental impacts ('natural' scientists), in decision making processes (‘policy’ scientists) or in transport and environment planning (‘planning’ scientists), each one involved in corresponding national or international research projects.

Chapter 1 'Indicators and their functions' aims at establishing and justifying how indicators are used in this report, addressing basic questions on the basis of a literature review: What are indicators, compared with other knowledge types and methodologies? When and why should indicators be used? What should an indicator measure? How should this measuring be performed? It introduces important distinctions between basic functions indicators can have, in particular between indicators as measurement tools, and indicators as policy

or decision making tools. Furthermore, this chapter discusses strengths and weaknesses of indicators with regard to such functions.

An indicator of environmental sustainability in transport is defined as ‘a variable, based on measurements, representing potential or actual impacts on the environment, or factors that may cause such impacts, due to transport as accurately as possible and necessary’. Such indicators are often necessary, because full models to describe interactions between transport activity and environmental impacts are not available or not practical. There are many different types of indicators, each of which may be suitable to measure particular aspects or help decide on specific issues. There is hardly one indicator able to represent equally well all aspects of sustainable transport. In all cases, it is necessary to reflect why the indicator is needed, what is to be measured, and how it should be done. Indicators can be applied for symbolic or strategic purposes, as well as rational ones, and decision making contexts may differ in a way that suggests different representations of sustainable transport.

The aim of chapter 2 'Transport, environment and sustainability' is to describe what indicators are supposed to indicate, or in other terms to define what "environmental sustainability in transport" may mean and what the indicators should represent. We describe firstly the role of transport as a system, and then we present shortly key aspects of the concept of sustainable development. Finally different meanings of the concept of environment are presented, and we define it by considering the processes between the sources and the impacts.

Environmental impacts of transport include a wide variety of negative influences in connection with construction, use and disposal of transport system components. There is limited availability of frameworks to describe fully these impacts. For that purpose, we developed a new approach through the concept of 'chain of causality', defined as an homogeneous process between the transport system (or any other human activity) and a final target of the impacts on the environment, made by one or several stages or steps. 49 causal chains have been identified and these should form a core of a systematic framework of environmental description and assessment for transport. The clear definition and description of each chain is the necessary solid ground for the search for corresponding indicators: Each chain of causalities is here characterized in terms of transport source, final target, and process between both described through a wide variety of scientific knowledge. The consideration of a comprehensive list of independent causal chains allowed us to give a precise definition of the term 'environment'.

The dimensions and context of decision making appeared to be a suitable basis for choosing environmental indicators, because decision making context influences the perceived and actual needs for indicators and methods, but this is hard to systematize at a general level. Chapter 3 'The dimensions and context of transport decision making' describes the main differences in type of information that is needed in different transport decision making situations, such as strategic versus short-term ones, and in type of conditions for applying different types of indicators in such situations. Critical factors are likely to include especially the degree of consensus versus uncertainty about facts and

values respectively. Indeed, conflicts were said to be a 'normal feature' of transport decision making, which were, however, more or less strong, depending on the overall consensus on values and solutions. The application of structured processes for channelling and managing conflicts was suggested to be of great importance. Whereas in concrete project situations with little or no conflict they may serve as *quasi* decision makers, in situations of great conflict they are likely to only inform actors. Possible functional conditions for selecting suitable indicators include the decision making tier and related to this the stage in the policy cycle at which decision making occurs (strategic, tactic, operational), the transport modes covered, the administrative and functional boundaries, the spatial scale of the impacts, the type of formal requirements, the users and stakeholders involved as well as the timescale.

Indicator selection is rarely documented in practice, hence indicator lists are often applied with no or only not transparent justification. Chapter 4 'Criteria and methods for indicator assessment and selection' assumes that following certain procedures, methods and criteria, and making them explicit may contribute to enhance the quality as well as the legitimacy of proposed indicators, and may also help to identify areas with a need for new indicator building. Based on the description of the context made in chapter 3 and a literature review, criteria and methods for the assessment and selection of environmentally sustainable transport indicators were derived. These criteria were classified into three groups: measurement or representation, monitoring or operation, and management or application. Ten criteria were highlighted and equipped with interpretation and examples: validity, reliability, sensitivity, measurability, data availability, ethical concerns, transparency, interpretability, target relevance and actionability. A general and simplified approach for assessing indicators was proposed, along with a suggestion to undertake more specific indicator assessments where concrete planning situations or needs are taken into account.

The method and the criteria are exemplified in chapter 5 'Assessment of some indicators within an impact'. It looks in detail at indicators for seven chains of causality, chosen to be qualitatively different: direct toxicity of air pollutants, natural habitat fragmentation, non-renewable resource use, loss of cultural heritage due to land take, noise as annoyance to humans, greenhouse effect, and waste. Some chains are short and easily grasped whereas some are long, complicated and characterized by multiple interacting inter-relationships. There is also a large variability between chains in terms of available knowledge and indicator availability.

A review of potential indicators for each chain is undertaken using criteria and other elements provided in chapter 4 as a basic framework. The chain "greenhouse effect" is well described since substantial scientific effort has been put into clarifying its multiple and complicated chain steps, and broad consensus has been reached on the scientific underpinning of the widely used indicator Global Warming Potential as well as more recently proposed ones. In contrast, the chain "waste disposal" has only relatively recently become subject to deeper scientific study, and existing indicators appear to cover only some of the chain steps. Together with "noise" and "non-renewable resource use", this

chain is also an example where there is a wide range of indicators for different types of usage. This is in contrast to “loss of cultural heritage”, where no indicator seems to have existed hitherto.

Typically, in decision making situations many indicators need to be handled together. Based on the outcomes of the previous chapters, on existing literature and on case studies, chapter 6 'Methods for joint consideration of indicators' deals with methods for a comprehensive joint consideration of environmentally sustainable transport indicators. After some introductory remarks on factors affecting joint consideration of indicators and related tasks, methods for building aggregated or composite indicators (such as life cycle assessment, ecological footprint, MIPS, and economic approaches), and common discrete and continuous multi-criteria methods are presented and evaluated from a general perspective, under abstraction of the specific application contexts.

The evaluation of indicators resulting from the application of typical joint consideration methods has shown that they differ in their performance with regard to criteria and categories defined in Chapter 4:

- Life cycle assessment methods such as the Ecological scarcity and the ReCiPe method appear to be medium to good performers regarding representation and operation issues and lower performers regarding application issues.
- The Material input per service-unit and the Ecological footprint are recommended for their operational character and the choice of a clear and well understandable assessment unit, however not for the non-additivity of their elements, at least according to what they are supposed to measure.
- Because of the variety of assumptions and methods, the economic indicators (external costs) do not appear to be very transparent, and the political process to build collective and official values is to be considered as being as important as the economic methods themselves.

General recommendations for the application of multi-criteria methods are difficult to establish under abstraction of the specific decision making context. In principle, every specific application case requires careful evaluation of existing methods and tools. Nevertheless, methods allowing to consider uncertainties and to set thresholds and constraints (such as ELECTRE III or TRI) seem to be particularly suitable in the context of (strong) sustainability.

The major challenge regarding multi-criteria decision analysis in the context of sustainability does not appear to be the development of more sophisticated methods, but rather to provide a consistent framework allowing to integrate the different stakeholders into the different types of (participatory) decision making processes, which guarantees mutual exchange of arguments and information, provides the participants with opportunities to add and challenge claims, and to create active understanding among them.

In addition to the above-mentioned general evaluation, chapter 6 describes five selected cases where methods to jointly consider indicators have been applied to transport policies, plans, projects or technologies, and identifies their strengths and weaknesses.

Chapter 7 identifies research needs, addressing topics for disciplinary as well as interdisciplinary research, in four fields: i) sustainability and environmental issues, ii) role of context for designing indicators, iii) design of indicators per impact on the environment, iv) joint consideration of environmental impact indicators.

In the conclusive chapter, we identify the major challenges in terms of paradigms, legitimacy of procedures, and role of context. We present the limits of the research and give some general recommendations in terms of research policy and methods to take into account environmental issue in the transport sector.