SWEDISH ENVIRONMENTAL PROTECTION AGENCY

Environmental impact from different modes of transport

- Method of comparison

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REPORT

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Foreword

Technical and economic developments during the last decades of the millennium have given rise to increased mobility of people and goods. As a result, the transport sector has undergone dramatic expansion during this period. In order to achieve long-term sustainable development, new demands are being placed on transport sector actors to promote greater environmental compatibility both individually and jointly. The Swedish Environmental Protection Agency (SEPA), in partnership with the Swedish National Rail Administration, BIL Sweden, the Swedish Transport and Communications Research Board (KFB), the Swedish Civil Aviation Administration, the Swedish Business Development Agency (NUTEK)[1], the National Heritage Board (RAÄ), the Swedish Maritime Administration, The Swedish National Energy Administration (STEM), the Swedish Institute for Transport and Communications Analysis (SIKA), the Swedish Petroleum Institute (SPI) and the Swedish National Road Administration, has been working on a project to establish the basis for a new method of measuring the impact transport has on the environment.[2] All co-operation partners have been involved in the financing of the project.

The method developed aims to account for the impact of transport on the environment in an across-the-board, accurate and transparent way. It is based on comparing the effect different transport methods have on the climate, human health, noise, acidification, land use and damage to the ozone layer, using non-monetary quantities. Within the framework of the method, a model has been devised in Excel to make calculations which can then be used as a basis for comparisons and help both sellers and purchasers of transport services to adopt their own standpoints.

The project was organised in a number of sub-projects focusing on methodology and environmental issues and has been conducted in two stages. It represents further development of the Swedish MaTs[3] project. The first stage of the project resulted in a preliminary report published in March 1998. The second stage of the project was then initiated and resulted in this report which also constitutes the concluding report for the whole project.

The report is based on the efforts of a number of jointly run projects in which everyone involved has had the opportunity of participating actively or exerting influence in some other way. Neither the method nor the model are fully fledged. This means that the calculated results presented in the report are, to a certain extent, incomplete examples

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[1] KFB and NUTEK are now part of VINNOVA (the Swedish Agency for Innovation Systems)

[2] SIKA only took part in the first stage of the project while STEM and RAÄ were only involved in the second stage.

[3] MaTs is a Swedish abbreviation meaning “An environmentally sound transport system”

that illustrate how the model might work. SEPA has functioned as a secretariat for the project. We hope that the method in its current form, despite its shortcomings, will be of use as background material and as a source of inspiration for further development.

Stockholm, April 2001

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APPENDICES

The model described in this report can be downloaded by the user from the SEPA On-line Environmental Bookstore at:
http://www.miljobokhandeln.com/

If you prefer, you can order the model on a diskette from:
Kjell Andersson
Naturvårdsverket, Hk
SE - 106 48 Stockholm
Sweden
Tel: +46 (8) 698 11 89
e-mail address: kjell.andersson@environ.se

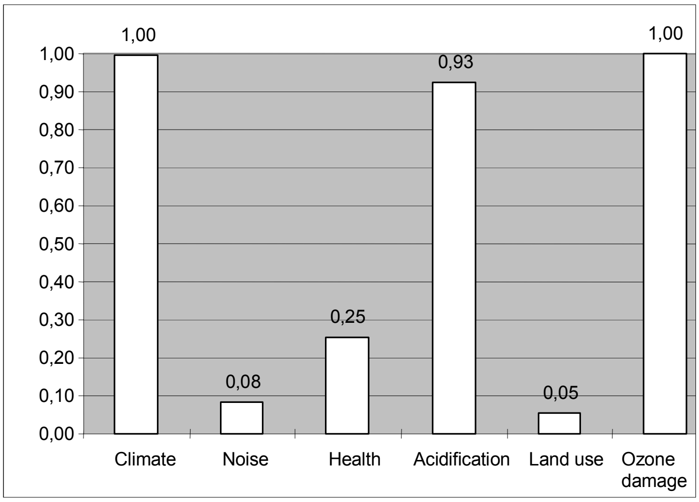
Researchers or other systems developers can also order the model from Kjell Andersson in an open version.

Summary

The concluding report for the MaTs (Environmentally Sound Transport System) project underlined the importance, among other factors, of informing the general public and purchasers of transportation services about the environmental impact associated with different transport solutions. The idea is that such information will stimulate demand for environmentally sound transport concepts. On the basis of the concrete proposals put forward in the MaTs report and in partnership with other interested parties, SEPA took the initiative to formulate principles for how comparisons between the environmental impact of different transport concepts might be calculated. The aim was to identify and analyse all the environmental effects that could be significant in comparing different transport concepts. During the course of the work, it was decided that impact on climate, noise, human health, acidification, land use and damage to the ozone layer should be examined. This type of comparison has not previously been feasible in a comparable and consistent way. The thirteen environmental threats/environmental factors, which later became the 15 objectives of environmental quality established by SEPA, were chosen as the point of departure. We would like to stress that the information should be presented in such a way to be as complete, accurate and clear as possible. The unique aspect of this project is that the results indicate environmental load and not just emissions.

Within the framework for the project the control group has chosen to develop a method based on non-monetary units for the comparison of environmental impact and environmental effects from different modes of transport. It is based on the effects and impact being gradually broken down into sub-layers. The method proceeds to describe the value capacity of different environmental parameters, known as performance functions. The reciprocal significance of the parameters is stated in terms of a weighting/relative evaluation. By means of mathematical manipulation of the value functions included, we can establish a value ratio which allows comparisons between different modes of transport/transport concepts. Within the project, we chose to present the results in bar charts shown in Figure 1a and 1b on the opposite page.

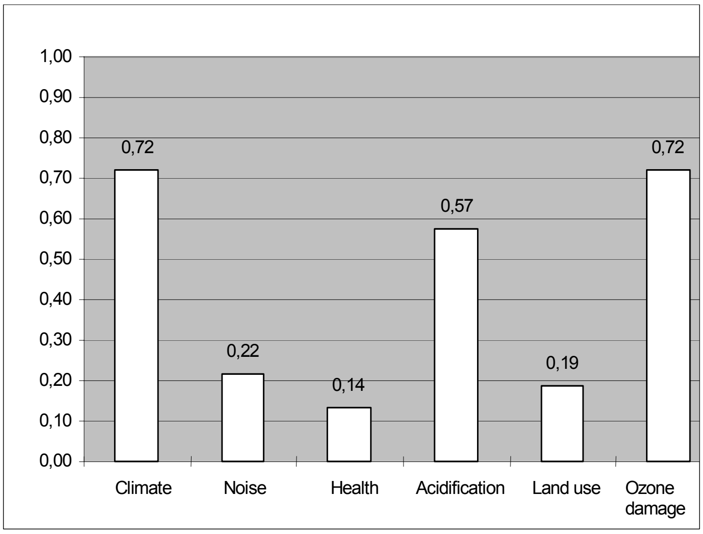
The fundamental idea behind the method is that all the environmental factors should be treated in a systematic way and that the method is based on an open presentation of results. The input data and sources for all the environmental factors are presented. We would like to emphasise here that neither the method nor the model, which was developed on the principles of the method, represents a finished product. For certain parameters there is more or less complete data while for others there are considerable gaps in the data which naturally influences the result. In Chapter 8, *Deficiency Analysis,* and Chapter 9 *Discussion of future use and development,* we describe most of these shortcomings, the problems associated with the work and the existing development potential. This publication should be seen as the first stage in the development of a method of comparison between different modes of transport in non-monetary terms where there remains a considerable need for further development and amplification.



Total emission estimates

	Total emissions g	Total emissions g/p
CO_2	5 328 390	80.9E+3
SOx	3.0E+3	44.1E+0
NOx	16.7E+3	241.9E+0
HC	5.0+3	76.1E+0

Figure 1a: Example of results from the model. Conditions: Journey by one person between town A and town B with vehicle X. Vehicle Y is used to reach vehicle X and vehicle Z is used to get from vehicle X to the actual final destination.



Total emission estimates

	Total emissions g	Total emissions g/p
CO_2	111 697	37.2E+3
SOx	42.5E+0	14.2E+0
NOx	95.8E+0	31.9E+0
HC	97.0E+0	32.3E+0

Figure 1b: Example of results from the model. Conditions: Journey by three people

Key facts

After the selected environmental factors were broken down into parameters, the performance functions were established which, using weighting and addition, provide a value ratio (see Chapter 4 which describes the procedure in detail). The outcome and overall result of the calculations are shown in a diagram as in the example above. The higher the results along the y axle are, the greater the environmental impact. The user can gain an impression from the results in the columns, as to the environmental impact a specific journey or transportation would have, both with the chosen mode of transport as well as with a combination of several vehicles. We can see that the journey between towns A and B has more negative impact with vehicle XY with regard to noise and land use. In the case where transport consists of X, Y and Z between towns A and B the result is more negative regarding climate, human health, acidification and ozone damage in comparison with the journey in figure 1b.

between town A and B with vehicle XY.

1 Introduction

1.1 Background

For long-term sustainable development to be achieved, the various activities within society must be adapted to what can be tolerated by humans and by the natural environment. Transport is an activity which affects humans and the natural environment to a very great extent. It is nevertheless vital for both the development of society as a whole as well as for the mobility of the individual. The ability to transport oneself and one's products wherever and whenever necessary is seen today by the majority of us as a matter of course. The design and development of the infrastructure for the transport sector and methods of transport are closely dependent on general social developments and have a decisive influence on the location of housing and industry. This is why coordinated efforts are necessary from actors who are active internationally, nationally, regionally and locally to assure maximum environmental compatibility as the transport system is being transformed.

Calculating their total environmental impact and looking at transport solutions in a holistic perspective has been brought much more to the fore during the last few years. Growth must be permitted without endangering the long-term function of ecosystems nor our health. What was previously seen as a contradictory relationship between the environment and development is now seen as a whole, with economic growth, social well-being and a sound environment as the objectives. To come to grips with the environmental problems generated by today’s transport sector, merely addressing their technical causes is insufficient. Society and the individual must contribute to a change towards environmentally and ecologically sound social systems, including the transport system. The transport sector therefore has to be analysed to be able to continue to develop sustainably.

Certain improvements have been made during the last ten years concerning the environmental impact of transport. Air pollution in Swedish urban areas has been reduced, for example, but in many places concentrations of certain substances deriving from transport activities are still at unacceptable levels and much more has to be done. Carbon dioxide emissions and noise are examples of environmental problems demanding further efforts. Measures to limit the exploitation of valuable natural and cultural environments and to protect biological diversity are also needed.

Development and measures aimed at limiting environmental impact have progressed at different rates within different modes of transport. The extent of transport and distribution between various modes of transport have a considerable bearing on the sector’s environmental impact Opinions differ as to the design of an environmentally sound transport system. There is considerable need for devising more collated information about how a comparative assessment of the environmental impact from different transport alternatives can be made. Comparative assessments are complicated by the fact that environmental problems from different modes of transport are of differing dimensions. Air transport causes different problems and rail transport differs in turn from road transport.

1.2 “The initiative”

In the autumn of 1996, a cooperation project was concluded involving the Swedish National Rail Administration, BIL Sweden, the Swedish Transport and Communications Research Board (KFB), the Swedish Civil Aviation Administration, the Swedish Business Development Agency (NUTEK), the National Heritage Board (RAÄ), the Swedish Maritime Administration, The Swedish National Energy Administration (STEM), the Swedish Institute for Transport and Communications Analysis (SIKA), the Swedish Petroleum Institute (SPI) and the Swedish National Road Administration. The project had been underway since the autumn of 1994 and was known as the MaTs project (environmentally sound transport system). The MaTs project’s management group instructed the parties involved to try to devise principles for how comparisons between the environmental impact caused by transport concepts could be made and wrote in its final report:

"Information to the public and purchasers of transportation services as to the associated environmental effects of different solutions is significant in creating the demand for environmentally sound transport concepts. It is therefore important that such information is presented in as complete, accurate and clear way as possible."

On the basis of the project’s concrete proposals, SEPA took the initiative to try, to devise general principles for how comparisons between the environmental impact from different transport concepts could be made, in partnership with the other agencies involved in MaTs. The development of an analysis method can be seen as a natural continuation of the MaTs project and it is a challenge to work out a method of this kind. The aim has been to observe and compare the environmental impact of different modes of transport in a comprehensive and accurate way.

1.3 Aim and strategy

This project aims to contribute by providing a stable cornerstone in the development of a method for non-monetary comparison of the environmental impact of different modes or chains of transport. The non-monetary principle has been chosen to increase the stability of the model by rendering it independent of current interests. Furthermore, there are no monetary evaluations for many emission parameters. For the project to lead to a product, in a wider perspective and with broad acceptance within different sectors, our strategy has been to depart from the holistic view of environmental impact established as part of the MaTs project. This strategy is believed to be important since the final MaTs report shows that an environmentally sound transport systems requires extensive investment and effort, necessitating the participation of many actors for a considerable time to come.

Taking a holistic view means that we strive to accurately cover all the relevant environmental factors of the different kinds of environmental impact along the entire transport chain in the model. The point of departure is the environmental factors and environmental objectives presented in the MaTs project. The relevant objectives, of the 15 environmental quality objectives adopted by the Swedish Riksdag in April 1999, have also been incorporated into the model. The cooperation partners have discussed these questions and reached an agreement as to which environmental factors were relevant to the transport sector and further identified appropriate parameters and indicators for these.

In the current situation, there are a great many calculation principles the user can choose according to the purpose of his/her own presentation, not least as far as emissions and energy factors are concerned. This renders our method initiative, with established principles of comparison and equally valued assessments of the environmental impact of the transport sector as a whole, even more significant. The basis for assessment maintains a high qualitative standard for the parameters where material was available and can be used in a direct calculation of the environmental impact. It should, however, be pointed out that the basis is still inadequate for a number of parameters and that the method cannot be considered a finished product. A basis for comparison of this kind is something new and it will take time before a high standard can be achieved across the whole spectrum.

The long-term goal is, in conclusion, to develop a broad-based method which in terms of environmental performance provides a collective, comprehensive and accurate description of environmental impact along the entire transport chain. The method should be transparent, user-friendly, include source references, be comprehensible as well as being easy to update and expand. The result is expected to provide a phase in the process of creating demand for environmentally sound modes of transport for both people and goods and also to contribute to creating a range of environmentally sound transport products for purchasers of transportation services and the general public.

1.4 Delimitations

An aid used increasingly often in devising total environmental assessments "from the cradle to the grave" for products, processes and systems is the Life Cycle Analysis (LCA). LCA involves both the consideration of all environmental impact and a mutual evaluation of the various factors. Within the concept, for practical reasons, delimitations are established in such a way as to allow assessment of the significance of the omitted environmental impact. A life cycle perspective was used in this comparative method as far as possible. Since it proved difficult to obtain relevant data for many variables, a number of limitations have been made. The environmental impact from the production and scrapping phases for vehicles and shipping, in common with the building and demolition of the infrastructure, was not available. We have also departed from the principle of showing the entire life cycle, the only exception being energy sources for powering the various means of transport. In this case a Life Cycle Inventory (LCI) was used which means that an evaluation of the various environmental factors was not made in full.

Otherwise, consideration was primarily taken of the environmental impact generated by transport activity itself. No consideration was taken of the production and scrapping phases for vehicles and shipping nor of the construction and demolition of the infrastructure. The effects of land use given over to the infrastructure and transport in the form of the impact on the natural and cultural landscape and on natural resources, along with noise, have been dealt with in a special way. Meanwhile, the model has been prepared to allow for the inclusion of the results from a project conducted by the Swedish National Road Administration in co-operation with the National Rail Administration, the National Heritage Board and SEPA. Furthermore, electricity consumption for street lighting and lighting for petrol stations has not been included nor have the losses occurring in the electricity grid when electricity is conveyed to trains. The model is, moreover, only adapted for transport within Sweden's national borders but the idea is that it could be expanded to incorporate international transport as well.

1.5 Target group

Before the method is completely ready for use, the shortcomings that exist in the data material should be complemented and the operative model would have to be developed. We hope that the method in its current form might be useful as a basis and inspiration for further work with research into methodology, data accessibility and quality, primarily for those able to develop the method and the user interface for the model such as researchers, PhD and MSc students as well as consultants who develop this type of tool.

The primary target group for this comparative method is those who in their occupations mainly work with selling or purchasing goods and/or passenger transport. This may include purchasers of passenger and/or goods transport within the commercial and public sectors, or transport sales personnel within transport and haulage companies. In addition there are a number of other groups that might be interested in this comparative method, not least those who in various ways work with or study environmental protection and/or environmental management systems.

1.6 Project implementation

An important stage in the work on the “comparison project” was to study published literature on research previously conducted or currently underway into developmental work, and methods and models concerning the environmental impact of transport both nationally and internationally. A striking shortcoming evident both nationally and internationally in comparative methods is that they often display a more or less one sided focus on air emissions and energy consumption, while other environmental factors such as noise, barrier effects or land encroachment are frequently not considered. Assessments which only take into consideration energy requirements and air emissions unavoidably present a false picture of the total environmental impact of the transport sector. The holistic perspective has to be highlighted and emphasised.

The project work has been conducted in two stages. During the first stage the work was conducted by a project organisation led by a control group and a working group. Minor investigation assignments were given to a couple of consultants which resulted in a report on transport and the environment (Chapter 2.2) and a study into system analyses (Chapter 2.3). The control group consisted in principle of representatives of those agencies involved in the MaTs project (the Swedish National Rail Administration, BIL Sweden, the Swedish Transport and Communications Research Board (KFB), the Swedish Civil Aviation Administration, SEPA, the Swedish Business Development Agency (NUTEK), the National Heritage Board (RAÄ), the Swedish Maritime Administration, The Swedish National Energy Administration (STEM), the Swedish Institute for Transport and Communications Analysis (SIKA), the Swedish Petroleum Institute (SPI) and the Swedish National Road Administration). They established the aims of the project and the main focus of the work as well as taking a coordinating responsibility. The day-to-day work was conducted by the working group in which all the interested parties have been able to take an active part. The working group also included representatives from SJ (Swedish Rail) and the Gothenburg branch of the Swedish Association of Local Authorities.

The first stage was concluded with a seminar arranged with the aim of discussing the usability of the method and the need for development from a number of different perspectives. Three opponents examined the method before the seminar and then presented their views. Several seminar participants also indicated a number of points where the method needed to be developed further. The views considered relevant by the control group were processed and integrated into the method during the second stage of the project.

During the second stage, the project organisation was restructured as necessary. The National Energy Administration and the National Heritage Board joined the project. On the other hand, SIKA was no longer able to take part. The project was led by a control group exactly as in the first stage and the day-to-day work was conducted by four working committees each responsible for their own special fields. During this stage, assignments were given to consultants who were requested to study four areas: land use, electricity, fuel and energy (Chapter 2.2). SEPA has functioned as a secretariat throughout the project both for the control group and the working group/committees, and has also been responsible for the production of the model, or rather, the computer version of the model.

2 The comparison project

During the spring of 1997, SEPA in partnership with the other parties involved in the MaTs project took the initiative to start another project with the aim of devising general principles for a method of comparison between the environmental impact of different transport concepts. The project was known as "the comparison project". The method proposal is based on the aim of covering all relevant environmental effects for the transport sector and the guiding principle in this work was that, ultimately, it would lead to a method of comparison with broad acceptance or consensus among the actors within the transport sector.

The challenge of the comparison project was to evolve a method which would provide more collective information than had previously been feasible. Authorities, companies, organisations and individuals can then proceed on the basis of the knowledge the method provides. In concrete terms, this means that environmental work can focus more on preventative efforts. The environmental problems of the transport sector can thereby be minimised before these problems even arise. This requires more active participation on the part of the actors, for instance, in planning each transport concept. To achieve sustainable development within the transport sector, it is important that even more parties become involved to a greater extent in these efforts from individuals to companies, organisations and authorities.

The environmental problems generated by transport are complex and consist of several different factors, each with differing consequences. Within the project, we have attempted to include all the areas we possibly could with the knowledge we have today. To achieve the goal of including all the relevant environmental effects, we need to ensure that the accumulation of knowledge continues and that further background material is developed in various issues of which we have insufficient awareness at the present time.

2.1 Project planning and procedure

The entire process of devising the method and the model presented in this report was very positive. We have come a long way in achieving a common view and considerable appreciation exists within the group of the difficulties inherent in the fundamental problems of environmental impact caused by transport. During the course of the project, we have had many internal meetings in addition to the continuous contact maintained to attune our thoughts and ideas. We also arranged a number of seminars with various experts and with specially invited researchers who examined the method from a scientific point of view. Furthermore, the relevant actors have been invited to a workshop where our preliminary proposal for a method was dealt with for the purpose of harmonising our initial draft.

We have not always agreed on all issues dealt with within the framework of the project but we did agreed that the method we were developing should be a comprehensive, accurate and transparent comparative method based on non-monetary terms. In addition, everyone agreed that environmental work did not function in isolation; that it should be linked to general social developments and that only through a joint effort will society be able to achieve the objective of an environmentally sound transport system. By comprehensive we mean that the information about environmental effects associated with different transport solutions should be based on a holistic perspective. All the environmental effects relevant for the entire transport chain should be accounted for in an accurate way. Furthermore, the method should be constructed in such a way as to be transparent in every aspect and on all levels of calculation.

2.2 Material from the working groups and consultant assignments

Four different working groups were set up during the latter part of the project. The aim was to bring together different experts in order to make the best use of expertise which does not naturally become available in conditions where a study focuses on only one type of transport at a time. Their task was to collect and collate the background material for the method and to examine in greater depth some of the areas which the control group believed were important to look into and describe. The areas of responsibility were:

- land use, comprising issues concerning natural and cultural environment, natural resources, encroachment, biological diversity and aesthetics.
- Noise and vibrations
- Energy consumption
- Performance functions and other issues concerning the model.

During the autumn of 1998 and up to the spring of 2000, the working groups held a series of meetings, organised seminars and some groups have also chosen to commission external consultants in order to collect relevant expertise in their fields. These assignments resulted in several reports presenting background material which were published separately.

The Report entitled "Land use for transport" (EPA Report 5044) is a collation of the expertise concerning the consequences transport has on natural and cultural values. The collection is based on the current level of expertise in Sweden along with inventories and value accounts conducted previously. The inventories and value accounts for natural values are relatively comprehensive for the whole country while the material for cultural values is not as extensive. The report was prepared by Ekologigruppen AB.

The report entitled "Environmental factors in the transport sector" (EPA Report 5045) is also a collation of expertise concerning the impact of the transport system on health and the environment in general. This report includes many different environmental factors along the entire transport chain departing from the thirteen environmental threats established by SEPA and work conducted in collecting this information was done by the working group during the first stage of the comparison project.

The report entitled "Survey of the accessible data for electricity and fuels" (EPA Report 5063) is a collation of expertise for the accessible data for electricity and fuels. The report was prepared by IVL Svenska Miljöinstitutet AB and examines the issue of whether sufficient data is available for devising a relevant descriptive approach for the method regarding electricity and fuels. It also outlines what needs to be complemented in this field.

A fourth report on energy issues (by Atrax/Kemiinformation AB) will be published in the spring in the report series issued by the National Energy Administration. This is a collation of the expertise concerning data based on currently available information for environmental effects of different fuels for transport including both fossil fuels and bio products. A review of the "environmental threats" was conducted and current environmental effects from fuels were examined and quantified.

An assignment commissioned from "Trafik och Miljö i Umeå AB" has also been published. This report was entitled "Flexiwagon" (InlandsBanan AB, dated 10/11/1997) and is an overview assessment of environmental effects including noise and encroachment effects along with an estimate of the unadjusted marginal costs.

Finally, a progress report was published in March 1998 describing the first phase of the project work with a summary of the results obtained at that stage.

2.3 Theoretical platform

Thure Valdsoo accepted an assignment during the course of the work into finding a method. The aim of this assignment was to analyse different descriptive methods in the form of systems studies with an emphasis on the environment. Five different methods for systems analysis were reported to the control group. The method for comparing the environmental impact of different modes of transport which was finally chosen was method 5 which is presented below. Briefly, it is based on non-monetary aspects and allows for comparison between the different modes of transport. Below is a brief outline of the descriptive method presented to the control group by Thure Valdsoo. The entire analysis including a detailed description of the five methods can be seen in Appendix 7.

1. Flow/changeover chains for different modes of transport and their fuel.

Considerable amounts of energy in addition to the fuel itself are used to power a vehicle. Flow/changeover chains provide energy analyses of *all* the energy supplied and required to run a passenger car, for example. This means that all energy sources are identified and included in the analysis. Energy is used in the production and maintenance of vehicles and spare parts, in the training and support of drivers and service personnel, in the construction and maintenance of the road network and so on. In a model based on flow and changeover chains it is easy to lose sight of a flow or underestimate its significance. At first glance for example, the training of drivers and service personnel may seem a negligible item. However, if the entire underlying energy chain is analysed, this flow may be important. Chains of this kind can become extremely extensive and difficult to perceive.

2. Life Cycle Analyses and cost estimates

The passenger and goods transport system has clear links to the road system and the fuel system which in turn are linked to the global oil supply system. In everyday terms, we usually refer to the transport system requiring an extensive infrastructure for its existence. A Life Cycle Analysis (LCA) is a way of quantifying and evaluating the environmental impact a product has from the cradle to the grave. These days we have access to international ISO based standards that can be used to compare different products on condition that the limits for the technical system are set in a relevant way. A comprehensive description of LCA and the way the method is used in this comparison project can be found in Chapter 3.3.

3. Selection method as a result of personal evaluation of different modes of transport

A family seeks its "sustainable transport development" within the system for passenger transport by choosing a car. The family specifies its control parameters and then looks for the car which best meets its needs. Many potential car buyers are guided by the consumer reviews published in the press and media and which give points for different parameters such as a number of "stars". One of these stars usually represents the criteria "environment" but it is often financial aspects that carry the greatest weight in this type of test. The stars are intended to represent value-neutral technical performance which after addition comprises a comparative criterion for personal evaluation when choosing, for example, a car.

4. Use a local/national/global welfare function as a selection procedure

Performance criteria and the choice between transport systems and other large, complex systems have been discussed using formulations such as "global welfare function" or slightly more pessimistically as "human poverty index". Here the performance aspect is based on sub-models for climate systems, ecosystems, social systems and economic systems, for instance. Concepts such as quality of life, health, education, personal security, political rights and collective security should be reflected in the calculations. Preferences between people, nations and parts of the world should also be considered. There are obvious difficulties with formulations concerning welfare. A family that buys bikes instead of a second car feels better and becomes healthier. But cycling reduces the growth rate in both the healthcare sector and the vehicle industry. Attempts to measure welfare in western Europe according to similar guidelines and calculations revealed that the "welfare curve" was clearly distinct from the GDP curve. To the extent that it is possible to reach an agreement as to the definition and a calculation procedure for a local/national/global welfare function, a method for a selection procedure could be established even though it may be a very complicated and opaque one for decisions makers and consumers.

5. Take into consideration control parameters, weighting, performance

A system consisting of politicians, consumers and technicians where each has a well-defined role and where the integration of relevance, values and technical performance can provide a "transparent" overall picture of the environmental impact of transport. This system approach was finally chosen as the working method and point of departure for this project. It is based on decision-makers and politicians formulating a number of control parameters through careful consideration of the hierarchies in natural and artificial systems. Buyers and consumers then weigh up the parameters by evaluating how they and their families would be affected personally. Technicians and researchers measure and establish the quantative, technical performance ratio for the system and all this is finally calculated in a mathematical procedure.

2.4 The status and updating of the method

The limits of our knowledge regarding environmental studies in relation to transport have been breached in this comparison project and can now function as a sound platform for future work. The task of creating a high-quality base of material for comparisons between alternative modes of transport should naturally continue. Spreading the method for further development by those who will use it is a positive step. No absolutely definitive calculation tool has yet been produced, nor was the aim to devise an operative model. Despite the work of developing a method and calculation model being incomplete within the resource framework of the project, the control group wishes to distribute the results of the project in its current form. The idea is to stimulate to further work. We hope that the method in its current form will inspire those whose job it is to develop this type of tool. User friendliness is now for the market to work on in accordance with its own preferences and requirements.

The calculation model can be downloaded free of charge from the SEPA environmental bookshop at: http://www.miljobokhandeln.com/ .The model is read-only but on request an exclusive read/write version can be obtained. The method and model are intended for external distribution to those who can develop them further. As mentioned before, a certain amount of background data is missing which can be seen in the appendices. The project control group take no responsibility for the updating that needs to be done and which may be completed by the users/developers themselves.

3 Method requirements

Conducting actual measurements for every conceivable transport operation would obviously be the most correct basis for an environmental assessment but this is not feasible in practice. Not least if the intention is to create a comprehensive basis for assessment of a number of alternative transport concepts. A theoretical method with certain limits and simplifications therefore has to be used for practical reasons. The framework for the theoretical method we chose for the comparison project is discussed below.

3.1 Environmental factors in the comparison project

Twenty or so years ago, the discussion on the environmental impact of transport focused primarily on harmful air emissions generated by transport in urban areas and to a certain extent also on noise. A few years later, the regional damage caused to forests by acidifying emissions from transport and other sources was at the centre of the debate along with an increased interest in damage caused to crops as a result of ozone precursor emissions. Recently, the perspective has broadened considerably to include consideration of global environmental effects such as damage resulting from climate change and ozone layer depletion in the stratosphere. However, even local environmental effects in the form of barrier effects, impact on flora and fauna, on the natural and cultural landscape, aesthetic values, the depletion of non-renewable resources and so forth have all been discussed. An attempt to take a more holistic view of the environmental impact caused by transport which requires the consideration of more objects of protection simultaneously has increased the need to be able to agree on a method that structures and accounts for complex information on the different environmental performance of different modes of transport.

In the section above concerning aims and strategy, we emphasised the importance of identifying and analysing all the environmental effects from the start which may be of significance for a comparison of the different effects of various modes of transport on objects of protection such as human health, biological diversity, natural resources and natural and cultural landscapes. The control group for this project decided initially to depart from the thirteen environmental threats/environmental factors which were used as a guideline in MaTs project. Those environmental quality objectives adopted by the Swedish Riksdag in April 1999 which were relevant to the project were also incorporated into the method at a later date. The aim has also been to include in principle all the relevant environmental effects of the transport sector.

The thirteen established environmental threats are stated along with the environmental quality objectives in Table 1. They are specifically referred to in brackets in *column 1*, in parallel with the respective environmental effects or environmental impact. In addition to the threats and objectives, other disturbing effects of radiation have also been incorporated although without any attempt to quantify them. The links between the environmental threats and the proposed national environmental objectives for natural deposit resources, land and water use and the impact of pollutants as described in the SEPA report "*Clean air and green forests*" (Report 4765) are presented in appendix 2 of this report.

In this project the environmental factors have been considered and grouped, from a weighting and comparison viewpoint, slightly differently than they would have been, by strictly maintaining the combination of effect and load categories based on the thirteen environmental threats originally identified by SEPA. The aim was to attempt to refine the divisions according to the type of effect rather than according to the type of emission or load. We then continued attempts to update the descriptions in order to take into consideration new effects not yet included and to finally improve clarity by, to some extent, attempting to group similar effect categories together such as emission and immission parameters, indicators and so on, required to best describe impact within the each effect category respectively. Examples of such impact factors/parameters which are currently deemed useful are provided in *column two of the table*.

In this project we have been compelled to screen/prioritise in our choice between different parameters (*column three*). The selection, symbolised by the filter funnel below, is the result, on the one hand, of consideration between the significance (in terms of emissions for instance) and the representative nature/relevance the chosen parameter has for the effect category concerned and the transport sector. On the other hand, the access to data for the various modes of transport and limited resources within the project have also been of decisive significance. The selection was, however, adapted for this project and could be extended and modified in a continuation of the project.

Identify the desired parameters within the respective effect category. Observe in principle *all* relevant parameters.

<u>Selection for this project</u>

Depart from the environmental factors previously incorporated in the MaTs project with the addition of certain others considered relevant. Select parameters for the most important emissions and for which we currently have access to quantative data for all modes of transport.

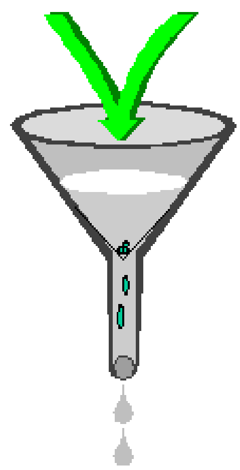


Figure 2: The selection process for parameters/indicators in this project - a balance between the vision of including everything of significance to the transport sector and the requirement for usability for the method within a reasonable time frame.

Table 1: Table of environmental factors considered in the comparison method and their respective parameters.

Environmental factors Environmental factors/-effects influenced by transport activities (equivalent environmental threats according to SEPA's previous environmental objective work in brackets along with environmental objectives, Government bill (1997/98:145))	**Parameters in a wider perspective** Examples of relevant parameters/indicators that can be selected to describe and quantify environmental effects/environmental factors and practical considerations of data accessibility etc. need not be made.	**Parameters chosen in this project** (considering the size of emissions, data accessibility, quantifiability and the resource requirement for this, previous work etc.)
Damage caused by impact on climate (*Threat 1: Greenhouse gases) (Objective: Limited climate change)*	*Impact on climate from gases and particles:* Carbon dioxide, methane, nitrous oxide, HFC, FC and SF_6.[CFC and HCFC are subject to phase-out] Substances released at high altitude (aircraft) and which are or form condensation cores. [Substances that can form ozone]	Carbon dioxide
Damage (to health, biological diversity/production in nature, technical material) through increased UVB radiation (*Threat 2: Depletion of the ozone layer in the stratosphere) (Objective: Protecting the ozone layer)*	Certain chlorinated or brominated organic substances such as CFC, HCFC and halons. Certain inert organic chemical substances emitted at ground level such as methane. [Aircraft emissions at high altitudes of substances contributing (catalytically or in some other way) to ozone depletion in the stratosphere should be considered [hydrocarbons, nitrogen oxides (NOx), sulphur oxides (SOx)] - net effect disputed and remains to be studied]	Have not been observed due to lack of emission data primarily of CFCs.

Damage as above of electromagnetic radiation other than UVB incl. ionizing radiation (*Threat: Not yet observed)* *(Objective: Safe radiation environment)*	Have not been identified in this work	Have not been observed
Damage as above of unnaturally acidified or eutrophied land and water caused by emissions from transport Includes damage to material due to acidified emissions. (*Acidification - threat 3 -* and *eutrophication - threat 6 - of land and water)* *(Objective: Natural acidification only)*	*Sulphur oxides* (SOx), *nitrogen oxides* (NOx) *Substances* which directly or indirectly *supply nutrients* [pollutants containing nitrogen such as urea, nitrogen oxides]	Sulphur oxides (SOx) Nitrogen oxides (NOx)
Damage to crops and technical material through increased levels of oxidants. (*Threat 4: Photochemical oxidants/ ground-level ozone)* *(Objective: Clean air)*	Nitrogen oxides and volatile organic compounds (VOC separated into substances/substance categories according to the potential for forming oxidants in Swedish conditions concerning NOx/VOC conditions, ozone levels, temperatures and solar radiation] concerning primarily long-term mean values /vegetation season, day time)	Nitrogen oxides (NOx) *(assumed to control ozone formation in rural areas)*

Health effects from air emissions (*Threat 5: urban air pollutants and noise and Threat 4: Photochemical oxidants/ ground-level ozone)* *(Objective: Clean air)*	Nitrogen dioxide, particles that can be inhaled, sulphur oxides, formaldehyde, acetaldehyde, unsaturated aldehydes and secondarily formed ozone (in episode conditions) with relation to respiratory problems. Regarding *cancer/ leukaemia/ genotoxic effects*: particle-bound and semi-volatile polyaromatic hydrocarbons (PAH) with a total of a number of carcinogenic PAH, PM 2.5 (gravimeter/number), certain gas-formed carcinogenic organic substances (VOC) with benzene, ethane, propane, 1.3 butadiene, formaldehyde, [for fuels containing alcohol also acetaldehyde, acrolein, other saturated aldehydes and alkyl nitrites] nitrified polycyclic organic substances (nitro-PAC, possibly with 1- nitropyrene as an indicator) and data from different established bio testing systems concerning mutagenicity, cancer conferring (TCDD- receptor affinity test] and also for irritation/inflammatory capacity.	*Respiratory problems:* Nitrogen oxides, sulphur oxides, particles that can be inhaled, formaldehyde, acetaldehyde and secondarily-formed ozone. (*Ozone production under episode conditions is assumed to be limited primarily by access to reactive hydrocarbons and good access to nitrogen oxides and sunlight.)* *Cancer/leukaemia/genotoxic effects:* Total particle-bound and semi-volatile (SVOC) polyaromatic hydrocarbons (PAH), certain carcinogenic gaseous organic substances (VOC) with benzene, ethane, propane, 1.3 butadiene. Formaldehyde not included due to lack of information. Consideration of where emission occur (urban/rural area).

Health effects of noise and vibrations (*Threat 5: Urban air and noise)* *(Objective: Good urban environment)*	*24-hour equivalent levels and maximum levels outdoors* with consideration of the time (day/night) and where the exposure occurs (urban, rural, national parks etc.) *The number of noise incidents (maximum level) and their duration. Measurement of vibrations and low frequency sounds. Consideration of where the disturbance takes place and the number of people disturbed by the noise.*	24-hour equivalent levels [sound level intervals: 50-55, 55-60, 60-65, 65-70 and 70-75 dB(A)]
Negative impact on health and ecosystems caused by unnatural changes in metal levels in the ground, water and air (*Threat 7: Impact from metals)* *(Objective: Non-toxic environment)*	Toxic metals: Lead, mercury and cadmium, copper [readiness for the introduction of new metals]	Not observed.
Negative impact on health and ecosystems as a result of impact from organic environmental toxins in the ground, water and air. (*Threat 8: Impact from organic environmental toxins)* *(Objective: Non-toxic environment)*	Organic environmental toxins: PAH (including creosote, tyres, bitumen, exhaust emissions, oil spills), polybrominated biphenyls and chlorinated dioxines, organic tin-based compounds, tensides nonylphenols /nonylphenyletoxylates, certain phtalates, PCB, chlorophenols and other biocides that are poorly degradeable.	Not observed other than as a contributing factor to carcinogenic air pollutants

Unbalanced ecosystems caused by the introduction and spread of xenobiotic organisms. (*Threat 9: Introduction and spread of foreign organisms)* *(Objective: A balanced marine environment. Sustainable forests and A varied agricultural landscape)*	Have not been identified in this project although basic research results into the impact of shipping as a result of ballast discharge is available and could be considered.	Not observed
Exploitation of land and water in such a way as to cause encroachment or present a threat to the capacity of the environment to nurture flora, fauna and micro-organisms as well as providing people with housing, recreation, cultural and aesthetic values and production and supply resources. (*Threat 12: Claim to certain important areas. Threat 10: Use of land and water as a product resource and exploitation of land and water for urban development, facilities and infrastructure threat 11).* *(Objective: Sustainable forests and A varied agricultural landscape).*	*Land requirement* *Barrier effects* *Indicators of biological diversity. (Diversity and balance of species/genetic variation) Viability of key species)* *Indicators of the preservation of cultural heritage and cultural values.* *Indicators of the promotion of aesthetic values.*	Use of land for the infrastructure.

Consumption of finite raw material and energy resources. *(Threat 13: Broken ecocycles, waste and environmentally hazardous waste products)* *(Objective: none)*	In the case of fuels, the working group has discussed the inclusion of a parameter for the consumption of fossil fuels. The net consumption of gravel used for sanding roads may also be included in a comparative model. Ballast in embankments and causeways would not be included in this model since only the operational phase of transport is included.	Not observed. In the future this may be incorporated into the National Road Administration's project on land use for the infrastructure ("Objectives, measurements and follow-up of natural and cultural values in the transport system").

3.2 Environmental impact and the effects of transport

We decided that the main line of approach in the comparison project was to focus on the environmental impact generated by transport, including air emissions, noise etc. and the effects resulting such as health effects. We restricted ourselves to six main areas of climate, noise, health, acidification, land use and ozone damage. The influence transport has in relation to these six main areas is described below.

3.2.1 Climate

The danger of climate change is a global environmental problem. A change in the climate influences the living conditions for and for mankind on earth. The measures required to reduce the emissions of greenhouse gases are large scale and comprehensive for society. As a result of these emissions, man enhances the natural greenhouse effect and can in the long term change the entire climate system. The accumulation comes primarily from fossil fuels, in other words from coal and oil and also from deforestation. Up until the last century and with industrialisation, the levels of carbon dioxide in the atmosphere have increased as a result of human activities.

Carbon dioxide is the most significant anthropogenic gas affecting the climate. Other important greenhouse gases include methane, nitrous oxide, certain stable chlorine and fluorine compounds, primarily HFC, FC and SF6 along with ozone. Ozone is formed secondarily as a result of the reaction of certain other gases which then indirectly contributes to the greenhouse effect. Among these are carbon monoxide and nitrogen oxides which in combination with volatile organic substances (VOC) form ground-level ozone.

Transport makes a considerable contribution to the greenhouse effect and represents around 35 per cent of Swedish emissions of carbon dioxide. It is also primarily carbon dioxide emissions from transport that are increasing and are expected to increase in the future. Emissions of greenhouse gases are an extremely relevant issue when it comes to our choice of transport means.

3.2.2 Health

Air pollutants are very significant in some urban areas primarily as a health risk. Air pollutants can be generally toxic and contribute to allergies and other hypersensitivity. They can also cause cancer or other genetic toxic effects. Road traffic and in some places even wood-fired central heating in homes are the dominant sources of pollution.

The over-representation of certain diseases has long been observed in certain urban areas. A series of factors contribute to this, partly air pollutants and partly the general lifestyle. A city dweller, in addition to this, runs a higher general risk of contracting certain types of disorders than a country dweller. For those who have already been affected by illness and hypersensitivity, the symptoms they suffer can be aggravated by air pollutants. In urban areas air pollutants such as nitrogen dioxide (NOx), sulphur oxides (SOx), ozone (O_3), particles, ethane, propane, benzene, butadiene, polycyclic aromatic hydrocarbon (PAH), formaldehyde and acetaldehyde are common.

Particle problems should be particularly noted. Road traffic is thought to cause at least half of the particle emissions in our urban areas and up to 90 per cent of those occurring at street level. Many countries are now focusing on the small inhalable particles (PM 10, PM 2.5) and which exist in diesel exhaust emissions and studies are underway into both the mechanisms and the effects as well as into formation and methods of measurement.

3.2.3 Noise

Many studies illustrate a link between exposure to noise and negative effects on people. The effects of noise are often indirect and combined in a pattern of interacting factors. Maximum sound levels or sudden changes in the surrounding acoustic environment can activate several physiological systems in humans which lead to changes such as increased heart beat, a rise in blood pressure and other reactions.

Noise masks other acoustic signals, such as speech and causes a degeneration in the understanding of speech for the listener, especially for people suffering any kind of hearing impairment. Other harmful effects of noise exposure include sleep quality, sleep disturbance and problems with waking up as well as problems in falling asleep.

The degree of noise from different modes of transport differs. The frequency of the noise, the location of the source and variations in the level of noise all affect the experience of it. Sensitivity to disturbance varies considerably from person to person. Disturbance depends on the sound level at the time and the number of noise events, their duration, the time and the situation of the individual when exposed to noise.

3.2.4 Acidification

Acidification of land and water is considerable in Sweden, partly due to the land and bedrock being very sensitive to acidification in extensive areas. The burning of fossil fuels is responsible for generating the greatest amount of acidifying agents. Natural biological processes contribute but measures within agriculture and forestry also play a part. The nitrogen compounds emitted into air also contribute to problems of nitrogen-saturated soil and the eutrophication of the seas. The extent of acidification is partly due to the extent of acidifying agents in fall-out and partly to the resistance to acidification of land and water.

Acidification is mainly caused by emissions of nitrogen oxides (NOx) and sulphur dioxides (SO_2) that cause the fall-out of acidifying agents. A considerable amount of emissions, mainly of nitrogen oxides, can be traced to transport. The source of emissions for the fall-out in Sweden is primarily from other countries (around 80 per cent) but transport is also an extensive source of emissions.

Acidification leads to tangible changes in the conditions of life for plants, micro-flora and animals. Soil acidification has affected large areas in Sweden and around a fifth of the forest areas are at risk of being extensively damaged. An equally large proportion of the country's lakes and watercourses are also damaged. In some areas, acidification has penetrated to a depth of several metres and affected the ground water. Acidification causes the soil's resources of nutrients to decrease and certain toxic metals are released while the biological availability of certain other agents, such as selenium, is impaired.

Acidified air pollutants also accelerate the degradation of many materials. Significant impact from acidified air pollutants has been confirmed with regard to many of our valuable buildings, especially cultural monuments such as older sandstone and limestone buildings. Other cultural monuments such as rune stones and rock carvings also display evidence of serious damage as a result of acidifying air pollutants.

3.2.5 Land use

The stability of the ecosystem and the variation of all living things is known as biological diversity and is extremely important for sustainable life. Biological diversity is not and has never been static. Species and ecosystems undergo continual, slow development. New species are formed and others become extinct. Plants may be completely dependent on a biotope having a hydrological link to a water-conveying feature of the landscape.

The land and water taken over by the transport sector, along with natural areas and natural resources, has both a direct and/or an indirect impact. Fragmentation and barrier problems arise as do problems for forestry and agricultural production. The road or railway itself with the traffic, operations and maintenance constitutes a continuous environmental impact on the landscape. The force of this environmental impact depends on the design of the infrastructure facility, the type of traffic, where the facility is located in the landscape and other issues.

Fragmentation effects depend mainly on how efficient a barrier is and how large the integral land area is. The area of arable land or forest is not only reduced by the road or railway itself, but also by the disturbance zones that are created on either side. The reason may be air pollutants and noise or the result of land becoming difficult to use due to poorer accessibility, field format or the structure of a property.

The environmental impact of the transport sector on parks and smaller open spaces in the proximity of housing caused by air emissions, noise and barrier effects is of considerable significance for recreation close to home for many people. Access to open spaces for recreation such as small areas of forest and larger interconnected natural areas are valuable features for inhabitants in large cities, smaller towns and rural areas.

3.2.6 Ozone damage

Emissions of nitrogen oxides (NOx) and volatile organic substances (VOC) , primarily certain types of hydrocarbons, interact under the influence of sunlight to create ozone and other oxidants in the air. Photochemical oxidants occur periodically at high levels known as episodes, over certain parts of the country. Episodes are large-scale phenomena caused by emissions over substantial geographical areas. In Sweden episodes occur when polluted air masses are transported here mainly from the European continent. High levels of ground-level ozone damage plants and material as well as impact on human health. In order to prevent the levels of photochemical oxidants from threatening human health, from reducing the life of technical material or inhibiting crop harvests, including forest, emissions of ozone-forming substances, that is nitrogen oxides and volatile organic substances, have to be radically reduced.

Transport is the greatest source of both nitrogen oxides and volatile organic substances. Photochemical oxidants irritate the respiratory tracts and the mucus membrane of the eyes. We suspect that ozone (O_3) and other oxidants can play a part in the development of cancer. The distinction between naturally occurring levels of oxidants and the levels where effects are damaging is small. The influence of ozone on health is dealt with in the project and presented under the heading "Health".

Ozone absorbs the radiation of heat and therefore contributes to the greenhouse effect. Ozone can also help to degrade organic material such as paint and plastic products. Photochemical oxidants cause extensive problems with smog in some countries especially during the summer months.

3.3 Life cycle analyses in the comparison project

Life cycle analyses are described in chapter 1.4 along with the implications of LCA and LCI. Extensive development is needed to promote broader use of life cycle assessments. This includes the production of relevant data, evaluation models and so forth. At the evaluation stage, different environmental effects are compared with each other.

We have seen that it is very difficult to obtain relevant data for several environmental parameters as a basis for LCA or LCI and in some cases even relevant units, or means of measuring. The inclusion of data in a model which is not based on sound factual foundations is hardly worthwhile. It is therefore important to establish an appropriate demarcation of LCA issues.

In principle, a life cycle perspective has been employed in this comparison project. A simpler inventory and analysis can identify where in the life cycle the greatest environmental problems arise. With this tool, we can prioritise investments in measures which will be of most benefit. In this project, both electricity and vehicle fuels are described in a life cycle perspective. The confines of the system have been set to include the *extraction* and *production* of fuels, *production* of electricity at a power station and *transportation* and *consumption* of vehicle fuel. The distribution of electricity throughout the grid has not been included nor have any distribution losses. The functional unit is 1 MJ electricity from the power station and 1 MJ of consumed vehicle fuel.

Each type of fuel is represented in the method by the fuel that best describes the production and distribution relevant in Sweden at the present time. The data material for the fuels includes the production and consumption of the fuel including transportation of raw materials and distribution of the finished product. This does not include the environmental impact of the production of machinery, facilities and infrastructure, nor the environmental impact on land or water but only in relation to air.[4]

The vehicle fuels included are petrol, MTBE/ metyl-tertiery-butyletes) - petrol, diesel, LP gas/motor gas (LPG), natural gas (CNG), ethanol from sulphite lye, corn and wine, E5 (5 per cent ethanol, 95 per cent petrol), E85 (85 per cent ethanol, 15 per cent petrol), RME (rape methyl ether#), DME (dimethyl ether) from natural gas, salix and biopulp, biogas and methanol from salix, wood waste and natural gas.

The electricity issue is complicated especially concerning the production structure of different sources which vary during a 24-hour period as well as seasonally. Environmental impact from electricity production depends on the method of production. The electricity production system is constructed to incorporate a large number of production units with different technologies. The environmental effects vary with the method of production such as, for example, hydropower, nuclear power, wind power or power station production as a result of the burning of oil, biofuels etc.

In this project, the aim has been to present data for all the currently known sources of electricity production methods. Certain general combined methods of electricity production have been examined such as the Swedish and Nordic mix, in other words, the average Swedish or Nordic electricity production with marginal electricity which exists as an alternative option. It is therefore possible for the user to select the alternative known as "contract-electricity" referring to the sales mix that a particular power company offers and for which an agreement has been signed. This way of counting, which can be of relevance for tackling certain problems, has become possible partly due to the deregulation of the electricity market.

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[4] Blinge, 1997

The methods of electricity production included are solar cells, hydropower, nuclear power, power stations burning oil, natural gas and LP gas, power heating from fuels such as oil, coal, natural gas, peat, waste, salix and forest fuel, condensing power from oil, and electricity from gas turbines powered by oil, natural gas and LP gas. Electricity production was studied from the production of the fuel and the construction of the power station, via the operation of the power station to the processing of waste products from used fuel and the demolition of the power station.

The model also considers the consumption of resources and air emissions resulting from the production of the electricity used in the life cycle, as for the energy conversion and emissions in the production of oil to various manufacturing processes and transportation, the construction of power stations including the manufacturing of material used in large quantities. The consumption of resources and emissions in connection with operating the power station are included, the known quantities of chemicals and occasionally even the resource consumption and emissions in the production of those chemicals.

On the other hand the production of certain other chemicals is not included, nor is the manufacturing process for the production of generators, turbines, cables etc.[5] Quantity details for land requirements and radiation are mentioned in the data material for electricity production used in the model but not details for noise, aesthetics and biological diversity. Radiation or radioactivity is most relevant in the production of nuclear power but also occurs in the production of other types of electricity or fuel production such as coal mining and the burning of coal. The radiation issue has not been considered in this method.

3.4 System demarcations

All the system demarcations can be divided up in three phases. "Before", or during the production phase, "during" in the operation phase and finally "after" in the destruction phase. The emphasis has therefore been placed on the operation phase for all kinds of vehicle since this phase is assessed to be most relevant for all parameters. Moreover, consideration is also taken of the land areas claimed by the infrastructure. The environmental impact from the production and scrapping of vehicles, ships and others is not included. In purely theoretical terms, the production and/or destruction phases can have a considerable impact but such an analysis has not been conducted. There are life cycle assessments conducted for cars which show that 80-90 per cent of the environmental impact caused by vehicles occurs during the use phase. Consideration has been taken of the environmental impact arising from the operation of vehicles and the refinement of fuels to a finished product, or production and distribution, and for electricity. Electricity consumption for the lighting of roads, the running of petrol stations etc has not been considered due to the limitations on resources for the project.

The method has been limited to include only evaluations and data for passenger transport within the borders

[5] Brännström-Norberg et al, 1996

of Sweden. The method needs to be extended to include transport abroad since many large purchasers and sellers of transportation services are active on the international market. Since evaluations of the relative significance of environmental factors and the individual parameters for effect contributions are distinct in different countries however, the method is currently only intended for transport within Sweden. In the light of this, it would be beneficial to have harmonised standards for measurements and material for the statistical calculation of emissions, for example, within the EU.

4 General description of the method

The method we devised is based on environmental factors broken down into successive sub-levels (Fig. 4). Base parameters were selected for the numerically highest level. These are not changed by the user. Performance functions were then formed for these parameters (Chapter 4.2.1). At each level weighting values were introduced that establish the internal significance of the parameters (see chapter 4.2.2). The performance functions and weighting values should not be changed by the user. The model requires a certain amount of input data (Chapter 4.3) such as emission factors, the number of modes of transport for a certain case and so on. This is entered by the user. If the input data is not available, a default value can be accessed. Value functions are constructed on the basis of the elements mentioned (Chapter 4.4). The construction principle can be seen in the figure below.

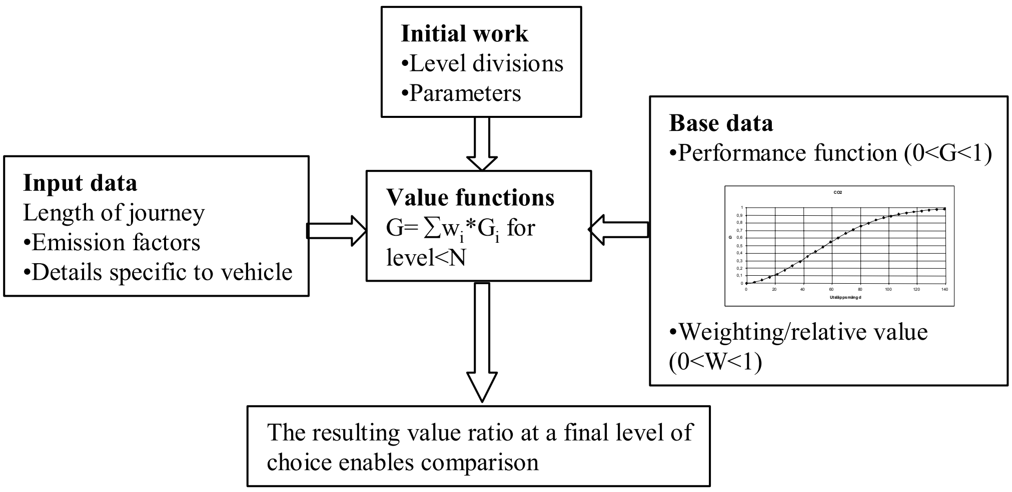

Figure 3: Principles of how the method is constructed

4.1 Initial work

The first stage in the work is the division into levels (Chapter 4.1.1) and parameters (Chapter 4.1.2).

4.1.1 Level divisions

The level divisions are illustrated in Figure 4. As an example we can see that "Health effects of air pollution" (level 1) is broken down into urban and rural areas (level 2), cancer and respiratory problems (level 3) and finally a number of parameters (level 4). The number of levels used for each general category (level 1) depends on how many sub-divisions are required.

4.1.2 Parameters

The parameters selected at the numerically highest level have been assessed to be the most relevant in terms of environmental factors. Hence, for the environmental factor "damage caused by acidification/eutrophication", the parameters SOx and NOx have been selected.

4.2 Base data

By base data we mean the data not to be changed by the user. This presents a condition for the model and consists both of the data that defines the performance functions (4.2.1) and the weighting/evaluation data that describes the internal significance of each environmental factor (4.2.2).

4.2.1 Performance functions

At the highest and most detailed numerical level what are known as performance functions (G) are created, see Figure 4, levels 3 and 4. Performance functions have the task of describing the environmental performance of the various parameters in a uniform system for each parameter. The higher the performance value, the worse the result, or the greater the environmental impact, of the parameters' environmental performance for noise, health or land use, for example. The function should be given a norm so that the value lies between 0 and 1.

The form of the performance functions was the subject of discussion during the process of devising the model. If a lineal form is chosen for the performance function, all the emission changes are valued equally throughout the interval. The disadvantage here is that problems may arise when handling the peripheral values. If an S-shaped function is chosen, on the other hand, such as a hyperbolic tangent, the peripheral values can be dealt with easily. Other effects can be obtained along with varying derivative values which means that the value result for one and the same emission reduction, for instance, will not be the same size throughout the emission interval. The control group has reached a compromise and decided to form the performance curves in the shape of a hyperbolic tangent function, G(x)=tanh(a*Xb). For X=0, the function G=0 provides the best performance value.

The curves have been produced as a result of a low emission per person/kilometre and tonne/kilometre being assigned the G value 0.05, with a high value of 0.95. The low emission has been set at 10 per cent of the high one. In this way, it was possible to establish the curve's equations in a transparent way.

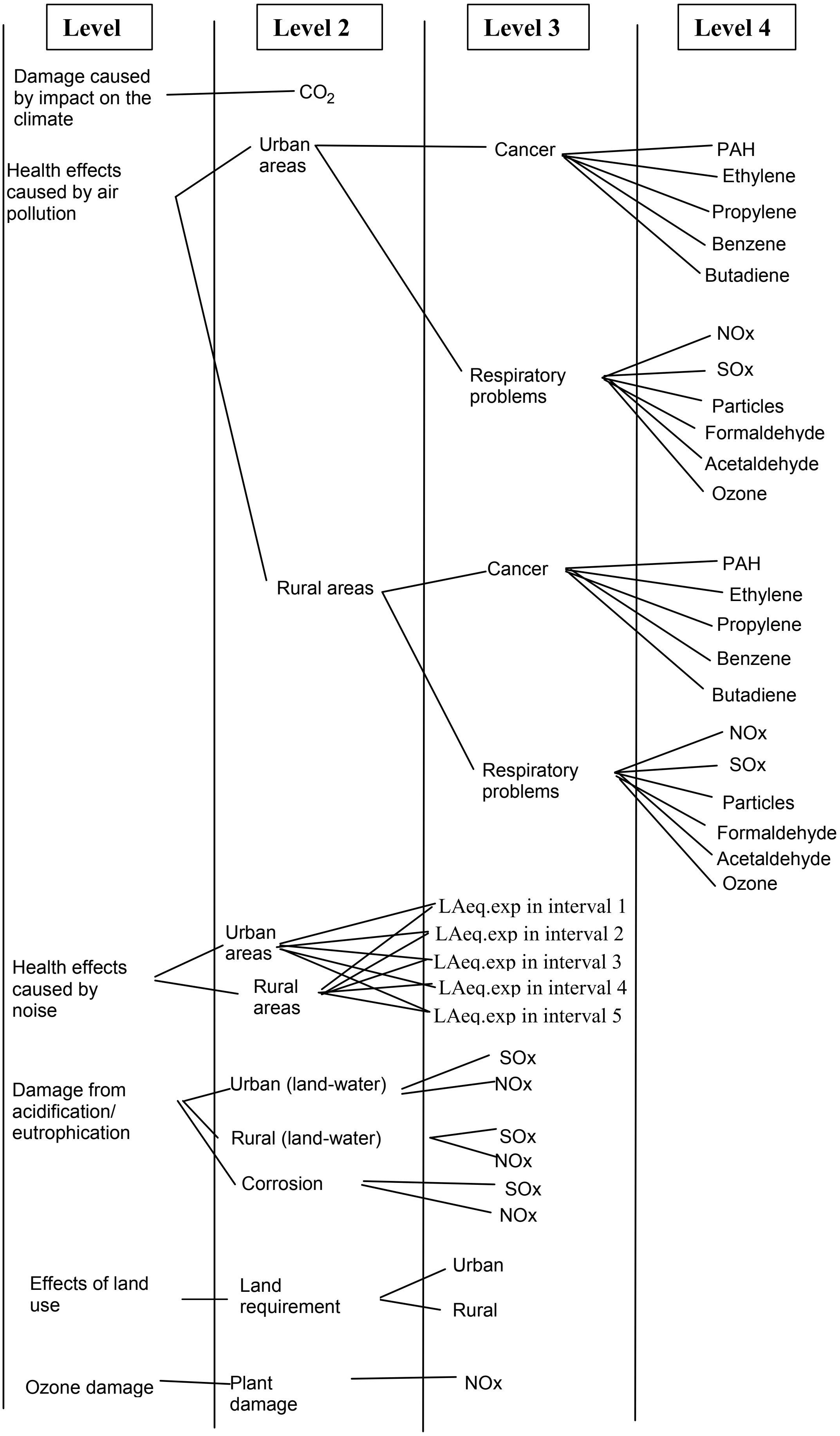

Figure 4**: Level divisions**

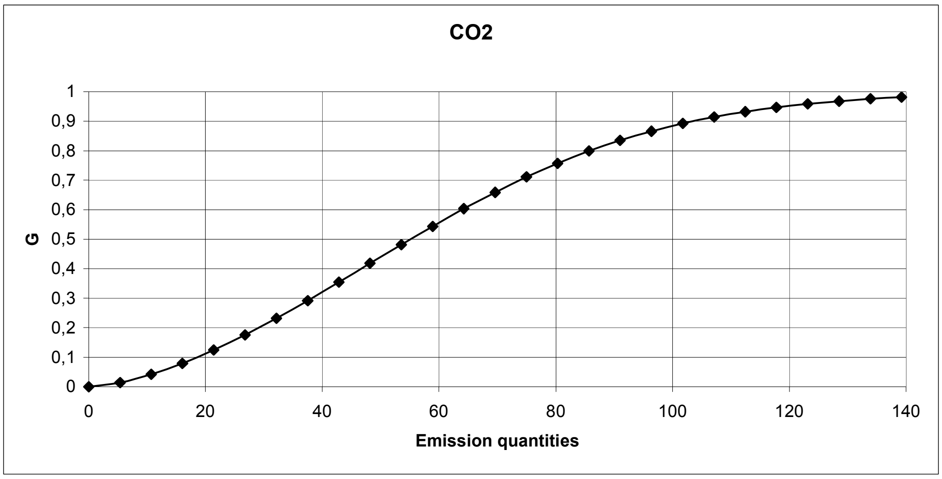

Figure 5: Example of results from the performance curve

4.2.2 Weighting/relative evaluation

The internal significance of the parameters is decided by establishing a weighting factor (w). The weighting factor should lie between 0 and 1 and the total of these factors within each level referring to the closest lower parameter should be 1.0.

The weighting of the relative significance of the various parameters is conducted at all levels and for all environmental factors. The weighting ($0<w<1$) in the highest and most detailed level within each environmental factor category tends to be more scientifically based than the weighting at lower levels. The lower the level, the more 'subjective' the appraisal. The point of departure for the weighting was the risk of suffering from some adverse effect such as cancer or respiratory problems on the basis of the activity of each substance. Weighting is represented by w.

The method provides the conditions for calculating a single final value for a mode of transport or transport mix. Meanwhile, it can be a sensitive issue to establish weighting factors to evaluate the significance of different environmental effects against each other at this general level. In this project, we decided not to set such weighting factors at level 1.

4.3 Input data

The model demands certain input data concerning the percentage of transport on the various modes of transport, the length of the journey/transportation, the number of urban areas and emission factors as well as determinants affecting the emission factors. Practical information for input data and how this should be handled can be found in a brief guide to the model (Appendix 4). The model takes both operational impact as well as the production and distribution of fuel into account.

4.3.1 Length of journey and urban area

The model requires a mix of input data between different modes of transport relevant to the transportation of passengers or goods. This is done by entering the length of the journey by various means of transport. In order to make a comparison of the environmental load, the length of the journey itself is not used, just the relationship between them. Distance details are used to calculate the specific total emissions information which the model does as an addition. The model in its current form cannot incorporate several vehicles of the same type, such as two lorries, in the same chain. A number of the effects at level 1 have been broken down at level 2 into urban area and rural area. In some cases an alternative distance can be longer than the comparative instance. The relation between them is entered as input data.

4.3.2 Details specific to certain vehicles

For road traffic, we need information about fuel consumption, the number of passengers or amount of goods using the vehicle and the vehicle's load capacity. For electric trains, we need information about the electricity requirement in MJ/km and per tonne/km and for passenger transport we need the number of people travelling on the train. For shipping, data is entered concerning the energy requirement in MJ/tonne/km. Shipping is not currently included in passenger transport, and air transport is not included in goods transport. This should not be interpreted as an indication that these modes of transport are not relevant in each case but rather that the time allowed for the project did not permit inclusion.

4.3.3 Emission factors

Emission factors in g/pkm and g/tonne km are mainly entered by the user. There is access to a default value, however, that can be used if data for a particular emission factor is unavailable. In order to account for production and operation data, you need information about the choice of fuel for road transport. Calculations for electric trains require the user to enter the way in which the electricity energy was produced.

4.4 Value functions and the resulting value ratios

The value functions at all levels lower than the highest level are formed as $\sum w_i*G_i$. At the lowest level, level 0, the total of the products forms a single resulting value ratio. This could provide a direct possibility to compare the different transport cases (see 4.2.2).

5 Detailed description of the model

A detailed description of the different parts of the method is presented below. The description has been divided into the following environmental factors corresponding to the divisions in the method at level 1 and which have also been selected for the final level. For visual aid in interpreting the text, please see figure 4.

- Damage caused by impact on the climate
- Health effects caused by air pollution
- Health effects caused by noise
- Damage by acidification/eutrophication
- Effects of land use
- Ozone damage

Passenger transport is relatively small in international shipping terms. In the same way, goods transport is also relatively modest in air traffic terms which in combination with limited project time, explains why these modes of transport were not included at this developmental stage of the method.

5.1 Damage caused by impact on the climate

Carbon dioxide is the most relevant gas to observe in relation to impact on the climate caused by transport. In the method we dealt only with carbon dioxide (level 2) under "damage caused by impact on the climate". Since this environmental factor only involved one parameter the weighting at level 2 was equal to 1.

The maximum value for performance function is 119g/pkm (passenger car 1.7 passengers) and 180g/tonnekm (14-tonne lorry with a weight filling ratio of 50 per cent). See Appendix 3 for a graph illustrating the performance function.

5.2 Health effects of air pollutants

Health effects caused by air pollutants are the most complicated environmental factor dealt with in the model. As we can see in Figure 4, the factor at level 2 has been divided into urban and rural areas, at level 3 into cancer and respiratory problems and at level 4 into base parameters.

- **Cancer**

- PAH
- Ethylene
- Propylene
- Benzene
- Butadiene

- **Respiratory problems**

- NOx
- SOx
- Particles
- Formaldehyde
- Acetaldehyde
- Ozone

Table 2: Base parameters for health effects

The working group has considered level 4 of the environmental factor "Health effects caused by air pollution" especially carefully. The point of departure was the risk for the population of contracting cancer or respiratory problems on the basis of the activity of each substance. To avoid distortions, consideration was taken of the quantities of emissions before the weighting (w) was established. In this case, only the emissions from road transport were selected, for the sake of simplicity, since these are predominant. The following applies for cancer:

	Relative risk factor (a)	Road transport's total emissions (thousand tonnes) (b)	Product (a*b)	Weighting (w) $\sum w=1$
PAH	300	0.021	6.186	0.251
Ethylene	0.9	7.153	6.438	0.261
Propylene	0.2	3.172	0.634	0.026
Benzene	0.8	6.762	5.410	0.219
Butadiene	9	0.669	6.0167	0.244

Table 3: Risk of cancer - weighting[6]

If we do not take the quantity of emissions into account, PAH would be predominant to the extent that other emissions, which may be of a quantity to cause a health risk, would not appear significant. This method, on the other hand, requires that the weighting is reviewed regularly since the nature of road transport emissions is constantly changing. A similar approach has been applied to the risk of contracting respiratory problems and produced the following result:

[5] Environmental health committee report (SOU 1996:124) concerning risk factors. SEPA calculations regarding road transport emissions.

	Relative risk factor (a)	Road transport's total emissions (thousand tonnes) (b)	Product (a*b)	Weighting (w) ∑w=1
NOx	0.075	0128.16	9.61	0.76
SOx	0.037	1.21	0.045	0.004
Particles	0.037	4.28	0.16	0.012
Formaldehyde	0.75	1.62	1.21	0.096
Acetaldehyde	0.01	0.70	0.007	0.0006
Ozone	0.093	18	1.67	0.13

Table 4: Respiratory problems - weighting[7]

At level 3, a weighting has been applied between cancer and respiratory problems. It should be pointed out that respiratory problems are not only related to comfort criteria but also to serious effects on health requiring hospitalisation and causing actual deaths, primarily in people suffering from cardio-vascular disease. The degree of seriousness of cancer and respiratory problems has been assessed to be equal and has therefore been given the same weighting since the number of deaths and hospitalisations for the two effects are of the same magnitude.[7]

At level 2, urban and rural areas are weighted according to Statistics Sweden's definition of an urban area. This weighting is based on the number of people living in the urban areas and in the rural area and has therefore been set at 0.84 and 0.16 respectively.

The following maximum values have been used for performance functions which according to the general description above have been established for the numerically highest level. These maximum values are not, however, equal to the absolutely highest emission level from a certain mode of transport but are rather set to obtain a spread when it comes to normal values.

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[6] Literature references: Environmental health committee report (SOU 1996:124) concerning risk factors based on short term values. SEPA calculations regarding road transport emissions.

[7] Literature references: Environmental health committee report (SOU 1996:124), Particles in ambient air - health risk assessment, Göran Pershagen et al, to be published shortly.

	Passenger transport[8] (g/pkm)	Goods transport[9] (g/tonnekm)
PAH	0.000005	0.000005
Ethylene	0.017140	0.002013
Propylene	0.012310	0.000905
Benzene	0.013060	0.003619
Butadiene	0.006004	0.001809
NOx	0.102100	1.723317
SOx	0.045530	0.064681
Particles	0.006755	0.047493
Formaldehyde	0.001801	0.003392
Acetaldehyde	0.000450	0.003392
Ozone	0.18843	1.29884

Table 5: Maximum values

Ozone formation has been dealt with in a special way. The reason for this is that the city environment is HC-dimensioned for O_3 production and the countryside is NOx-dimensioned for O_3 production. Furthermore, it is assumed that for each gram of HC produced in the use of petrol-driven passenger cars, a maximum of 2.657g of O_3 is formed. The equivalent for a heavy diesel lorry is 2.063.

The model takes account of the amount of road traffic in urban areas during the time ozone is formed. For aircraft and trains, the transport/energy production is considered to be associated to rural areas to such an extent that NOx are considered to be dimensioned for O_3 production. For constructing the performance curve for ozone formation for passenger transport, a passenger car with 1.7 passengers has been selected travelling 50 per cent in urban areas and 50 per cent in rural areas which gives us 0.18843 g/pkm. For goods transport, a lorry was selected with a load capacity of 14 tonnes, fuel consumption of 0.45 1/km, weight filling ratio of 50 per cent, travelling 30 per cent in urban areas and 70 per cent in rural areas, which gives us 1.29884 g/pkm. See Appendix 3 for the graph of performance functions.

5.3 Health effects caused by noise

Exposure to noise has been handled in the model in a slightly different way than air emissions. The reason for this is that the model has to be adapted for the data currently available.

The point of departure has been passenger transport activity for the respective modes of transport. Data has been obtained from the joint environmental report of the transport authorities from 1998. The numbers exposed in the various intervals were obtained from the Working Group for Socio-economic Calculations (ASEK). Here a distinction was

[8] Passenger car 1.7 passengers

[9] 14 tonne lorry with a weighting output ratio 50 per cent.

made between the number of people associated with passenger transport and with goods transport. The National Road Administration figures revealed that half of those exposed are associated with passenger transport and the National Rail Administration figures puts the equivalent figure for rail transport at 26 per cent. We have assumed that goods transport for air traffic is negligible and that therefore the entire exposure situation is linked to passenger transport. The following details were obtained for passenger transport.

	Transport activity (million pkm)	Exposed interval 50-55 53	Exposed interval 56-60 58	Exposed interval 61-65 63	Exposed interval 66-70 68	Exposed interval 71-73
Road	100,000	734,000	420,000	202,500	135,500	32,500
Rail	10,200[10]	108,640	62,400	32,760	12,220	3,380
Air	8,600	113,000	64,600	31,800	2,600	700

Table 6: Noise exposure for passenger transport

In order to create performance functions, the number of people exposed at the different exposure intervals has been related to passenger transport activities and the following performance data was obtained for 100 per cent of each mode of transport respectively.

	Interval 50-55 53	Interval 56-60 58	Interval 61-65 63	Interval 66-70 68	Interval 71-73
Road	0.6344	0.6286	0.6126	0.9488	0.9454
Rail	0.8717	0.9503	0.8990	0.90553	0.9510
Air	0.9528	0.9503	0.9497	0.1726	0.2023

Table 7: Noise exposure for passenger transport, performance

Some reports claim that exposure to noise from trains does not have the same disturbance potential as other types of traffic noise. Some information indicates that rail transport should have a 'bonus' of 5 dBA. Such a bonus has not been included in this stage of the model's development. It would be quite simple, however, to introduce this element into the exposure table above by moving the numbers exposed for rail down one step. For the interval 50-55, the exposure situation would therefore be 62,400. Time did not permit this type of sensitivity analysis.

[10] Including the Metro, commuter trains, local trains and trams in Stockholm, Gothenburg and Malmö.

Noise exposure has also been related to the quantity of transport operating in urban areas. This has been done by multiplying the details about the quantity of transport in urban areas for each mode of transport, in combination or individually, by the numbers exposed within the noise interval divided by transport activity. The result has then been entered in the performance function and a performance value has been obtained for each noise interval. Noise exposure does not account for the number of passengers in the respective mode of transport or the amount of goods in this version of the model. The equivalent value for goods transportation is as follows:

	Transport work (million tonne km)	Interval 50-55 53	Interval 56-60 58	Interval 61-65 63	Interval 66-70 68	Interval 71-73
Road	32,675	734,000	420,000	202,500	135.500	32,500
Rail	19,019	310,060	177,600	93,240	34,780	9,620
Air	-	-	-	-	-	-

Table 8: Noise exposure for goods transport

Performance functions:

	Interval 50-55 53	Interval 56-60 58	Interval 61-65 63	Interval 66-70 68	Interval 71-73
Road	0.9494	0.9488	0.9497	0.9503	0.9483
Rail	0.8026	0.8020	0.8540	0.4700	0.5584
Air	-	-	-	-	-

Table 9: Noise exposure for goods transport, performance

Interval medium dB	Schultz, Highly annoyed %	Standardised weighting
53	2	0.02871
58	5	0.071429
63	10	0.142857
68	20	0.285714
73	33	0.471429

Table 10: Weighting

The weighting used at level 3 can be seen in the table above.[11] At level 2 (Figure 4), the same weighting is used as under "Health effects caused by air pollutants", in other words, the number of people in percentage terms living in urban or in rural areas.

No data was available for exposure to noise from shipping.

5.4 Damage from acidification/eutrophication

Damage caused by acidification/eutrophication has been divided up at level 3 into SOx and NOx emissions. An evaluation was conducted of the risks deriving from acidification and the risk factors have been standardised in the same way as for the risk of contracting cancer and respiratory problems. The standardisation for level 3 led to the following weighting values.

	Relative risk factor (a)	Road transport - total emissions (thousand tonnes) (b)	Product (a*b)	Weighting (w) $\sum w=1$
SOx	1	1.21	1.21	0.013
NOx	0.7	128.16	89.71	0.987

Table 11: Weighting for acidification/eutrohpication[12]

At level 2, urban/rural/corrosion factors have been weighted as 0.1/0.7/0.2. The weighting should be seen as an alignment. A guiding factor has been that rural areas are more sensitive to acidification than cities.

See "Health effects caused by air pollutants" for the performance curve (Chapter 5.2)

5.5 Effects of land use

Considerable effort was put into defining land use and its content in the project. A special consultant assignment was also conducted. The working group recommended a link to the work the government commissioned the National Road Administration to do on the subject of "Objectives, measurements and the monitoring of natural and cultural values in the transport system". At a relatively late stage, it transpired that this commission would not be completed within the time frame for our project. In order to

[11] Fidell, Barber & Schultz

[12] Nordic Manual for Life Cycle Analysis, Draft 2 (1994), Table 17.

gain some relation to the specific land use factors for the different modes of transport, it was natural to link environmental factors to land use. Table 12 presents the surface areas associated with the respective modes of transport.

	Land requirement (hectares)	Transport activity (million pkm)	Surface/transport activity/ passenger	Transport activity (million tonnes km)	Surface/transport activity/goods
Road	270,000	100,000	2.70	32.675	8.26
Rail	37,000	10,200[13]	3.62	19,019	1.95
Air	7,675	8,600	0.89	-	-

Table 12: Land use[14]

A performance function has been devised in the form of a hyperbolic tangent, using the values in the table above as a starting-point.

Once again, consideration has been taken of the quantity of transport in urban areas in the same way as in "Health effects caused by noise", for example. In practice, this means that transport in urban areas is valued at 0.84 while transport in rural areas is valued at 0.16. The number of passengers or amount of goods was not included.

5.6 Ozone damage

Under the heading "Damage caused by ground level ozone", we claim that ozone damage can be related to the total emissions of NOx, since NOx is assumed to be dimensioned for ozone production in rural areas.

"Damage caused by ground level ozone" has not been related to any other parameter and has therefore been given a weighting of 1 for NOx at level 3. During the course of the work, we discussed the feasibility of including damage to material under "Ozone damage". This attempt was abandoned at this stage of developments, however. This also explains why NOx is at level 3. See the section on "Health effects of air pollutants" for the performance curve (Chapter 5.2).

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[13] Including the Metro, commuter trains, local trains and trams in Stockholm, Gothenburg and Malmö.

[14] Statistics Sweden, Environmental report from the transport authorities.

6 Databases and references

Primarily the user should enter "his/her" input data in the method. To make this easier, there is a series of default values available. Data for "production and distribution" of fuels cannot be influence by the user but is fixed. An account of the data used for passenger and for goods transport can be seen below.

It is important that the database includes full emission factor chains since any empty cell counts as zero emissions and disrupts the comparison.

6.1 Passenger transport

The database includes data for several different types of fuel for passenger cars. The emissions factors are expressed in terms of g/MJ fuel. Petrol and diesel are included under fossil fuels. The renewable alternatives are ethanol, methanol and gas as well as combined fuels. Passenger transport by ship has not been included as mentioned earlier. Diesel railcars are included as an option. Air transport is treated separately, see below. It should be noted that the Otto engine can only be powered using an 85 per cent alcohol mix. For some fuels, data was unavailable for the operational phase but is still included with the comment "not available" in the matrix. The reason for their inclusion is that data does exist for the production and distribution phases.

6.1.1 Operation

The default values used can be seen in Appendix 2. Many different sources have been used which can be seen in the footnotes to the tables. The private car is equivalent to a environmental class 1 car.

The emissions generated from a journey by air consist of an LTO-component[15] and a component of the journey which is not included in the LTO cycle.[16] The LTO cycle component is large for a short flight and vice versa. It is therefore difficult to stipulate general emission factors. These should be calculated separately for each case using the data from the Swedish Civil Aviation Administration's (LFV) website which can then be used in the model. For example, the following data can be obtained for a flight between Stockholm and Gothenburg and the data included in the model.

[15] Landing and take-off (LTO emissions) generate emissions in the vicinity of the airport, during a flight these are accounted for separately from the total emissions.

[16] The part of the journey not included in the LTO cycle should be referred to as "flight excluding LTO cycle".

Boeing 737-600	
Cabin factor	90%
Max number of passengers	108
Fuel	42 g/pkm
CO_2	132 g/pkm
NOx	0.32 g/pkm
HC	0.07 g/pkm
Fuel consumption	1.6 tonnes

Table 13: Example of emission factors for a flight between Stockholm and Gothenburg

6.1.2 Production and distribution

The emission factors used for production and distribution of fuel are shown in Appendix 2. Data is not currently available for specific hydrocarbons. See the background report "Survey of the data platform for electricity and fuel"[17] for the parts of the LCA included in the factors.

6.2 Goods transport

For road transport, diesel environment class (EC) 1 is included but not petrol which is seldom used. Renewable alternatives are included as for passenger transport. Flight cargo has not been prioritised in this project and the database does not include any appropriate data. Data for diesel trains and shipping is included.

6.2.1 Operation

Once again several different sources have been used. The default values and sources can be seen in Appendix 2.

6.2.2 Production and distribution

The same values are used as for passenger transport.

[17] SEPA 2000

6.3 Electricity production

The model does not include any operational emissions for electricity consumption but concentrates instead on the production and distribution phases. The tables in Appendix 2 show the emission factors included for different types of electricity production. See the background report "Survey of the data platform for electricity and fuel"[18] for the LCA components included in the factors. Losses in the supply grid have not been included due to limited resources but have been calculated by the National Rail Administration to amount to 20 per cent.

[18] SEPA 2000

7 Sensitivity analysis with calculation examples

The sensitivity analysis conducted within the project is based on what impact changes in different variables would have on the result. Changes have been studied:

- in the peripheral conditions for the G-function
- in the dimensioned maximum emission value (Lmax)
- in the dimensioned minimum emission value (Lmin)

The weightings of different parameters included in the model have, in the majority of cases, a sound scientific basis. No analysis has been carried out here into how these affect the result.

This chapter also includes some calculation examples.

7.1 Sensitivity analysis

In the following analyses the carbon dioxide parameter is used as an example.

7.1.1 Peripheral conditions for the G-function

As we saw in chapter 4.2.1, the performance functions have been obtained using a low emission per passenger kilometre and per tonne kilometre where the G value is established as 0.05, and a high value as 0.95. The low emission (Lmin) has been set at 10 per cent of the high one (Lmax). In this way, the curve equations can be established in a transparent way. This can be seen from the dotted line in the figure below. If G=0.1 were selected for the low emission instead, and 0.9 for the high emission the unbroken line would result.

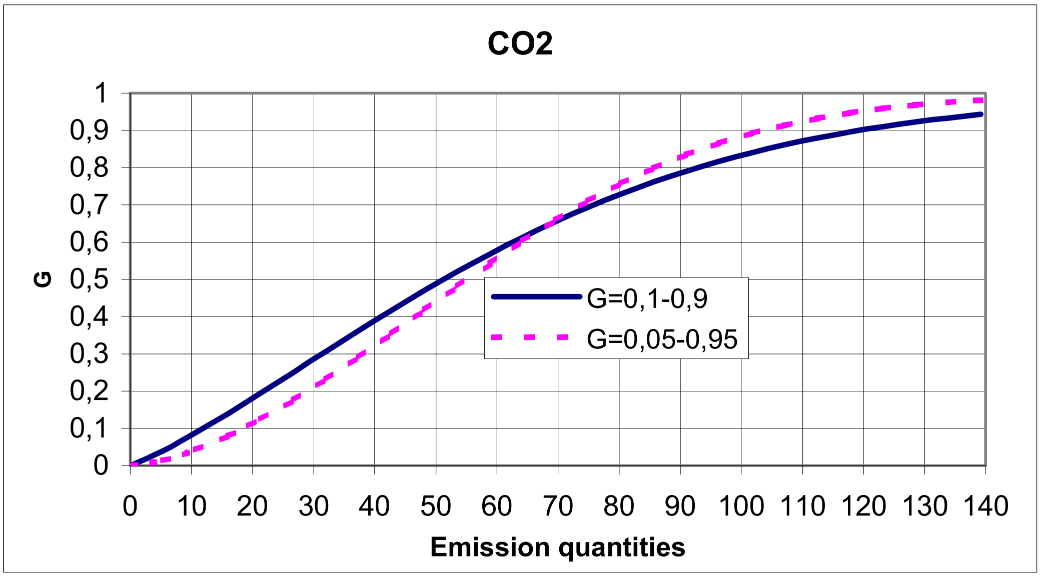


Figure 6: Peripheral conditions for the G function

The dotted curve implies greater variation in value within an area which commonly occurs. The unbroken line is more discriminating for very low emissions. At these emission levels, the environmental performance is so good that there is no need for such radical distinctions. It is obvious that the differences between the two curves is only small. The implications are that the resulting value ratio is only slightly influenced by the choice made.

7.1.2 Dimensioned emission values

Lmin

As mentioned above Lmin has been set at 10 per cent of Lmax. It is also of interest to see how other approaches would affect the result. To illustrate this we have chosen the carbon dioxide parameter. The figure below shows the performance value as a function of different sizes for Lmin - 5, 10 and 20 per cent.

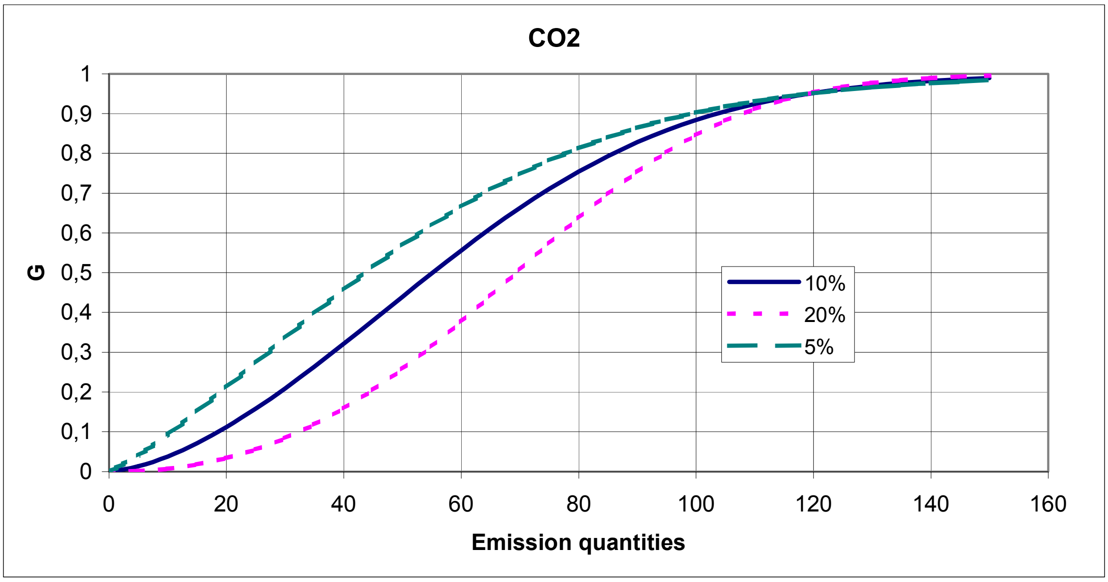


Figure 7: Dimensioned emission values, Lmin

As we can see, the approaches are quite distinct. If 60 g/pkm is selected as the emission, this gives us around 0.67 as the G value at the 5-percent level, 0.55 at the 10-percent level and 0.39 at the 20-percent level. The 5-percent level provides the worst result while the 20-percent level gives us the best result.

The 5-percent level therefore presents a harder assessment while the 20-percent level presents a milder assessment than the 10-percent level. If we study the end values, i.e. the emission quantities in the proximity of 0 g/pkm and of 140 g/pkm, we can see that the highest emissions in principle are equally assessed between the approaches while fairly large differences are indicated in the assessment of small emissions. The difference in the G value in the emission interval 40-100 g/pkm is greatest for the 20-percent level and smallest for the 5-percent level. Considering the result of the end values, the working group chose the 10-percent level.

Lmax

One stage in the definition of the performance function is the selection of the 'correct' Lmax, or the value most equivalent to G=0.95. Choosing a high Lmax results in high emissions giving relatively good performance. The figure below illustrates the results for CO_2.

The base value is equivalent to that chosen for the model and 2* base value is double the base value to test the different results.

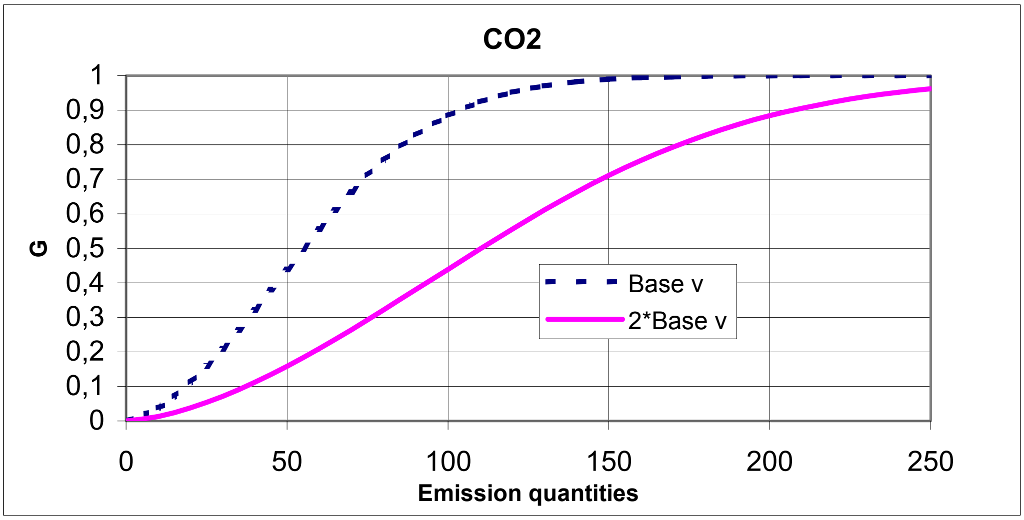


Figure 8: Dimensioned emission values, Lmax

The "Base v" curve is steeper which means that we obtain a greater effect in regular emission intervals. We also have good sensitivity for low emissions. On the other hand, we lose sensitivity for high emissions. For the selected curve, this means that the difference in the G-value between the emission 150 g/pkm and 200 g/pkm is very small. We can say that a car with one person generates around 200 grams of CO_2/pkm and an X2000 with the normal number of passengers and electricity produced in line with the Swedish electricity mix generates around 2 g/pkm.

The effect depending on what maximum value is selected for the performance function can best be seen by presenting some concrete examples. The following values have been tested:

Parameters	Base values	2* base values
CO_2	119	238
NOx	0.1021	0.2042
Particles	0.006755	0.01351
HC	0.1034	0.2068
PAH	4.52E-06	9.04E-06
Ethylene	0.01714	0.03428
Propylene	0.01231	0.002462
Benzene	0.01306	0.02612
Butadiene	0.00E-03	1.20E-02
SOx	0.004553	0.09106
Formaldehyde	0.001801	0.003602
Acetaldehyde	4.50E-04	9.01E-04

Table 14: Alternative base values

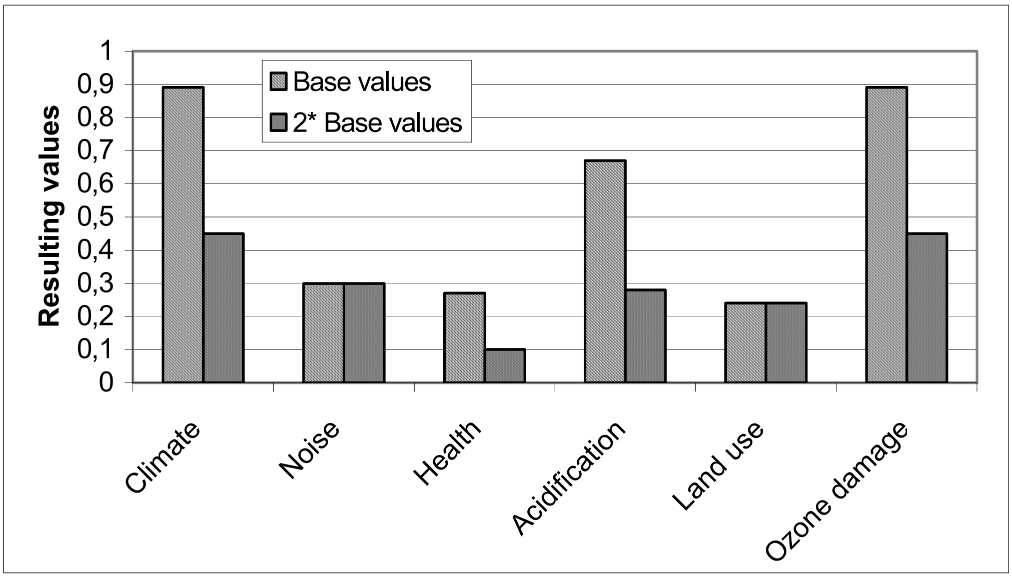


Figure 9: Examples equivalent to a car journey for 2 people

As we can see, the different approaches result in significant differences. Since "Noise" and "Land Use" are dealt with in a special way, they have not been affected. The base value requires lower values to provide better results. This pattern is even clearer if we look at very small and relatively small emissions per person/km.

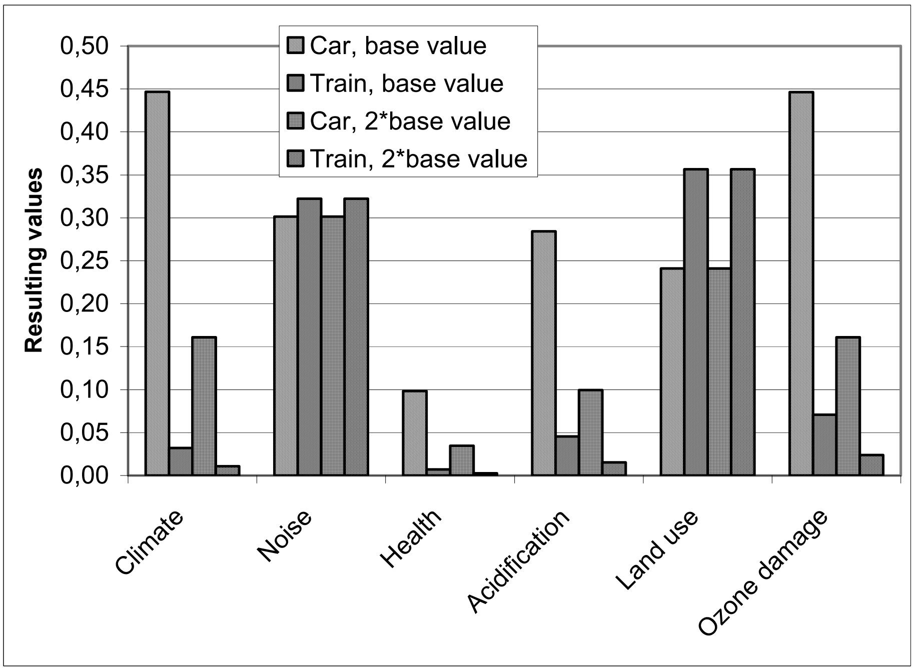


Figure 10: The example illustrates a car journey for 4 people and a train journey with 25 passengers.

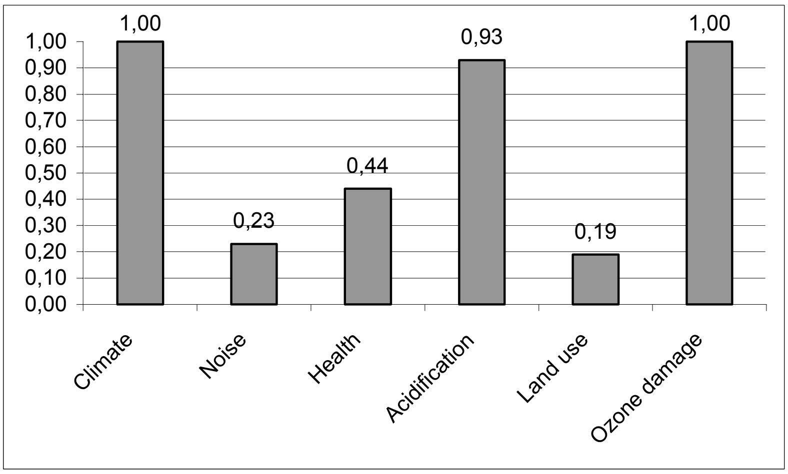
The figure shows a car journey and a train journey. There are 4 people in the car and 25 people on the train. Air emissions from the car are normally higher to much higher per person/km than from the train (operation + production and distribution of fuel). The example 2* base value results in a smaller difference between the two cases than the example using the base value.

7.2 Passenger transport - example

Below we can see a number of examples illustrating the results in the way presented in the model. The conditions are given for each example. The resulting value ratio - the y axis - varies between 0 and 1 where 0 is the best result with the least impact.

7.2.1 Example 1. Stockholm-Gothenburg

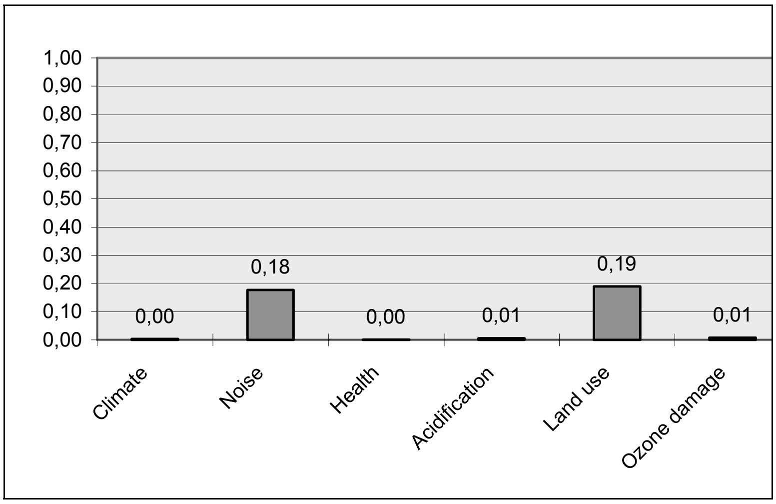
Example A: A car journey with one person in the car and a fuel consumption of 0.079 1/km. The car is equivalent in environmental terms to EC1 - EC2, in other words a good car. The example is also based on 20 per cent of the journey routed through urban areas. To the right of the graph, we can see the emission values associated with the production and distribution of fuel.



	G/pkm
CO_2	202,34981
NOx	0.1735156
Particles	0.0114827
HC	0.1758121
PAH	7.681E-06
Ethylene	0.00291404
Propylene	0.02909239
Benzene	0.0221998
Butadiene	0.0102068
SOx	0.0770613
Formaldehyde	0.003062
Acetaldehyde	0.0007655

Figure 11: Results from Example A

Example B: Train journey, X2000, 10 per cent urban transport, electricity requirement 42.84 MJ/km, Swedish electricity mix, 99 passengers.



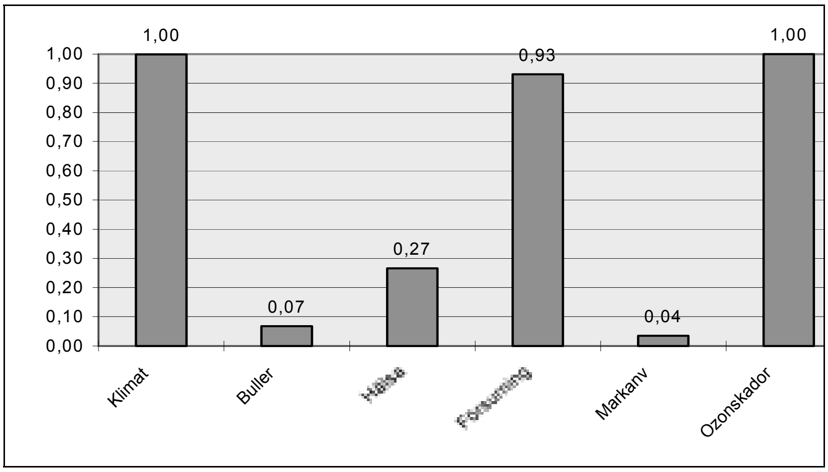
	G/pkm
CO_2	2.27E+00
NOx	3.23E-03
Particles	1.08E-03
HC	2.97E-04
PAH	0.00E+00
Ethylene	0.00E+00
Propylene	0.00E+00
Benzene	0.00E+00
Butadiene	0.00E+00
SOx	3.57E-03
Formaldehyde	0.00E+00
Acetaldehyde	0.00E+00

Figure 12: Results of Example B.

Example C: Below we can see an example of a combination journey by car and plane. The plane is a Boeing 737-600.

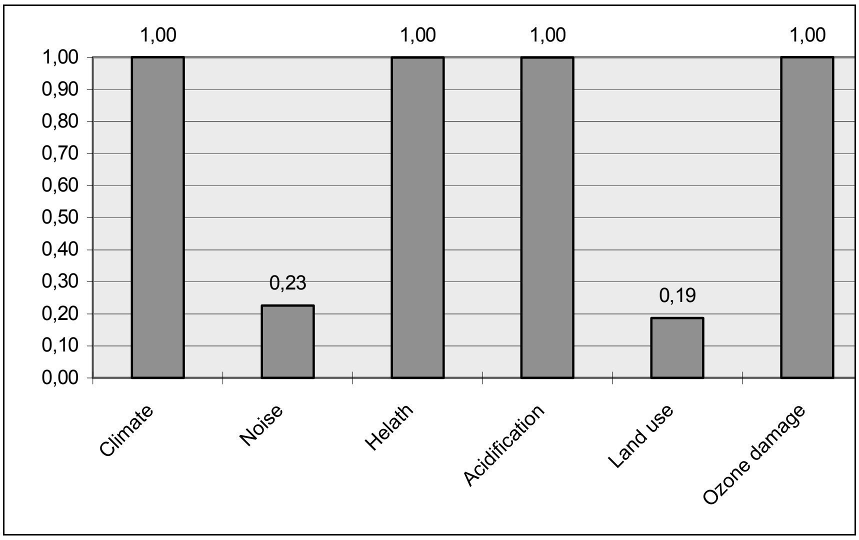
Mode of transport	Length of journey	Per cent	Urban transport	Cabin factor
Plane	393	97.5	5	65%
Car	10	2.5	90	1 person in the car.

Table 15: Conditions for Example C.



	G/pkm
CO_2	1.92E+02
NOx	5.98E-01
Particles	3.20E-02
HC	1.84E-01
PAH	1.20E-05
Ethylene	1.80E-02
Propylene	6.00E-03
Benzene	2.40E-03
Butadiene	2.00E-03
SOx	1.06E-01
Formaldehyde	1.47E-02
Acetaldehyde	4.50E-03

Figure 13: Results of Example C:



	G/pkm
CO_2	2.02E+02
NOx	2.64E+00
Particles	7.14E-02
HC	5.26E+00
PAH	6.63E-04
Ethylene	5.36E-01
Propylene	2.86E-01
Benzene	8.86E-01
Butadiene	1.20E-01
SOx	7.71E-02
Formaldehyde	6.12E-02
Acetaldehyde	4.59E-02

Figure 14: The example is equivalent to a car journey for 2 people, the same as in Example 1 (Figure 9) but with an older car without a catalytic converter.

7.2.2 Example 2. Umeå- Stockholm

Here we can see the results from three different passenger transport alternatives between Umeå and Stockholm. The results are summarised in a graph.

The following conditions apply in the example:

Train:	X2000, 42.84 MJ/km, 99 passengers on board, Swedish electricity mix, 5 per cent urban transport, transport distance 1.66 times the flight alternative.
Car:	Fuel consumption 0.079 1/km, 2 people, EC1-EC 2 car, 20 per cent urban transport, transport distance 1.32 times the flight alternative.
Plane + connections:	Train 20 kilometres and car 5 kilometres, Intercity train, 72.29 MJ/km, 190 passengers, Swedish electricity mix, 20 per cent urban transport, EC 1-EC 2 car, 0.079 1/km, 1 person, 100 per cent urban transport. Plane MD 81, 65 per cent cabin factor, other features according to the Swedish Civil Aviation Administration website, 5 per cent urban transport.

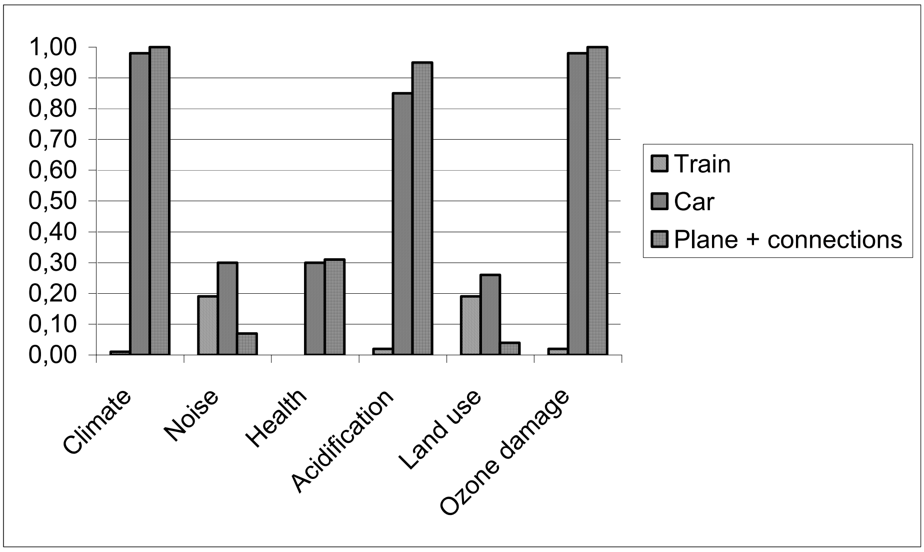


Figure 15: Results of the example Umeå - Stockholm.

7.2.3 Example 3. Urban transport

The number of people in the car is equivalent to the average of (1.7), 100 per cent urban transport. An ethanol mixture of 85 per cent based on sulphite lye.

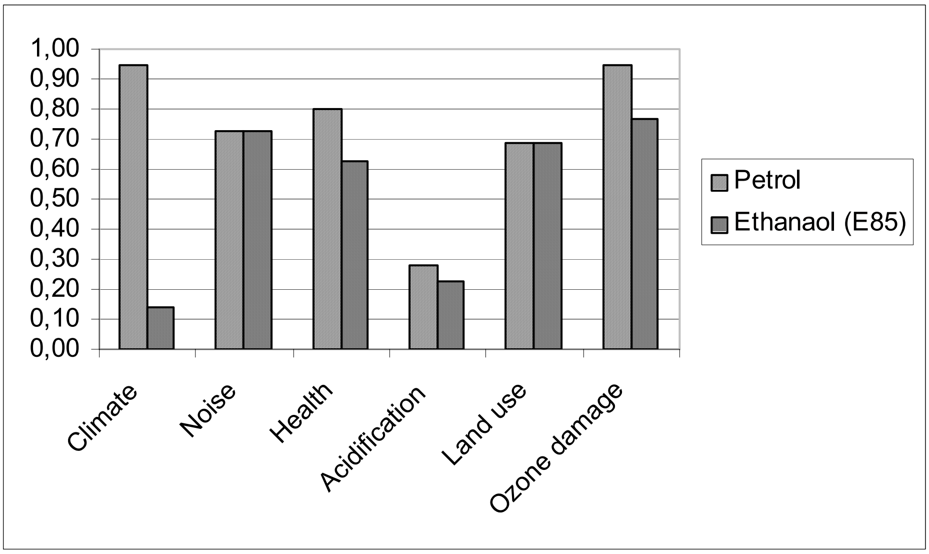


Figure 16: Result of the example Urban Transport

7.3 Goods transport - examples

7.3.1 Example 1. Sundsvall - Gothenburg

The model also allows us to calculate the value ratio for goods transportation. Below we have chosen an example with a 7-tonne transport between Sundsvall and Gothenburg. The following conditions apply for this example:

Lorry: Load capacity 14 tonnes, fuel consumption 0.45 l diesel/km, 10 per cent urban transport, weight filling ratio 50 per cent.

Train: 10 per cent urban transport, electricity requirement 0.15 MJ/tonne km, Nordic energy mix.

Ship: Bulk carrier with an energy requirement of 0.097 MJ/tonne km, 2.08 times the distance of land based transport.

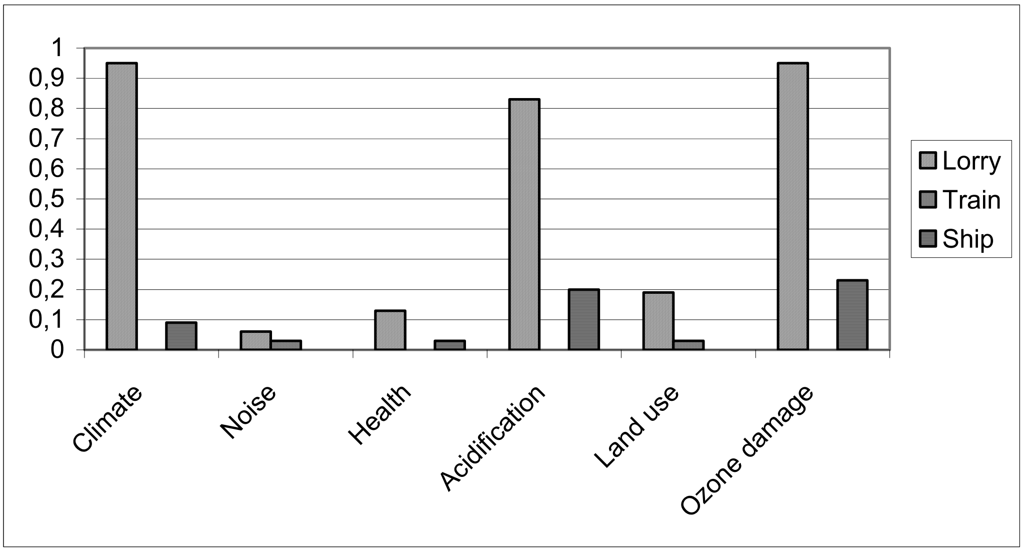


Figure 17: Results of the example Goods Transport

8 Deficiency analysis

Today we have insufficient data for a comprehensive description of environmental impact. One example we can mention of this is the negative impact of CFCs on the ozone layer. Nor have we included all the agents that affect the climate but chose carbon dioxide as the most significant parameter. Other parameters that should be prioritised in future work include noise levels and the number of people disturbed by noise, vibrations, electromagnetic fields and electromagnetic radiation, the fragmentation of the landscape and barrier effects along with many other factors. In the same way, we also have to reach agreement on viable indicators, parameters and so forth, for biological diversity and aesthetic values.

In the method, we have included the production and distribution of energy carriers and the operation of vehicles. We have not, however, included the production nor the destruction of vehicles, ships or facilities such as roads, harbours or airports. This should also be included in subsequent development. One alternative is to estimate the extent of environmental impact excluded by the system demarcations used.

In this chapter we summarise most of the deficiencies and estimate the extent to which they affect the results in use of the method.

8.1 Noise

The situation regarding exposure to noise from the transport sector has improved. Noise exposure in this method refers to the equivalent level in various intervals but vibrations have not been included at all. They should be studied in the future. When interpreting the results this means that the model is not sensitive to the "cabin factor" for noise. Nor is the maximum sound level discussed.

Two different methods for comparing noise between different modes of transport were discussed within the control group. One method is based on "noise emissions” deriving from the source and the second method on an "mean exposure level". Both methods are described in detail in Appendix 6 and a general account is provided below.

8.1.1 “Noise emission” method

The point of departure is a description of the emission data in the form of specific noise levels from respective sources measured from a certain distance. The model is based on maximum levels and is related to the specific source used, also taking into consideration the "cabin factor". A sound output level, which is comparable between sources, is then calculated. The model is constructed on a definition of sound sensitivity for different specified areas. These may be based on population density or feasible measures such as noise barriers. The type of area should be linked to certain weightings related to how sensitive the area is. This may be where most people live, for instance, or it might be a national park where silence is an important factor. Moreover, the results of research into sociological effects of noise could also be considered.

8.1.2 “Mean exposure level” method

The effects of noise, or disturbance, represent the common foundation for comparisons between different modes of transport. Disturbances from the different modes of transport are valued within the same template to be comparable. The implications of "very disturbing" or "socio-economic cost" should indicate the same degree of disturbance or sacrifice. There are evaluated disturbance levels for residential environments used in the planning of the infrastructure. The same degree of noise disturbance is measured with different indices and has different ratios depending on the source. For transport, the 24-hour mean value is used while for rail and air, which have different indices for maximum noise, the maximum noise level is most relevant.

8.2 Emission factors

The user should enter the emission factors relevant for the individual or combined transport solutions studied. It can be difficult at the present time to obtain all the parameters (emission factors) the model includes. This is also reflected in the default values provided in the model. Despite extensive work to devise a complete series of default values, this area still requires further refinement in the future.

8.3 Land use

Continued development of the criteria for use in the field of land and water use is needed. Work should be intensified within the near future. For example by continuing the National Road Administration project on “Objectives, measurements and monitoring of natural and cultural values in the transport system". Values for natural resources should also be incorporated into the model, primarily concerning the extent of forest and agricultural land. In the current situation, this is not included but the values for environmental load on natural resources comprising forest, cultivated land and pastureland should be included.

Only landscape divisions into urban and rural areas are currently being used. It could be very interesting to study other alternative categories which provide information about more aspects of the environmental impact of the transport sector such as the degree of sensitivity to acidification. Interpretation of the results implies only the consideration of town/countryside along with the land requirement of the respective mode of transport related to transport activity that has significance for the result.

8.4 Transport abroad

The method currently only deals with transport activities with departure and destination points within Sweden. The parameters for land, noise and fuel and electricity production are devised for Swedish conditions and cannot be used for other countries. The default values for other parameters are intended for use under Swedish conditions. The user could well introduce specific emission values into the model for their modes of transport to include transport abroad, on condition that the emission values are available of course. The model could then be used for a simplified version.

Extension of the method to include transport abroad would be of value to purchasers on sellers of transport services. It would be in the actors' interests to actively lobby the EU to introduce harmonised standards and routines concerning the measurements or statistics for calculation so that the method could also be used for transport beyond Sweden's borders in the future.

8.5 Energy

Electricity production and distribution from the power station and for vehicle fuel includes extraction, production, distribution and consumption. The type of fuel chosen for use in the model is the fuel assessed to be best described from an LCA perspective as well as the fuel most relevant at the present time in Sweden. The model does not include the environmental impact of production of machinery, plant and infrastructure, nor the environmental impact on land or water but only the environmental impact in terms of air emissions. The functional unit is 1MJ electricity from the power station and 1 MJ consumed fuel.

One difficulty in demarcating electricity consumption is the way in which lighting should be evaluated since it is a significant safety aspect for parking areas and for roads. Nor are the losses in the electricity supply grid taken into account here. With regard to the interpretation of the results, this means that the figures would be slightly worse if the energy supply chain were to be expanded.

9 Discussion on future use and development

This project has devised a method that makes it possible to compare the environmental impact of different modes of transport. A number of parties have been involved in the project. The control group decided in principle to concentrate on the environmental impact generated by transport operations only. Despite not being able to complete the work to develop a method and calculation model within the framework of the project resources, the control group would like to publish the results achieved in their current form. The aim is to stimulate further work. We hope that the method in its current form will inspire those whose job it is to develop this type of tool.

Development of the method is needed within a number of fields. These include work on developing the evaluation of individual parameters and environmental factors such as noise and land use. The method is deficient in certain areas but can, along with other work in the field, provide a good basis for further work on the evaluation of environmental impact in a scientific way. The project control group recommends that the basic ideas, for a non-monetary approach for instance, should be retained.

Better insight is needed and greater interest from the actors concerned is needed if the material on which the method is based is to be refined in the future. Greater investment is also needed from sector authorities in order for greater emphasis to be placed on these issues on a general level as well as attempting to achieve a holistic perspective with regard to the environmental impact of the transport system. Alternative fuels and methods of transport, such as mopeds/electric mopeds, should also be incorporated into the model.

The user interface for the model should be refined for easier use. Different user interfaces could be developed for different users, for example, for model developers, transport purchasers, students and others. A book of regulations and a manual with instructions for use should be formulated to enable the method to be used in such a way as to promote accurate and sound comparisons between different studies. There should also be some kind of quality assurance and scope for supervision of the way in which data is used. The method could act as the basis for a portal for transport infrastructure on the Internet for better distribution.

The method should be compared with other methods and models both nationally and internationally. It is of extra importance that an international comparison is made. The conditions for how the method could be used within the EU could then be examined, such as whether there is any interest from the European Environment Agency in having access to use of and for development of the model at EU level.

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REPORT 5183

Environmental impact from different modes of transport

- Method of comparison

A PREREQUISITE OF LONG-TERM sustainable development is that activities of various kinds are adjusted to what humans and the natural world can tolerate. Transport is an activity that affects humans and the environment to a very great extent and in this project, several actors within the transport sector have together laid the foundation for the development of a comparative method to able to compare the environmental impact at the different stages along the transport chain. The method analyses the effects of different transport concepts on the climate, noise levels, human health, acidification, land use and ozone depletion.

Within the framework of the method, a calculation model has been created in Excel which acts as a basis for the comparisons. The user can choose to download the model from the Swedish EPA's on-line bookstore or order it on a floppy disk. Neither the method nor the model are as yet fully developed but our hope is that they can still be used in their present form as a basis and inspire further efforts and research in the field.

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