REPORT

Methods and Possibilities for Application of Life Cycle Assessment in Strategic Environmental Assessment of Transport Infrastructures

BEACON
Competitive and Sustainable Growth, FP5

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Report Summary

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Summary

This report covers the subject: “Methods and Possibilities for Application of Life Cycle Assessment in Strategic Environmental Assessment of Transport Infrastructures” and is written as a part and contribution to a European Union project - Building Environmental Assessment CONsensus on the transeuropean transport network (BEACON). BEACON is an EU network of excellence and IVL Swedish Environmental Research Institute has been a so called “member” of this network. This report is written by IVL and based on experience from several infrastructure projects in the LCA area. It includes LCA results for the infrastructures of roads, railroads and air transports.

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Preface

This report covers the subject: "Methods and Possibilities for Application of Life Cycle Assessment in Strategic Environmental Assessment of Transport Infrastructures" and is written as a part and contribution to a European Union project - Building Environmental Assessment CONsensus on the transeuropean transport network (BEACON). BEACON is an EU network of excellence and IVL Swedish Environmental Research Institute has been a so called "member" of this network. This report is written by IVL and based on experience from several infrastructure projects in the LCA area. The work has also gained valuable experience from Magnus Blinge at TFK-Transport Research Institute.

Gothenburg and Stockholm, May 2004

Håkan Stripple Martin Erlandsson

Contents

1 Introduction

Transports are essential parts of a modern society. New transport technologies and production methods have dramatically increased the possibilities for long and fast transports in a historical perspective. The need for increased transport capacity has grown constantly and is still growing relatively fast. This situation has also increased the environmental problems related to the transport sector. The transport sector stands today for a significant part of the environmental problems in Europe. One of the first environmental problems to be observed was different emissions from the exhaust gases of road vehicles. Later, the emissions from ships, aeroplanes and trains were investigated.

However, to be able to give a complete a description as possible of the environmental problems related to transports, the entire transport system has to be analysed in a holistic way, which include a life cycle approach. Such life cycle approached analytic system includes not only the transport vehicle, but also the entire infrastructure needed by the transport logistics. For a road transport such a system can for example consist of: construction, operation and maintenance of the road, manufacturing of vehicles, operation of the vehicle, loading and unloading operations, production and distribution of the fuel, production of electric power etc. It is obvious that such a system is very complex and the analysis of such a system requires both a structured methodology and analytical tools. The tool used in this case is Life Cycle Assessment (LCA) which is described in more detail in the next chapter.

The situation of choice between different transport alternatives is very common. In your daily life you can chose to take the car, the boat, the train or the aeroplane to a certain destination. The choice can also be between different freight alternatives for a company or between different national strategic transport infrastructure solutions, which will have affect for decades. The common factor is here the situation of choice. The question is however which criteria that should be used as a base for the decision. In an overview perspective there are many different, sometimes also competing alternatives like; economic criteria, regional political aspects, labour market (employment) policy aspects, environmental criteria, energy criteria or travel time aspects. The methodology described in this report covers only the environmental aspect for a decision-support, and not the multi-criteria problem, which has to be dealt with to actually make the most appropriate choice. In any case, it is however important to have complete and accurate basic information concerning all three pillars[1] covered in the sustainable context applicable for potential improvement of the transport system and its infrastructure.

2 Life Cycle Assessment (LCA) – a short introduction

Life Cycle Assessment (LCA) is a versatile tool to investigate the environmental aspect of a product, a service, a process or an activity by identifying and quantifying related input and output flows utilised by the system and its delivered functional output in a life cycle perspective. The use of a product or a process involves much more than just the manufacturing of the product or use of the process. Every single industrial activity is actually a complex network of activities that involves

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[1] Environmental, economic and social aspects.

many different parts of society. Therefore, the need for a system perspective rather than a single object perspective has become vital in environmental research. It is no longer enough to consider just a single step in the production. The entire system has to be considered.

The LCA methodology has been developed in order to handle this system approach. An LCA covers the entire life cycle of the product, service etc. from its "cradle to grave" including crude material extraction, manufacturing, transport and distribution, product use, service and maintenance, and end-of-life such as; reuse, recycling, energy recovery and final waste handling such as incineration or landfill. In an LCA a system analytic model of the studied product etc. is designed. This model is of course a representation of the real system with various approximations and assumptions. With LCA methodology it is possible to study complex systems, where interactions between different parts of the system exist to provide as complete a picture as possible of the studied system's related environmental impacts.

A number of applications for an LCA are listed below, divided into internal and external use for an organisation:

Internal
Knowledge generation
Strategic planning
Forecasting
Development of environmental strategies
Environmental improvement of the system
Design, development and optimisation of products or processes
Identifying critical processes for the system
Development of specifications, regulations or purchase routines
Environmental audit
Waste management
Environmental management systems (EMAS, ISO 14000)

External
Environmental information
Environmental labelling
Environmental audit of companies

An LCA usually evaluates the environmental situation based on potential ecological effects (i.e. impacts) and resource use. In a few cases the work environment has also been included. The LCA framework, as defined by ISO 14040 series, does not cover the economic or social effects.

The international standards for LCA methodology, prepared by the International Organisation for Standardisation (ISO) are divided in the following parts:

- Principles and framework (ISO 14040), [3].
- Goal and scope definition and inventory analysis (ISO 14041), [4].
- Life cycle impact assessment (ISO 14042), [5].
- Life cycle impact interpretation (ISO 14043), [6].

Generally the method can be divided into three basic steps with the methodology for the first two steps relatively well established while the third step is more challenging. The third step (Impact assessment) is however important hence the environmental understanding of the inventory step is performed by calculation the contributions to different impact categories, like climate change, acidification etc. The first two steps are usually referred to as the life cycle inventory (LCI) and can be applied separately without the following impact assessment. In addition to the different steps in the procedure, an interpretation phase can also to be performed. The three basic steps are shown below:

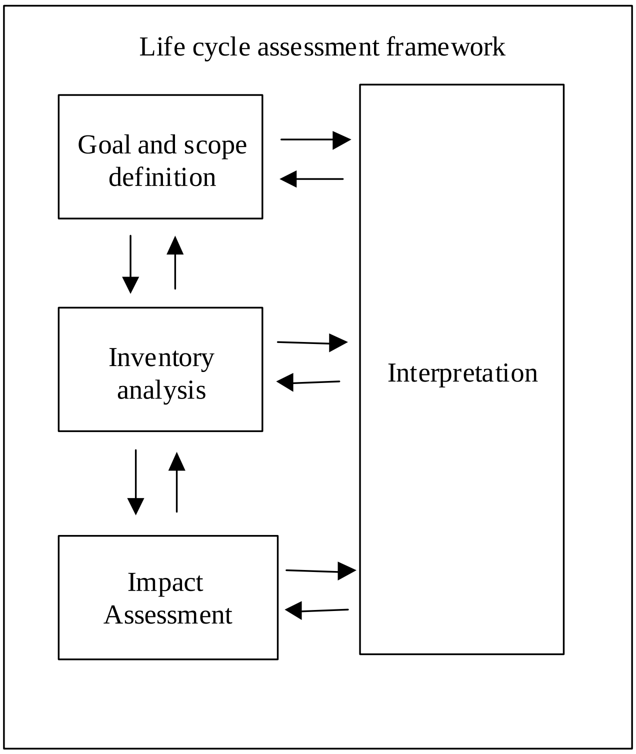

Figure 1 The LCA framework procedural steps.

The *goal and scope definition* consists of defining the study purpose, its scope, system boundaries, establishing the *functional unit*, and establishing a strategy for data collection and quality assurance of the study. Any product or service needs to be represented as a system in the inventory analysis methodology. A system is defined as a collection of materially and energetically connected processes (e.g. fuel extraction processes, manufacturing processes or transport processes) which perform some defined function. The system is separated from its surroundings by a *system boundary*. The entire region outside the boundary is known as the *system environment*.

The *functional unit* is the measure of performance, which the system delivers. The functional unit describes the main function(s) of the system(s) and is thus a relevant and well-defined measure of the system. The functional unit has to be clearly defined, measurable, and relevant to input and output data. Examples of functional units are "unit surface area covered by paint for a defined period of time," "the packaging used to deliver a given volume of beverage," or "the amount of detergents necessary for a standard household wash." It is important that the functional unit contains measures for the efficiency of the product, durability or lifetime of the product and the quality/performance of the product. In comparative studies, it is essential that the systems are compared on the basis of equivalent functional unit.

Other important aspects to consider in the goal and scope definition include:

- whether the LCA is complete or if some component is excluded from the study
- which type of environmental impact is considered in the study
- a description of other important assumptions

In the *inventory analysis* the material and energy flows are quantified. The system consists of several processes or activities e.g. crude material extractions, transport, production, waste handling. The different processes in the system are then quantified in terms of energy use, resource use, emissions etc. Each sub-process has its own performance unit and several in- and outflows. The processes are then linked together to form the system to analyse. The final result of the model is the sum of all in- and outflows calculated per functional unit for the entire system.

The ISO standard on *life cycle impact assessment* (LCIA) [5] is a so called procedural standard that includes mandatory parts and non-mandatory parts. One such voluntary step is weighting of different impact categories into a limited ore one single figure. The application, however, of such weighting method is limited for internal use and not for public dissertation, since it in great extent depends on and includes subjective elements. So far, no further specified standard procedure exists for the implementation of an entire impact assessment. Several methods/tools have been developed for impact assessment and the tools can usually be integrated with different LCA computer softwares. The modern tools today usually include a classification and characterisation step where the different parameters e.g. emissions are aggregated to different environmental impact categories such as acidification, climate change or eutrophication. There are of course also possibilities for direct evaluation/interpretation of the different emissions or environmental impact categories.

3 Implementation of LCA to Transport Infrastructures

3.1 Introduction - Goals and Tools

As already has been pointed out there is a need for a system concept in the transport sector that includes both the transport vehicle and its infrastructure etc. There are several system analytic based applications applicable for the transport sector, such as Environmental Risk Assessment (ERA), Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), Environmental Product Declarations (EPD) and many other strategic decisions supports concerning investments in different infrastructure systems.

There are few other choices but Life Cycle Assessment (LCA) that can be applicable and used as a tool for the aimed system analysis, and is pointed out within EC Integrated Product Policy (IPP) as the life cycle approached method in the IPP toolbox. Several LCA studies of different infrastructures have also been performed the last 10 years. One of the first studies that covered the road infrastructure was Life Cycle Assessment of Road [1], which was performed in the beginning of the 1990th. In this study a basic methodology was developed and applied to an entire road construction. Three different pavement materials were tested; normal hot asphalt, cold asphalt and a concrete pavement. Two different engine alternatives (standard and low NO_X) were also analysed.

After that study, several other studies of different infrastructures have been performed in several countries but the experiences can anyhow be characterised as an early stage of development. Most of the studies have been focused on road infrastructures and very little on other transport infrastructures. To our knowledge, some works have been done for railroad infrastructures but very little cover the infrastructures for air and ship transports. One study has been performed at IVL Swedish Environmental Research Institute, which covers and compares the infrastructure of railroad and aircraft transports [2]. To our knowledge there is no LCA study that covers the infrastructure of ship transports, (harbours, fairways etc.).

This paper written for the BEACON project will focus mainly on the experiences and reports from IVL.

3.2 General IVL specified LCA methodology

The general methodology for transport infrastructures used at IVL was developed in the project 'Life Cycle Assessment of Road' [1]. This basic methodology has than been used for other road projects and also other types of infrastructures (railroads and aircraft infrastructures). It can therefore be a good start to present some of the basic ideas around the methodology for LCA of roads.

From a methodological point of view, a road differs significantly from other types of products that are produced, used and wasted with a more or less defined lifetime. A road or other infrastructures can be seen more as an on-going activity even if individual components in the system have a defined lifetime. A road construction process differs noticeably also from other manufacturing processes through its great variation with regard to manufacturing conditions. Large and important variations exist between different sites, but even within the same strip of road the conditions can vary substantially.

The methodology used to overcome those problem is based on a simple strategy namely to brake down the infrastructure in smaller process units. An analytic LCA model of the infrastructure can then be build up of the different processing units. As already has been pointed out different infrastructures vary significantly in terms of its design and other production conditions. The LCA results are thus more or less individual for a specific infrastructure. This situation can be handled in the model by varying the model-input data.

Relative to an ordinary product, a road is considered as more or less permanent, beginning with the start of construction. In maintenance procedures the pavement is constantly upgraded. It is thus more useful to analyse a particular time period than to work with a "cradle to grave" concept. The time period used in the IVL studies has been 40 or 60 years. With a longer time period the initial construction phase will be less dominant and the maintenance and operation processes will be more and more important. Another significant time aspect is the residual value of the road or other infrastructure. An ordinary product is usually worn out at the end of its life cycle. Such a product has a very low residual value and is therefore disposed of. A road can however have, due to the maintenance procedures, a very high residual value. After a time period of 40 years the road can be in almost the same design condition as a new road.

3.3 System boundaries for infrastructures

The system boundaries used for infrastructures follows in principle the same pattern as for other LCA studies according to the ISO standard. A useful principle for infrastructure analyses has been to divide the activities in three groups: Construction, Maintenance and Operation. In a full transport LCA there are two parts, which have to be combined; the LCA of the infrastructure and the LCA of the actual transport vehicle. The overall layout must be design in such a way that the two parts can be added. This requires a uniform way of handling the functional unit and the used parameters. The main structure of a full transport LCA is shown in table 1. The End of Life procedures are normally included in the maintenance procedures for infrastructures while for the traffic the End of Life Vehicle (ELV) processes have to be included e.g. in the operation of the traffic module or added separately. Sometimes it can be difficult to distinguish if a parameter should be assigned to the infrastructure or the traffic. An example of this is the allocation of noise.

Table 1 Main structure of a full transport LCA.

	Construction	**Maintenance**	**Operation**
Infrastructure			
Traffic			

Other difficulties when comparing different infrastructure solutions are the allocation between different transport types. In fact, it is only the road transport that can operate as a single transport type. The other transport types (railways, air transports and ship transports) need an interaction between other transport types. Thus, you need e.g. a road to transport the cargo or passengers to the airport. One need car parks at the airports, one need loading facilities to load, unload and reload between different transport types. All those aspects have to be considered and an allocation strategy has to be set up.

3.4 Environmental parameters and limitations

A goal for an environmental evaluation is of course to include as many environmental aspects as possible to create a complete a picture as possible. However, some parameters can easily be represented as a number such as the NO_X emission and therefore also easily be included in a LCA model. Other parameters such as biodiversity or biological barrier effects are much more difficult to handle and very difficult to quantify and therefore not possible to include in an LCA model. A suggestion to handle this problem can be to include the difficult parameters in a checklist. The list can then be handled separately. A simple yes/no form can be used in environmental impact assessment or some kind of index or point system can be used in the final evaluation.

3.5 Functional units for infrastructures

The functional unit utilised for a justified comparison in LCA is always very important when comparing different systems. To compare two LCA model results in a correct way the LCA models used must have the same functional unit i.e. deliver a minimal set up functions or performance requirements. This generates some difficulties to define a common functional unit for different transport alternative and the facilitated infrastructures. A schematic picture of a transport and its infrastructure is shown in figure 2. The figure shows the main part of the transport and as can be concluded from the figure there are a main difference between road and railroads on one hand and air and ship transport on the other. The traffic can usually be represented with the transport distance as the functional unit (per km and tonnage). The infrastructure of roads and railroads can also be represented by the transport distance and tonnage as the functional unit. This is however not the case for air and ship infrastructures. The infrastructures for an aircraft transport is almost entirely related to the airports and thus independent of transport distance. This means that a generic representative transport and distance have to be chosen when comparing those transports, when specific information is not available.

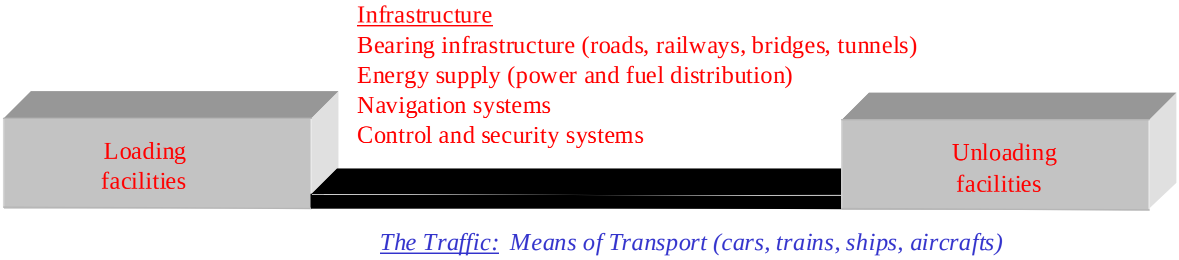

Figure 2 Schematic picture of a transport with its infrastructure.

Another important aspect is how to allocate between passenger and cargo. For aircraft transportation the weight is the determining factor independent of if the weight is caused by passengers or by cargo. For e.g. railroad transports the situations is different. A model that has been used is to represent a passenger with one tonne of cargo. This allocation has of course a significant influence on the final result.

The time aspect is another factor to consider. In fact, one of the main reasons for having different types of transport systems is the transport time. It is obviously much faster to go by aeroplane than to take the boat. Thus, the functional unit is not exactly identical for the different transport systems even with a proper model and a correct allocation. This factor is however quit obvious and can be left out in an analysis but can anyhow be good to keep in mind when doing the final evaluation.

4 Infrastructure case studies and results

4.1 Overview

In this chapter some selected results from two IVL studies are presented, [1], [2]. The studies cover transport and infrastructures for road transports, railroad transport and air transport. The aim of the chapter is to give an overview picture of the different infrastructures and its relation to the actual transport vehicle. Data gaps and data accuracy of the models can be found in the original reports.

4.2 Selected results from railroad transports

The infrastructure for railroads has been investigated in the railroad construction project “Botniabanan”. This is a new railroad build in the north of Sweden. This railroad is built in an area with a relatively hilly landscape. It has therefore typically somewhat more bridges and tunnels than an ordinary railroad in Sweden. The functional unit for the railroad infrastructure has in this case been chosen to 1 km railroad during 60 years to be able to calculate the effect of long-term maintenance.

Figure 3 shows the overall results from the LCA models for the infrastructure (without the transport vehicle). The relative environmental effects are shown divided into different parts of the railroad infrastructure. As can be seen from the figure different materials and equipments stand for a significant contribution. The use of iron for the rails plays here a significant role. The construction works stands also for a large contribution of especially the climate change effect, the eutrophication potential and the acidifying potential. Those effects are strongly related to diesel driven construction equipments (CO_2 and NO_X emission).

The use of energy is also an important factor for the environmental behaviour, figure 4. In the figure the use of different fuels are shown divided into different parts of the infrastructure. The production of electric power is here included and calculated back to the use of its original resources. In this case, a Swedish power mix has been assumed which consists of typically 44 % nuclear power, 48 % hydropower and the remaining part is a mixture of coal, natural gas and oil based power production. The unbalanced relation between nuclear power and hydropower depends on the fact that an efficiency of approximately 30 % has been used for nuclear power production.

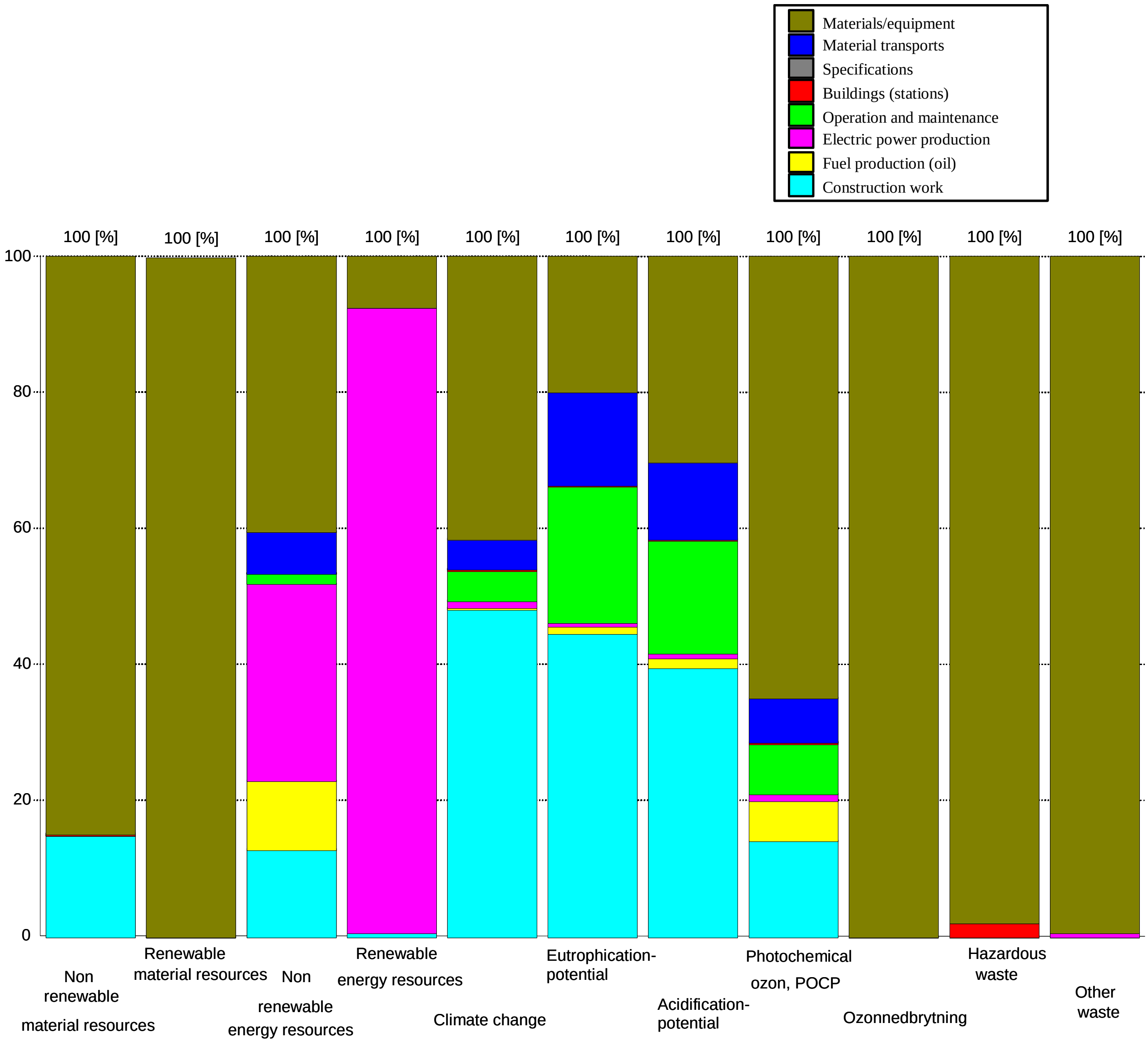

Figure 3 Overview picture showing characterised data for different environmental classes and different parts of the railway infrastructure.

The total energy use for 1 km of railroad during 60 years has been calculated to $4.3 \cdot 10^7$ MJ (≈12 GWh). The figure shows that a relatively large part of the energy use comes from electric power. The use of crude oil is also relatively high. The contribution from coal use is also high and direct related to the production of steel for the rails (83 %).

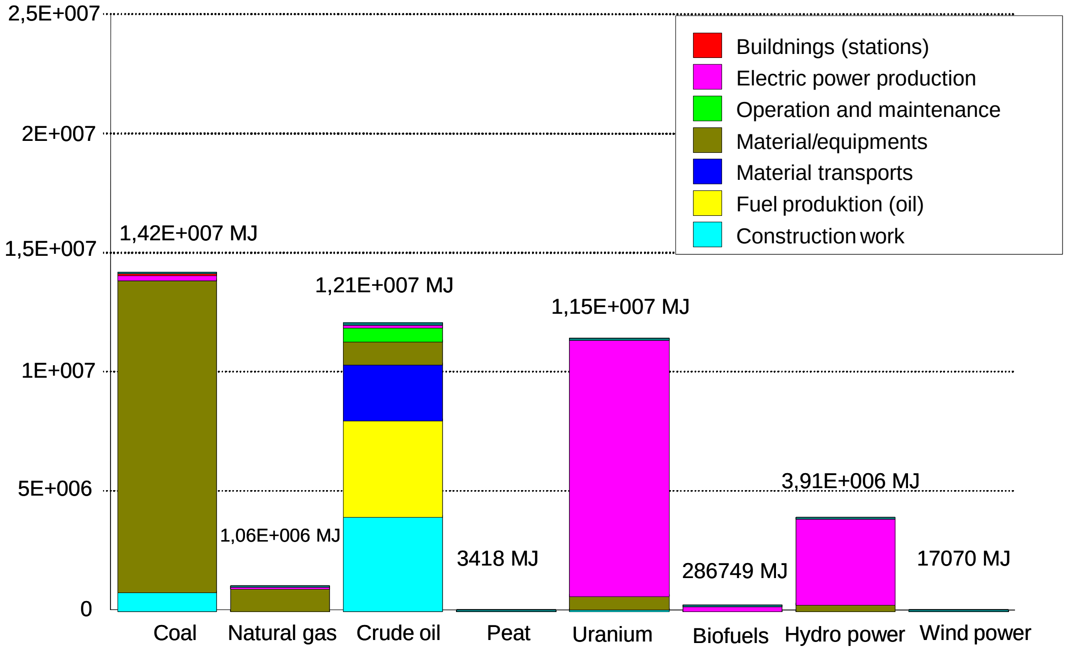

Figure 4 Energy use (MJ) for 1 km of railroad infrastructure divided in different energy resources and different part of the infrastructure.

The NO_X emission has been chosen as an example of an important emission from the infrastructure. The NO_X emission gives a significant contribution to both the acidifying potential and to the eutrophication potential. The emission is shown in figure 5. The construction work is a dominating source (46 %). The use of diesel driven machines plays here an important role. Operation and maintenance is the second largest sources and also here the use of diesel driven machines is a large source. Emissions from material production are also an important source (17 %). Production of steel for rails and bridges stands for 11 % and production of cement stands for 5 %.

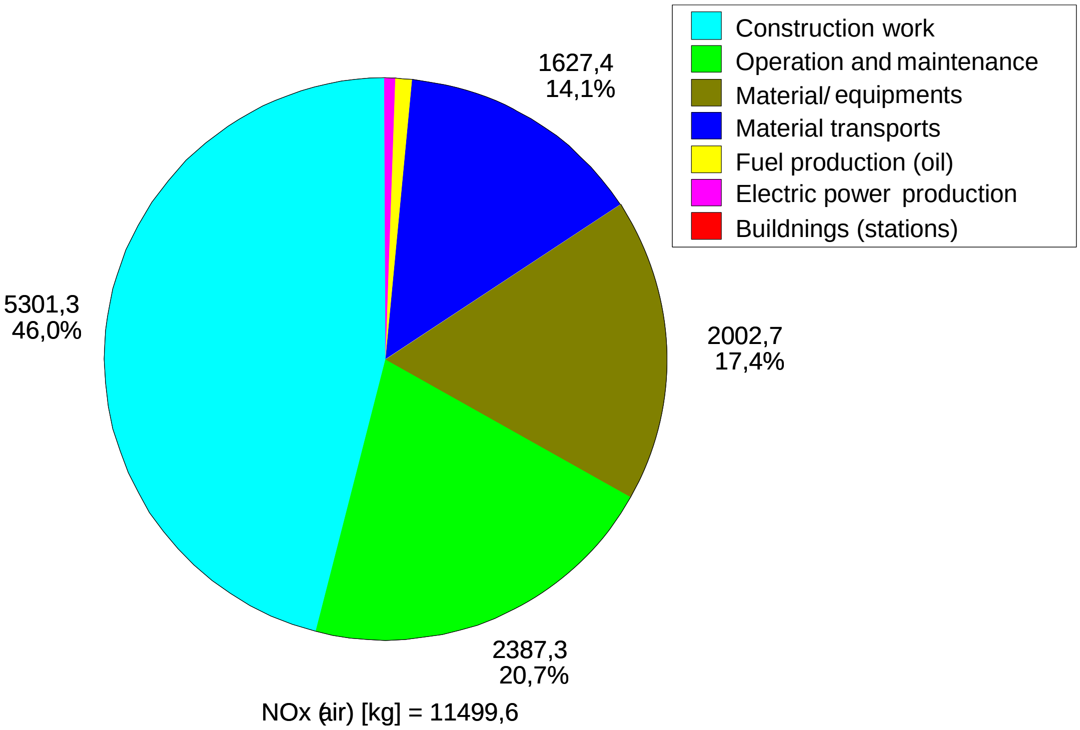

Figure 5 Emissions of NO_X (kg) from 1 km of railway infrastructure.

An interesting factor is the relation between the infrastructure and the actual transport work (the train). This relationship is shown in figure 6. The figure shows a railroad transport of 1000 kg, 500 km and the calculated time period has been 60 years. The transport work (the contribution from the train) is shown in dark green colour. The transport work is only dominating for the energy resource use. An important factor is here that the train is driven by electric power and that a Swedish electric power mix has been assumed (small emissions from hydropower and nuclear power). Large contributions to the emissions come instead from the construction work and from production of materials (e.g. steel and cement).

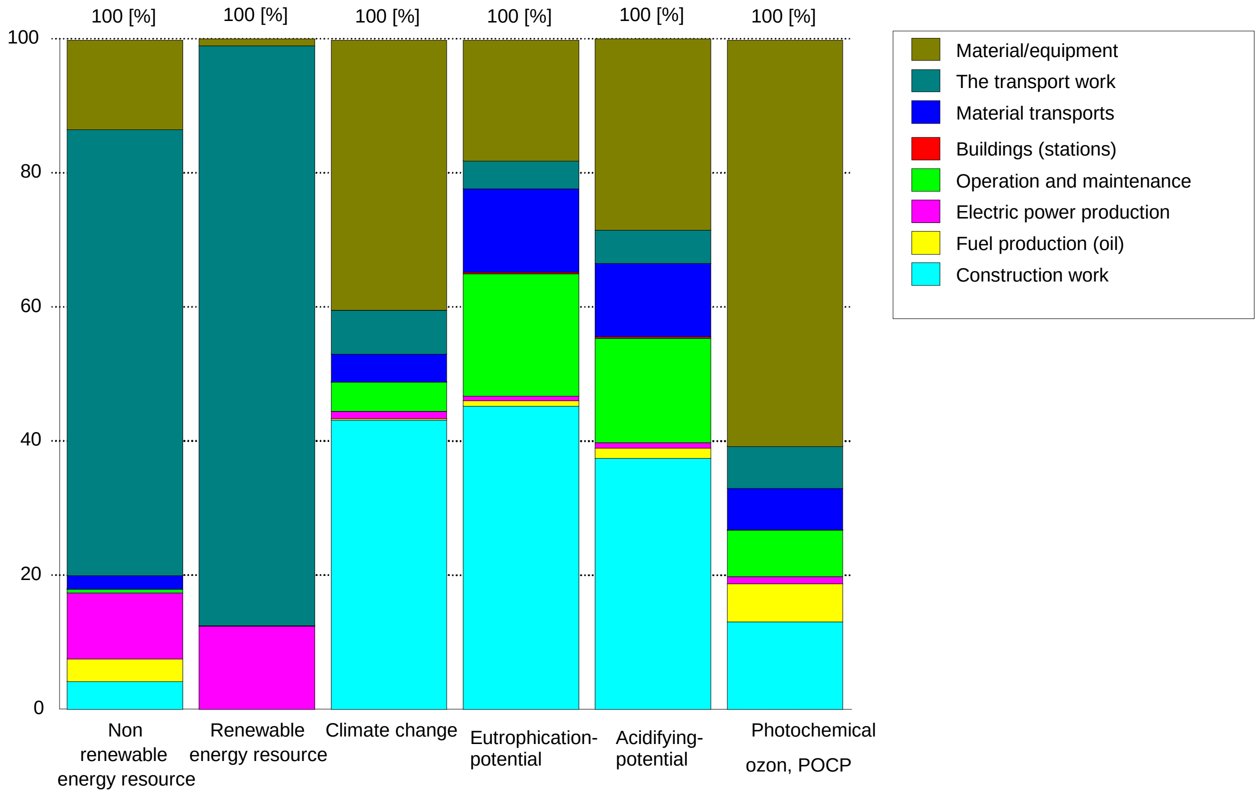

Figure 6 Distribution in different environmental classes of different process operations from an entire transport (infrastructure and the transport vehicle). The figure shows a railroad transport of 1000 kg, 500 km.

4.3 Selected results from air transports

The data for the air transport infrastructure model comes mainly from two sources; average data for Sweden or specific airport data from Landvetter airport in Gothenburg, Sweden. An overview picture of the air transport infrastructure, its relative environmental effects and the contribution from different parts in the infrastructure is shown in figure 7. From an energy point of view one can conclude that electric power is an important energy form. For the emissions, two major factors can be detected namely construction work and the operation of the airport.

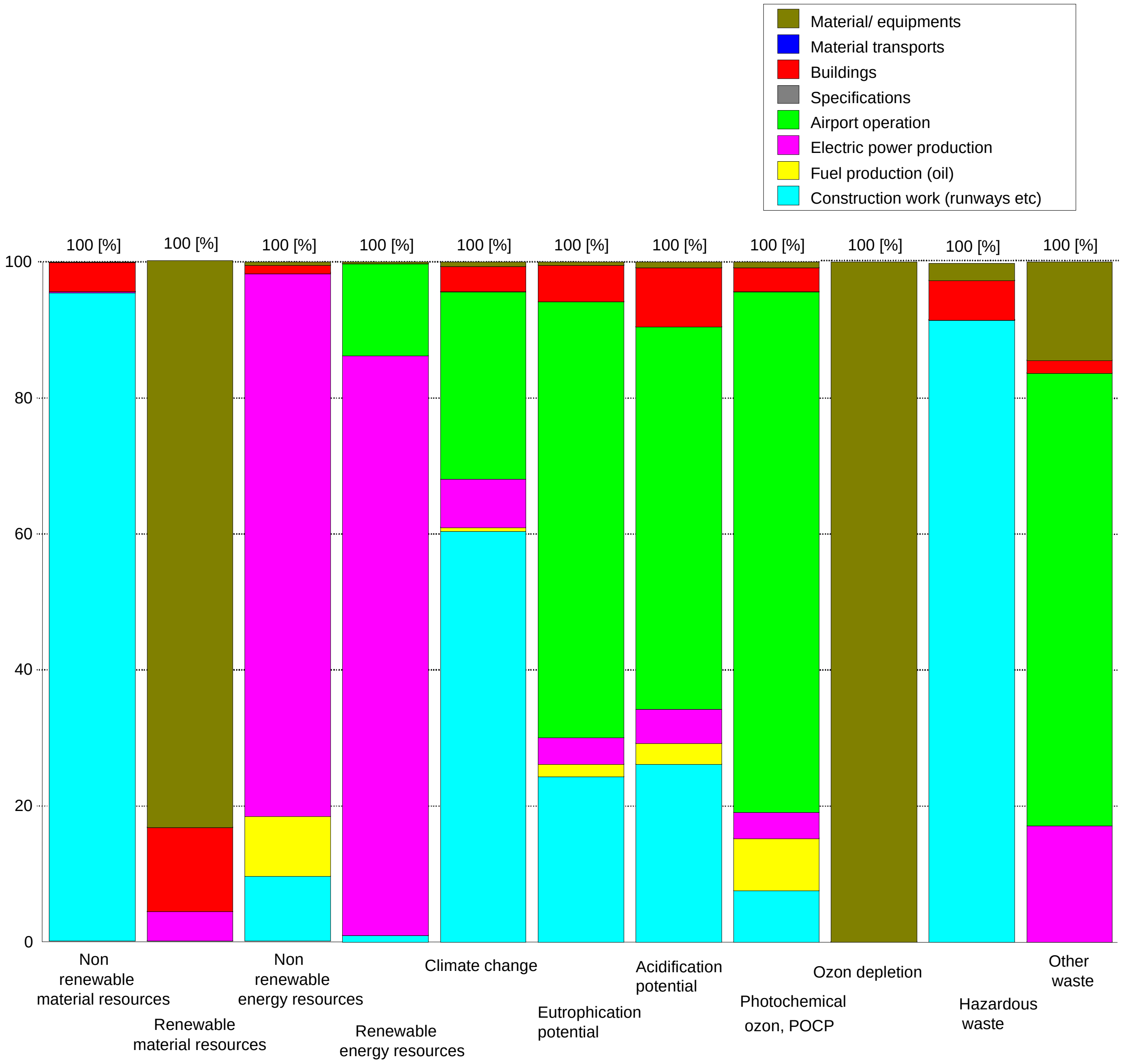

Figure 7 Overview picture showing characterised data for different environmental classes and different parts of the air transport infrastructure.

The energy use for the air transport infrastructure is, as already has been pointed out, totally dominated by the use of electric power, figure 8. The energy resource distribution is a consequence of the assumed Swedish electric power production mix. Some crude oil is also used in the construction work of the airport and in the operation of the airport. Some district heating is also used for heating up the airport buildings. This figure is an average for Sweden but this technical solution is only used at some airports.

The NO_X emission is totally dominated by the emissions from the operation of the airport (65 %). The construction work stands for 24 % of the NO_X emissions. The entire distribution is shown in figure 9.

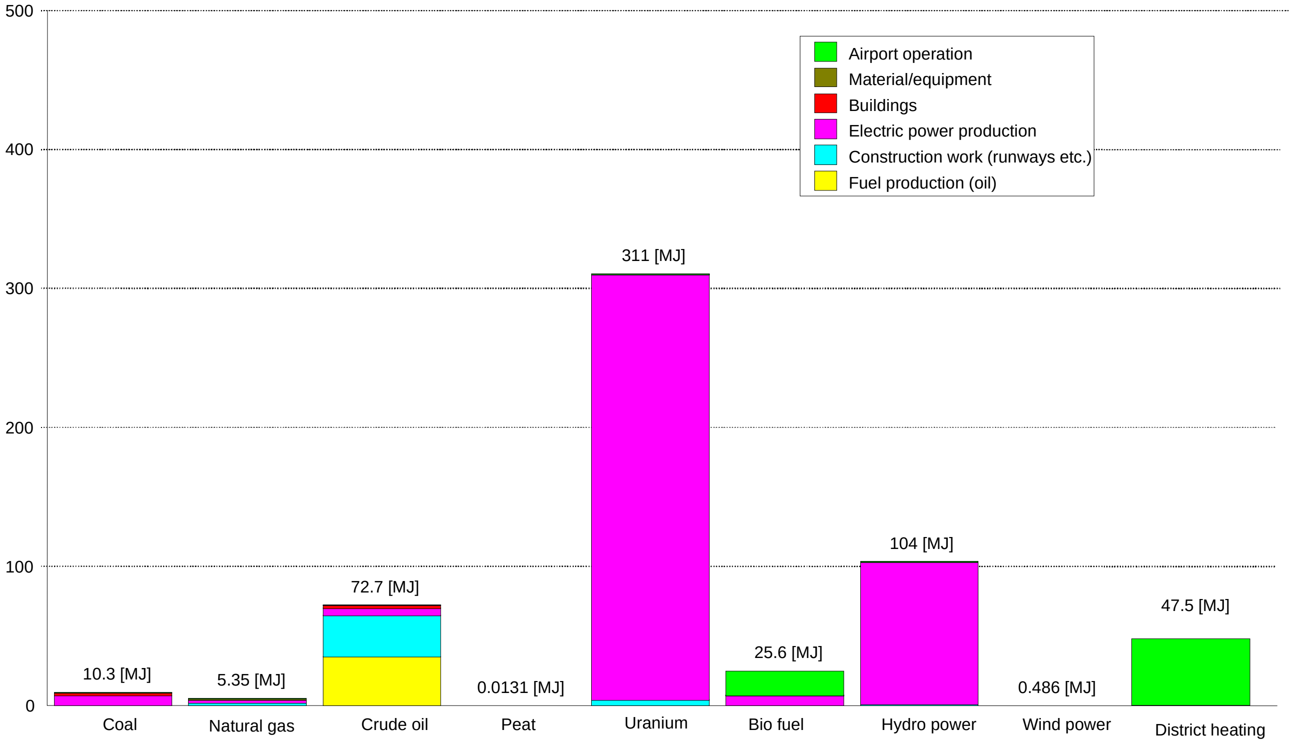

Figure 8 Energy use (MJ) for air transport infrastructure divided in different energy resources and different part of the infrastructure. The results are shown for one airport equivalent.

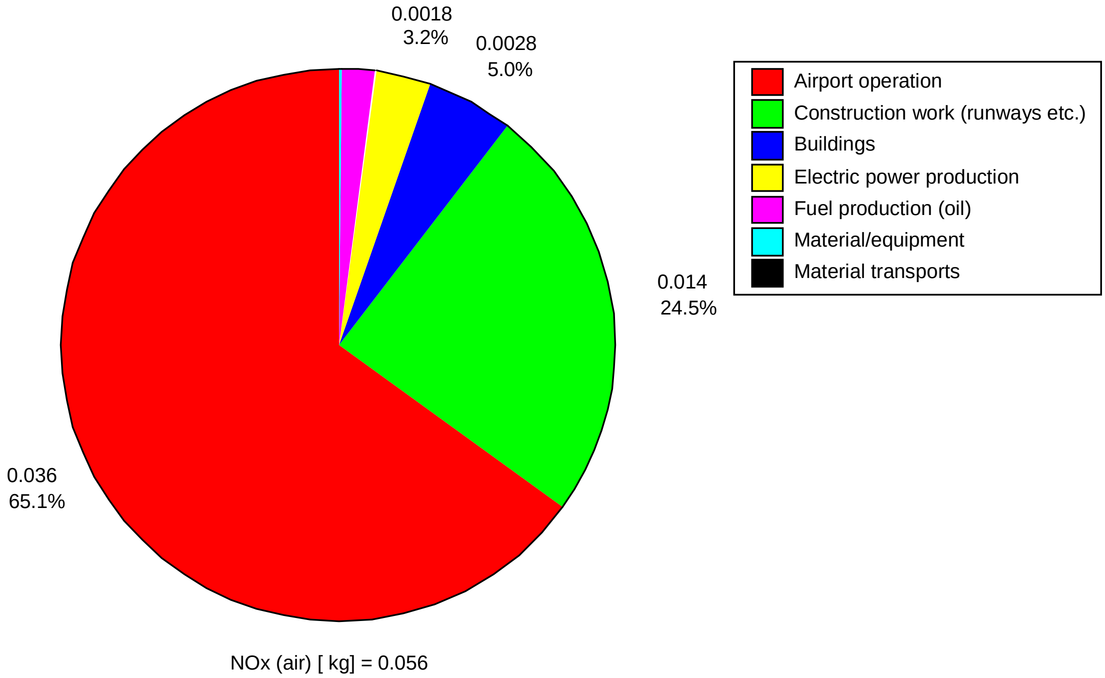

Figure 9 Emissions of NO_X (kg) from air transport infrastructure. The results are shown for one airport equivalent.

If the air transport infrastructure and the air transport itself (the aircraft) is compared, one find a total domination of the emission from the aircraft for all the environmental classes, figure 10.

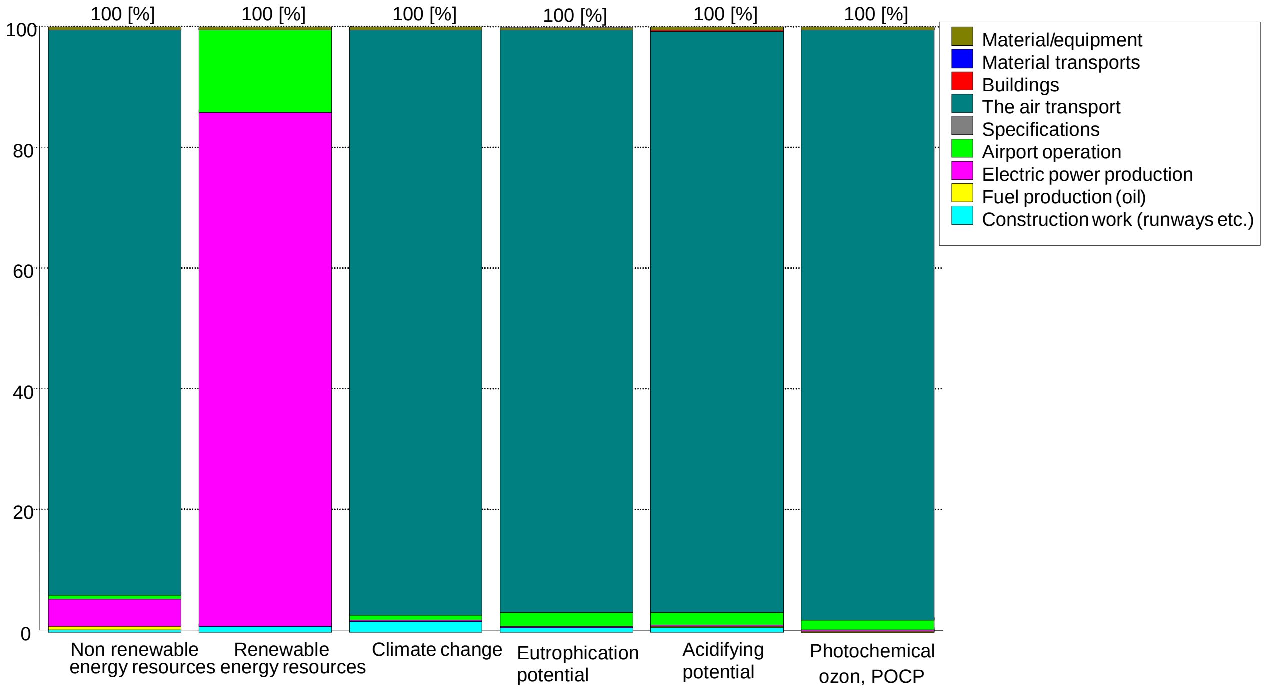

Figure 10 Characterised data showing an entire air transport including the infrastructure.

4.4 Selected results from road transports

An overview of the total energy consumption divided into construction, maintenance and operation in a life cycle perspective is shown in figure 11. In addition, the inherent energy bonded in the asphalt layer is also shown in the same figure. The inherent energy is however not a direct energy use due to the fact that the bitumen material is not combusted and the energy is thus not released. The inherent energy use can be treated as a resource use of bitumen. The figure shows the situation without asphalt recycling. An asphalt recycling process can reduce the resource use of bitumen.

The total energy consumption in construction, maintenance and operation of a 1 km long road during 40 years has been calculated to 23 TJ for an asphalt surface and 27 TJ for a concrete surface where the energy differences are small for the hot and cold asphalt methods. Of the total energy consumption, the 40 years of operation accounts for a large part of the consumption. This energy consumption originates from consumption of electrical energy from road lighting and traffic control (approximately 12 TJ) i.e. nearly all of the energy consumption for the operation of the road. An equal intensity of lighting has been assumed for asphalt roads and concrete roads. A brighter road surface can however require less illumination intensity and thus a reduced use of electric power. The difference in energy consumption for a conventional diesel engine and a low emission diesel engine is small and thus shows no significant difference in the total energy consumption.

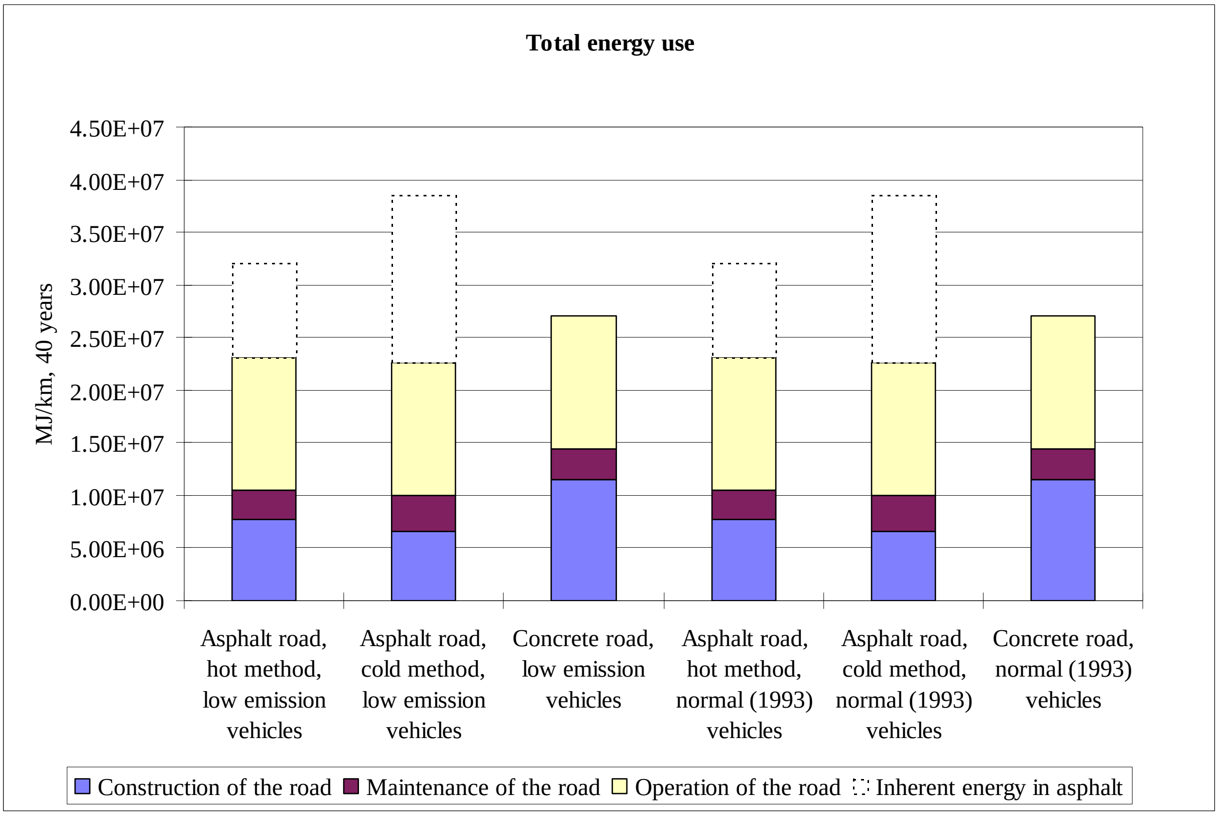

Figure 11 Total energy consumed for three different road surface materials and two different engine alternatives for construction vehicles divided into road construction, road maintenance and road operation for a 1 km long road during 40 years of operation. Dotted lines show inherent energy bonded in the road materials but not released as energy. Of the energy used for operation, approximately 12 TJ is consumed by road lights and traffic control.

Table 2 The energy use of the road as a percentage of the energy used from traffic with a traffic intensity of 5000 vehicles/day with and without road lights and traffic control.

Road type	**The energy use of the road compared to the energy use of the traffic with a traffic intensity of 5000 vehicles/day and with road lights and traffic control. (%)**	**The energy use of the road compared to the energy use of the traffic with a traffic intensity of 5000 vehicles/day and without road lights and traffic control. (%)**
Asphalt road, hot method	10.1	4.9
Asphalt road, cold method	9.9	4.7
Concrete road	11.8	6.6

The emissions of NO_X for the road system divided into construction, maintenance and operation of the road are shown in the figure 12. The calculations of the emissions for the different engine alternatives are based on the assumption that the emission of NO_X is decreased with a factor of 2 when using a low NO_X emission diesel engine compared to a conventional diesel engine.

The dominating activity for the emission of NO_X is the construction of the road. The maintenance of the road is the second largest source of the emissions and for the NO_X emission this activity gives a significant contribution. The operation of the road accounts only for a small part of the total NO_X emissions. However, it should be borne in mind that the emission calculations from the electric power production are based on a Swedish average production mix that mainly consists of hydropower and nuclear power.

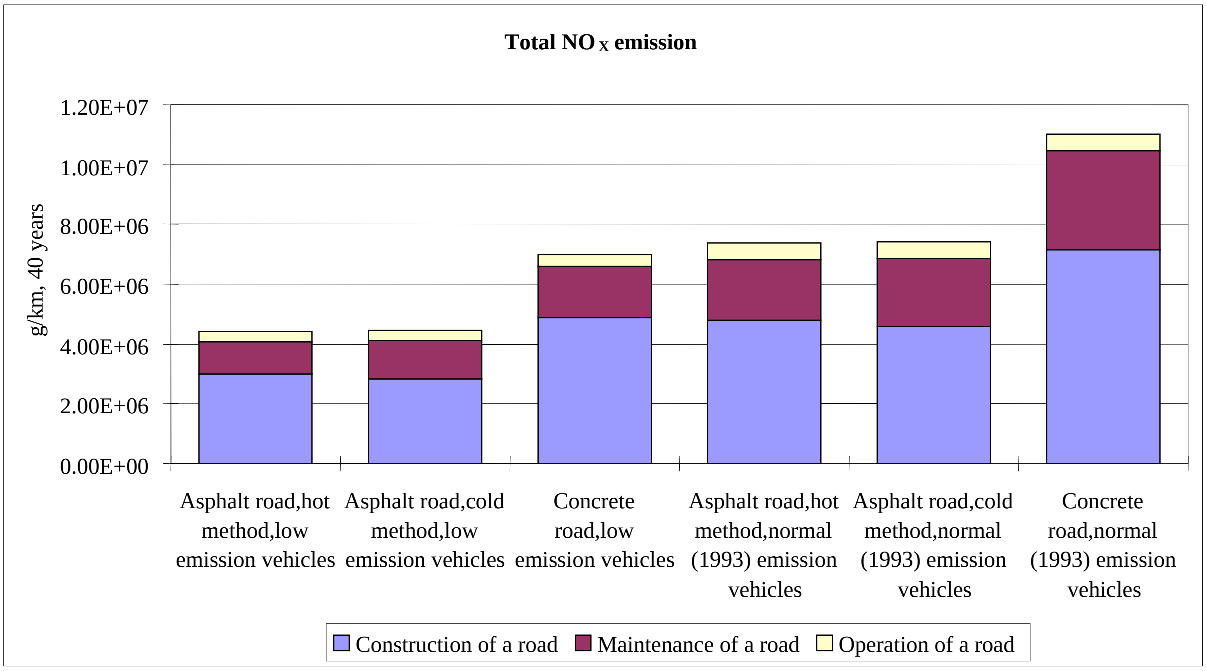

Figure 12 Total NO_X emission for three different road surface materials and two different engine alternatives for construction vehicles divided into road construction, road maintenance and road operation for a 1 km long road during 40 years of operation.

5 Application of LCA in SEA

5.1 Current standards and their practice

The objective of the SEA directive (2001/42/EEC) is that it will ensure that environmental consequences of certain plans and programmes are assessed and treated in so that they can be taken into account while they are actually being developed. The already established and implemented EIA Directive (85/337/EEC), which is utilised on major projects that is likely to have an impact on the environment, do not takes place at a stage when options for significant change are possible. Therefore, the SEA Directive fills a gap by requiring assessment on the environmental effects of a broad range of plans and programmes. In addition, the SEA directive shall also be regarded as a tool to achieve the goal of sustainability development. At the moment, a SEA Guideline is launched that will contribute to the implementation of the directive worked out [7], and state as follow:

> *"Whilst the concept of strategic environmental assessment is relatively straightforward, implementation of the Directive sets Member States a considerable challenge. It goes to the heart of much public-sector decision-making. In many cases it will require more structured planning and consultation procedures. Proposals will have to be more systematically assessed against environmental criteria to determine their likely effects, and those of viable alternatives. There will be difficult questions of interpretation, but when properly applied, these assessments will help produce decisions that are better informed."*

A number of SEA have been performed on the transport sector, such as in the IMPEL project [8], that besides to contribute to the development of the environmental assessment methods, also included economical related methods. However, so far no attempt to include a life cycle approached tool, such as LCA, is performed and evaluated in respect to improve the SEA tool box with a time and cost effective method.

Therefore, in respect of the SEA overall scope to cover all three pillars in the inherent meaning of sustainability development, this paper's focus is on the possibility to add LCA as an optional environmental related method to the SEA toolbox. The implementation of LCA as a tool within a SEA should then potentially give the SEA decision support and holistic (e.g. "cradle to grave" approach), non-subjective and qualitative information. The LCA based SEA decision support accounts for the environmental problem in a holistic way that means that activities' environmental burden are analysed in a life cycle perspective. Therefore a SEA including LCA contributes to a final assessment that will highlight product-service sub-optimisations [9]. In conclusion,

> *while EIA assessment mainly are focused to the studied object and its geographical limitation including site specific considerations, LCA instead operate on a more cross sectoral level, including aspects that highlight improved solution for the transport infrastructure system in its entirety.*

This imply that LCA is the tool that can justify locally increased environmental quality objectives, for instance, if a transport corridor in a life cycle perspective illustrate such benefits that this could be justified. In this respect we can identify that LCA has the inherent possibility to integrate the three so called *tiering principles* accounting for the network, corridor and project level respectively into one analyse model, which give the LCA tool a unique platform for the decision support.

5.2 Settings of significant aspect related to the consensual framework of LCA

5.2.1 System boundaries

To perform the life cycle inventory (LCI) step of an LCA a number of system boundary specifications have to be defined. Some of these system boundaries will be dependant on the specific goal and scope relevant for the specific studied object, while other are of a general matter and therefore also subject to be harmonised within the member states. Such generic system boundaries to describe are the technosphere infrastructure system and its substructure parts. These system boundary settings are possible to standardise and a suggestion, based on the experience reported earlier, and developed in order to facilitate all three tiering levels defined in the SEA manual is found in table 3.

Table 3 Illustrative generic structuring of the studied infrastructure object, divided in the tiering levels and subsystem parts, indication of technosphere system potential inclusion on case study basis.

Tiering level	**System part**			
	Loading facilities	Transport infrastructure	Transport vehicles	Unloading facilities
Network level				
Corridor level				
Project level				

The system boundaries illustrated in table 3 indicate the inventory scope of the LCA in order to generate a homogenous generic structure and basis for system cover reporting. However, it should be noticed that the three different tiering levels corresponds to different system complexity and also, so to say, answers different questions, where the network levels represent the most holistic approach. In relation to LCA methodology a reference unit applicable for comparison of different developing alternative has to be established on each tiering level. In the context of LCA such reference unit is called functional unit (even though no functional performance as such from the studied system has to be specified). For this reason we will from now on – when LCA is applied in SEA – instead refer to *reference unit* when we defines a unit that is used to carry out a fair comparison.

5.2.2 Reference unit

When an individual infrastructure object shall be evaluated with other alternatives an adequate reference unit has to be established. This applied reference unit can be defined on a generic delivery basis (representing system functional output), and then further specified in respect to the case study goal and scope, as developed and illustrated in table 4.

Table 4 Description of the system functional delivery and basis for allocation divided in the three tiering levels.

Tiering level	**Generic functional delivery**	**Specification units examples that the impact will be distributed to**
Network level	*transport service*	*yearly transportation consumed per capita,* *yearly transportation consumed for a geographical area*
Corridor level	*transport operation*	*per tonnage and km,* *per person and km*
Project level	*transport object*	*per km road,* *per bridge and carrying capacity*

On the project and corridor tiering level, the strait forward study of an infrastructure object has prescriptive transportation settings, where the transportation vehicles and intensity are defined etc. While a more complex scenario related analysis and evaluation that is valid on the corridor and the network level make it possible to account for more performance-based or product-service related assessments, where the initial scenario settings instead are specified in terms of transportation amount of goods and individuals and their transfer coordinates. This latter alternative makes it possible to really evaluate quite different infrastructure and transportation systems and combinations thereof. The network tiering level is also the most adequate level for making cross sectoral improvements, since the scope of the studied technosphere system on this level is the most embracing alternative.

5.2.3 Spatial and temporal resolution

The life cycle approached inventory applied in LCA covers the span from extraction of recourses until it is discharged, transformed into emissions and meets a recipient. The basic life cycle inventory (LCI) therefore accounts for emission flows and extraction of raw materials and energy resources. An inventory could also include impact on land use (also referred to explorative impact) and resource consumption, often limited to account for energy carrier (e.g. energy consumption). The life cycle approach requires analysis of a lot more activities that are involved with the activities direct facilitated by the transport infrastructure system. To make an environmental impact assessment possible the traditional LCA only accounts for emissions to air, water and ground.

These emissions are then summed up for the entirely product system behind the infrastructure system and its functional delivery.

For this reason generic applicable impact assessment methodologies have been developed for use in LCA. This means that different impact categories are assessed within category indicator that are found on a inherent chemical property or at midpoint level in the cause-effect chain, typically illustrated by global warming potential that aim at the driving forces behind climate change rather than evaluating potential effects in nature. However, an improvement is taking place within the development of LCA research field, where the traditional site generic dependencies are complemented by a spatial resolution that make so called site dependency impact assessment possible [10]. This is a development that is still in its initial stage, even though concepts were presented already in 1997 by IVL [11]. Such site dependency impact assessment seems reachable within the concepts by LCA. Truly site specific, however, implies to requirements of an improved LCI that do not seem to be realistic, at least not for large products systems.

The temporal resolution within LCI is not accounted for as such. When the environmental meaning of the inventory profile from the LCI is evaluated in the life cycle impact assessment (LCIA) step in the LCA, no dynamic models are yet developed. A sort of time dependence that includes a spatial dimension are utilised in LCIA step, since background situations are utilised in different characterisations model, when a margin approached is utilised to define an impact category indicator.

Concerning the spatial and temporal resolution in an LCA it can in its most streamlined way, so to say, be integrated universe geographical generic level were the emission recipients are enough, and integrate the time frame so all impact is assesses as they were momentary happen. In conclusion,

> *The inherent limitations of the LCA methodology give that it shall be applied for risk minimisation and for comparative purpose, rather than estimation absolute measures on effects or damage to humans or nature. For this reason LCA is a given alternative to other methods like Environmental Risk Assessment (ERA, like the EUSES model), as traditional EIA*[2] *or IEA*[3]*.*

5.3 Environmental characterisation factors in LCA

In the LCIA step of an LCA the different data from inventory step are transformed into different impact categories via so called characterisation factors. Current common praxis covers at least the following impact categories (SETAC 2004);

- Climate change
- Stratospheric ozone depletion
- Acidification
- Eutrophication
- Photochemical ozone formation
- Human toxicity
- Ecological toxicity

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[2] Environmental Impact Assessment.

[3] Integrated Environmental Assessment.

From the list above we can read that no common acceptable praxis is today available on for instance resource consumption or explorative impact.

The result from transforming the inventory profile through the characterisation factors to an environmental impact profile will be reported in different equivalents per impact category (CO_2-equvivalents indicating global warming potentials). To evaluate the relative magnitude within the different impact categories normalisation is the first option. Then in order to integrate the environmental impact to a single score index, weighting methods are applied (also known as valuation). However, weighting methods always includes such subjective elements that it limits its application. In ISO 14042, that specify the requirements on the impact assessment in LCA, it is stated that weighting methods should not be applied in comparative purpose in public communications [5]. For this reason normalisation show a profitable final outcome of the LCIA step, at least in the context of public applications.

5.4 An approach for a European common impact assessment method

A developed normalisation method that is found on environmental quality objectives (EQO), i.e. estimations on acceptable effects or no effects levels on what the nature and human health can accept is called the *EQO normalisation method* [12].

The benefits with this impact assessment method are that no direct value choices are made. Instead the precautionary principle is applied. This means that the relative importance between different impact categories can be made (see figure 13), which means that a high environmental relevance and comprehensible result can be obtained without introducing model and valuation uncertainly that appears when index methods are applied, see figure 14.

The EQO-normalisation method is currently developed for Swedish conditions, but some impact categories are made on a global or European level, such as climate change, human and ecological toxicity [13-14]. The development of the EQO Normalisation method will be an operationalisation of the European long term objectives for an ecologically sound development.

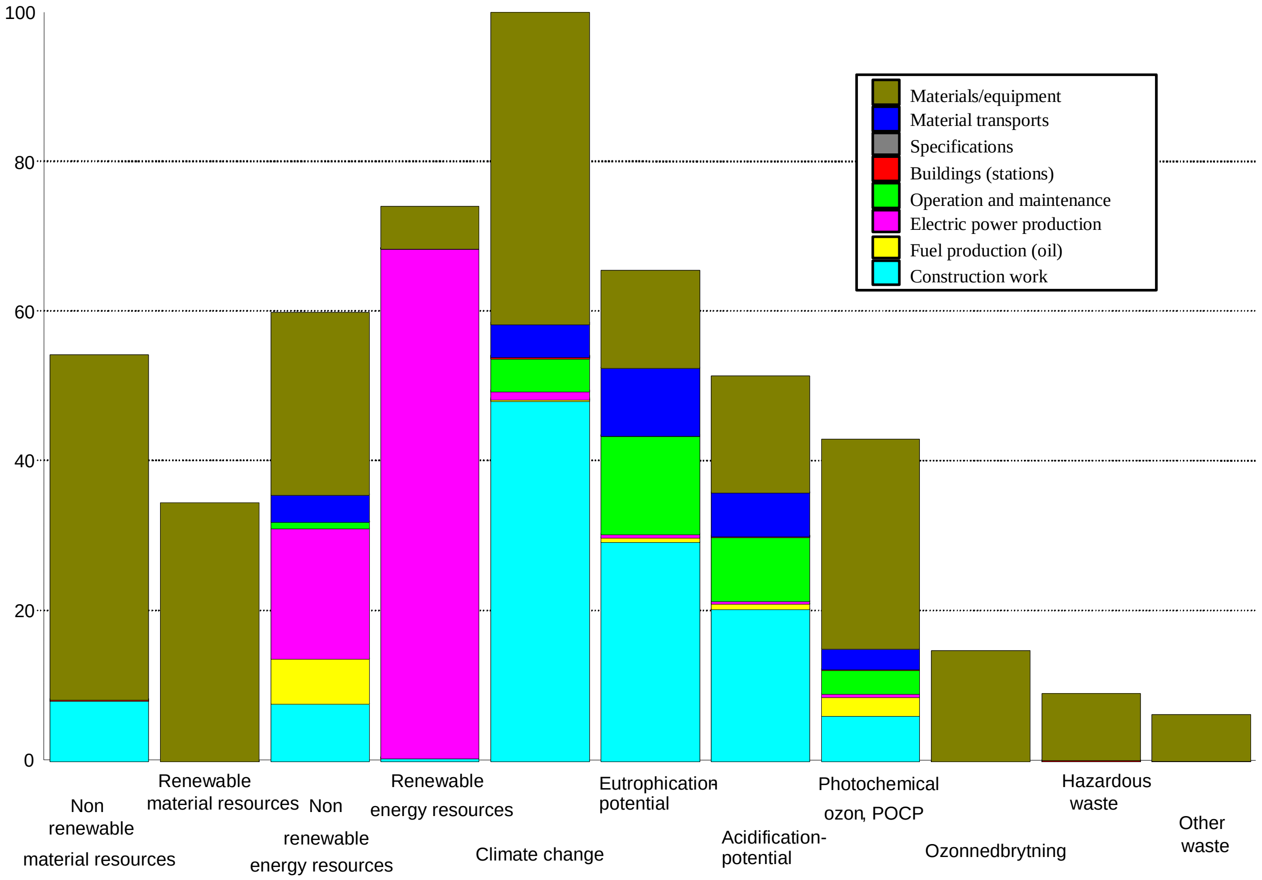

Figure 13 An illustrative example of a normalisation between the environmental impact that gives the relative importance between the impact categories. The figure corresponds to the same result that it showed in figure 3.

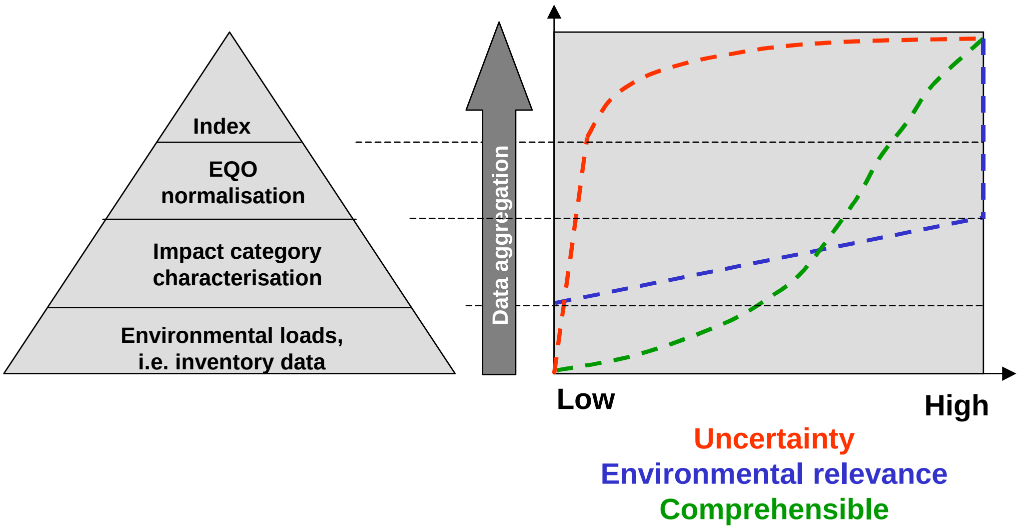

Figure 14 The aggregation of LCI data and an illustration of its resulting uncertainty, environmental relevance and comprehensible of the final result.

5.5 Evaluation of current LCA practice

Since SEA is aimed to look into the future and facilitate scenario technique, and in this respect, always will have to rely on qualified assumptions, the first approach will be to use generic LCI data and site generic impact assessment methods. This fact will make the LCA application, in the context of SEA, very time saving and therefore cost effective to run, since it is realistic to develop a commonly applicable database including the most frequent activities etc. The development of site dependant LCA will be less important in the context of SEA, since other parts of the SEA toolbox like EIA and IEA methodologies covers these site dependant aspects more properly than is likely to be realistic within LCA-methodology. Besides, EIA and IEA applications also embrace more ecological aspect that is covered by current LCA practice. So, in conclusion:

> *LCA is a cost effective tool in the SEA toolbox, that complement other more site specific environmental tools, why generic approached LCA methodologies will be preferable. The generic applicable LCA methodology specifications have then to be complemented with object specific settings, focusing on specification relevant for analysed the infrastructure system.*

5.6 New constrains when LCA is applied in SEA

The following constrains are identified in this pilot study on LCA in SEA, as described below.

5.6.1 Environmental permit dilemmas

It is here supposed that traditional element included in EIA will be part of the SEA toolbox (as well as IEA). This will result in two different environmental performance-related results, where the EIA may gives an estimation of, for instance, a concentration of a substance in the ambient air that is above a national environmental quality standard. Nevertheless, in the same case a performed LCA could hypothetical then indicate that this very same alternative is the most profitable one in a more holistic perspective. The problems that appears, is equal to a question asking;

> *can a holistic profitable infrastructure solutions be justified by causing locally increased impact, e.g. above a quality norm?*

With other words the dilemma is; how can we compare and evaluate flow related environmental performance versus locally appearing concentrations, in a way that is acceptable that an overall optimisation can be achieved and commonly accepted in the community.

Partly, this problem could be traced back to the problem if it can be allowed to contribute to an already to high background concentration of a specific substance in a recipient. Is it always obviously that it is the latest appearing emission source that shall be the one that shall take the "full" responsibly, or is it juridical and practical possible to share and distribute this responsibility between the different emissions sources, which then could make an holistic and potentially cost effective solution possible? The problem area also partly share the same socio-economical interest as e.g. allocations plans for allocation trading and country specific emission limitations defined by the ceiling directive.

5.6.2 Accounting of historical data and potential future restoration

The entitled problem area is here described together with suggestions of how this could be handled.

In traditional LCA the entire life time of a service or a product are accounted for, starting with its resource extraction, manufacturing and so on via usage phase until it is discharged, which is justified by a plain life cycle approach. However, when LCA are applied in SEA, a margin thinking approach must be a more adequate system perspective. This implies that all existing infrastructures that are facilitated in a new corridor etc. shall not be accounted for the historical impact that origins from when "reused" materials or part of the existing infrastructure was constructed. Consequently, only additional impact that are part of the new infrastructure – and treatment of the potential existing one – has to be accounted for. This line of argument is known as a *sunken cost* in economics, and is found relevant here as well. Moreover, discharged material treatment and site contaminations etc. that has to be performed due to the new infrastructure investment, but caused by the existing infrastructure object, will be accounted for the same new infrastructure investment.

In parallel to the discussion above, no potential future restoration of the land, facilitated and caused by the new analysed infrastructure object, will consequently not be accounted for as part of the same infrastructure object. Hence, this will be accounted for the potentially next infrastructure investment. The backlash of this allocation solution is that an infrastructure contributes to a potential future environmental restoration cost that will not be accounted for. This problem could partly be solved if quality parameters for brown fields were able to establish and met by the design of the new infrastructure object. This kind of environmental quality objective is not developed, but a project suggestion is developed as part of in project interest for the 5th Environmental Research Program by IVL et al.

6 Approach for future work

As already indicated above the following aspects are found relevant for further work and to be a part of a common solution in order to make LCA to a competitive tool in the overall SEA toolbox:

- Environmental permit dilemmas
- Accounting of historical data and potential future restoration

Besides these aspects, to make the LCA cost efficient enough to be applied by any practitioner and to harmonise the final result in line with EU policies, the following issues will also be subjects for further work:

- Develop and establish LCI modules that can be utilised in "construction" an LCA for the specific SEA/LCA objective.
- Establishment of a pan European LCI data format that most LCA tool facilitate, e.g. the EcoSpold format [15] or SPINE [16], and complement this with defaults documentations parameters that improve the data collection and the interpretation, see e.g. reference [17].
- Developing of a LCI database reported in the format established above and covering the LCI modules defined above.

- Develop a European generic EQO normalisation method that will harmonise the result from an SEA/LCA, but will not exclude the application of other country related or any other impact assessment method.

Furthermore, it could be adequate to evaluate overlapping and shared interest areas with different near related directives etc. such as the relation to other EC directives such as "auto oil II" directive, ceiling directive, green/white paper on Integrated Product Policy (IPP), other research and development initiatives such as [18] and [19] where guidelines for Environmentally Sustainable Transport System (EST) are discussed.

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