Environmental Performance of the Rail Transport System in a Life-Cycle Perspective

- The Importance of Service Life and Reuse in Sweden

Karin Swärd

Karin Swärd
Author
Författare
– The Importance of Service Life and Reuse in Sweden
Järnvägstransportsystemets miljöprestanda i ett livscykelperspektiv

Storage and documentation of products. Tradition and routines also stand in the way of creating a sustainable reuse of these products. The administration of the used material is the main problem in order to create a well-functioning reuse of railway articles. This includes transports, actions of maintenance prolong the durability of the products, e.g. by increasing the stability in the embankment and hence reduce the wearing.

Energy allocated to the tracks where the products are reused is calculated to 3 GJ/yr and km for the railway ties and to 7 GJ/yr and km for the rails. This derives from the rails and the railway ties. In reducing the environmental pressure it is important to make use of the products as much as possible, depending on that the most energy efficient strategy is to reuse the products possible to reuse. The main part of this improvement potential is as much as 69 % altogether. If the Realistic Scenario is applied, the improvement span is calculated to 23 % and if the Best-Case Scenario is applied the span is calculated to 7 %, depending on that the most energy efficient strategy is to reuse the products possible to reuse. The main part of this improvement potential derives from the rails and the railway ties. If the New-Technology Scenario is applied, the improvement span goes up to 50 %. A great improvement potential exist for all the products if the New-Technology Scenario is applied and to 33 % if the Realistic Scenarios are applied. If the Low Realistic Scenarios are applied the reductions goes up to 50 %. A great improvement potential exist for all the products if the New-Technology Scenario is applied and to 33 % if the Realistic Scenarios are applied. If the Low Realistic Scenarios are applied the improvements are calculated to 38-39 %.

Scenarios are applied. The products where the main improvement potential when it comes to the Realistic and the Low Realistic Scenarios exist are the railway products, as well as reuse of them. The objective is to map estimated service lives and reuse in order to create scenarios representing the present state of how the products are used and reused in Sweden. The scenarios are used in order to analyze the importance of focusing on service lives and reuse when reducing environmental pressure. The objective is also to find out which possibilities and hindrances there are to increase the service lives and the reuse of the products.

To investigate the environmental pressure of the railway infrastructure, embodied energy is used as indicator. Embodied energy represents the energy needed to produce a product, from extracting the materials to the production phase. The present state concerning service lives and reuse of the studied products are mapped through interviews with employees at Banverket and at VTI. The empirical material is analysed and scenarios are created in order to evaluate the environmental importance of service lives and reuse. Organizational issues concerning service lives and reuse are also investigated.

The present state service lives varies between 25 and 100 years for the realistic scenarios for all the products, between 15 and 80 years for the new technology scenarios and between 60 and 120 years for the best-case scenarios, depending on railway product. The only products reused today are rails and railway ties. There are considerable improvements to be made by increasing service lives of all the studied products. The reductions in embodied energy per year go up to 75 % if the New-Technology Scenario is applied and to 33 % if the Realistic Scenarios are applied. If the Low Realistic Scenarios are applied the reductions goes up to 50 %. A great improvement potential exist for all the products if the New-Technology Scenarios are applied. The products where the main improvement potential when it comes to the Realistic and the Low Realistic Scenarios exist are the macadam-ballast, the cables, the rails and the railway ties. If the New-Technology Scenarios are applied for all the products the total improvement span is as much as 69 % altogether. If the Low Realistic Scenario instead is applied, the improvement span is calculated to 38-39 %.

If the Realistic Scenario is applied, the improvement span is calculated to 23 % and if the Best-Case Scenario is applied the span is calculated to 7 %, depending on that the most energy efficient strategy is to reuse the products possible to reuse. The main part of this improvement potential derives from the rails and the railway ties. In reducing the environmental pressure it is important to make use of the products as much as possible, i.e. to reuse them and use them as long as possible. All energy invested in the products is then made use of. This is the most environmental sound alternative. This gives a need for embodied energy of 16 GJ/yr and km for the railway ties and 38 GJ/yr for the rails on the mainline track. The energy allocated to the tracks where the products are reused is calculated to 3 GJ/yr and km for the railway ties and to 7 GJ/yr and km for the rails. Actions of maintenance prolong the durability of the products, e.g. by increasing the stability in the embankment and hence reduce the wearing. The administration of the used material is the main problem in order to create a well-functioning reuse of railway articles. This includes transports, storage and documentation of products. Tradition and routines also stand in the way of creating a sustainable reuse of these products.

Nyckelord
Embodied energy, infrastruktur, järnväg, livslängd, miljöprestanda, återanvändning

Keywords
Embodied energy, environmental performance, infrastructure, railway, reuse, service life
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1 Introduction

The anthropogenic impact on the environment is strongly depending on the ways that we change the natural flows of energy and materials. The man-induced environmental impact has increased rapidly ever since the industrial revolution. The strategies to reduce the environmental problems have however changed focus through the years. An early utilized strategy is trying to remove and dilute the pollution by e.g. employing high smokestacks to get rid of the discharges. The dominating strategy in the end of the last century was to clean the discharges from e.g. industries and in this way reduce the environmental pressure, a strategy called the end-of-pipe solution. This strategy has been very effective and has reduced the local industry discharges greatly. This is however not enough to create a sustainable society (Ammenberg, 2004; Rydén et al., 2003).

A lot of the environmental problems cannot be solved only by the end-of-pipe solution. The materials passing through the gates of the industries are by using only the end-of-pipe solution not handled at all. This is the reason why the focus during the last decades in many cases have shifted to include all the phases in a product’s (or a service’s) life – the so called life-cycle perspective. This implies that you consider the environmental pressure from the cradle to the grave; hence from extracting the raw materials, creating the product, using the product and finally wasting the product, for example by recycling or reuse. Important factors to consider in the whole life cycle are energy consumption, material usage and discharges in any form (Norrblom et al., 2000; Thormark, 2001). There are different ways of evaluating environmental impact in a life-cycle perspective. A common way is to perform Life-Cycle Assessments (LCA), which can be done at different levels of detail, from complex computer models to overview sketches (Norrblom et al., 2000).

The transport system has a large environmental pressure on the environment, e.g. because of its pressure on the climate change (Potter & Enoch, 1997). This pressure is mainly due to the usage of fossil fuels. Train traffic is habitually regarded as an environmentally preferable transport mean, mainly depending on that trains can be, and often are, driven by electricity. This is also true when the operation phase alone is considered, at least if the electricity derives from renewable sources (Smith, 2003), but in a life-cycle perspective the advantages of this mean of transport get less apparent. For example does the extraction of the raw materials require plenty of energy, energy which in turn often is produced by fossil fuels, and therefore affecting the climate change anyway (Svensson & Eklund, 2001 and 2003b). A study made by Maibach et al. (1997) indicates that rail is the most efficient transport form when its operation alone is considered. But when what the authors call the pre- and post-transport processes, particularly building and maintaining of the infrastructure are included; the quantity of energy that is needed is almost the same as public road transport. Approximately 80 per cent of the energy relates to these pre- and post-transport processes (Maibach et al., 1997).

The energy that is embodied in the infrastructure is often called material-related energy, or embodied energy. A dominating part of the material-related energy requirements in the railway infrastructure can be referred to a few materials. The main part of these materials can in turn be found in a few products which are rails, railway ties, ballast materials, cables and products of copper in and contact wire system (Svensson & Eklund, 2001). It is here that the effort to reduce the environmental impact of the railway infrastructure has to lie to become most efficient.
There exist question marks considering on which factors focus should lie in order to best improve the energy efficiency of the railway transport system. One question mark pertains to how the service lives of the energy-intensive materials affects the energy requirements for the infrastructure. The service lives stands for the technically possible durability of the products, but also the time the products are used in practice. Reuse of materials on less busy stretches is common, and this factor is also important to consider. To be able to reuse materials is an environmental benefit, but new energy investments follow with the allocation, such as transports and construction of the new tracks, factors which also need to be addressed. To create an accurate organization in order to reduce the environmental pressure may not be easy; measures affect each other and opinions on how to create a sustainable environmental management may diverge.

1.1 Aim and objectives

This master thesis is a part of a research project which has the aim to investigate the environmental pressure deriving from the rail transport system, with focus on the railway infrastructure. This is done to be able to decide how to improve the environmental performance of this transport form.

The aim of the thesis is to investigate how the material-related energy utilization, and hence the environmental pressure, is affected by the service lives of the most energy-intensive railway products, as well as reuse of them. The objective is to map estimated service lives and reuse in order to create scenarios representing the present state of how the products are used and reused in Sweden. The scenarios are used in order to analyse the importance of focusing on service lives and reuse in reducing environmental pressure. The objective is also to find out which possibilities and hindrances there are to increase the service lives and the reuse of the products.

1.2 Questions in focus

The aim could be transformed into five specific research questions:

- How can the environmental pressure be influenced through changed service lives?
- How does the present state considering service lives and reuse in Sweden appear?
- Do the estimations of service lives diverge between different actors?
- How do the actions of maintenance affect the service lives and the environmental pressure?
- Which measures are important to take for the different products groups?
  - What can be done by Banverket; the Swedish Rail Traffic Authority?
  - What can be done by the producers/suppliers of the products?
1.3 About this thesis

In order to facilitate for the reader it is here presented how the report is structured.

In the background chapter the studied products are first presented. This information is not necessary to read if you are familiar with the studied products. Information about recycling potential of the materials used in the railway is also presented. This information is important to read to be able to understand the results.

The method chapter consist of information about how the study was performed. Here you also find information about energy indicators and embodied energy, together with information about qualitative interviews, system analysis, system boundaries and the creation and comparison of scenarios. Information about the applied allocation method is also presented.

The chapter Background values and information is created to show the data which the scenarios are based on, i.e. the data used for embodied energy and material use on a kilometre railway.

Chapter 5, 6, 7 and 8 form the results. In Chapter 5 the present service life estimations are presented. Chapter 6 consists of information about actions of maintenance concerning the studied products, and how these actions in turn may affect the service lives and the energy demand. Aspects of reuse and recycling are presented in Chapter 7. The results in Chapter 5, 6 and 7 forms the information obtained at the interviews. In Chapter 8 the results from the scenario calculations are presented, which are based on the information about the present state, which is obtained in the previous result chapters.

Eventual sources of error and other factors which may affect the results are presented in Chapter 9. In the discussion chapter, Chapter 10, the results are reflected upon and organizational and administrative issues are lifted, together with factors which may complicate the creation of a sustainable environmental management considering the railway sector. The conclusions of the thesis are shown in Chapter 11.
2 Background

Information about the studied railway products and their recycling potential is presented in this section.

2.1 The studied products

Here information about the studied materials is presented. A vocabulary of the railway specific concepts used in this thesis is presented in Appendix 1.

The environmental pressure deriving from the railway infrastructure is connected with the different components, the working process (both construction and maintenance) and waste management. The environmental pressure depending on the used products derives mainly from the spreading of metals and organic contaminants (Boëthius & Karlsson, 1996) and the energy embodied in them. In the working process emissions from machines, energy requirements and consumption materials are included (Boëthius & Karlsson, 1996).

2.1.1 Ballast material

The railway embankment is constructed in different layers, as presented in Figure 1. The quality of the ballast material is important in order for the trains to travel safely and softly. The macadam-ballast makes the track stable and the train to run softly. It consists of crushed aggregates or natural gravel, and is usually about 30-50 cm deep. The sub-ballast drains the embankment and spread the pressure. This layer can consist of crushed material, soil material, coarse crushed rock or blasted rock. The embankment filling stabilises the embankment and leads out water (Grus- och makadamföreningen, 2001). The quality demands for macadam is higher than for the sub-ballast, the qualities considered are the distribution of grain sizes, the shape of the stones, the angularity, the strength and that they are clean (not contaminated) (Banverket, 2005).

![Figure 1. Schematic description of the different layers of ballast material in the railway embankment.](image)

Macadam-ballast is usually consisting of grain sizes between 32 and 64 mm. In the rearment process of a railway embankment macadam is regularly used (Grus- och makadamföreningen, 2001). In marshalling yards maximum grain sizes of 32 mm is ordinarily used, to create a good work environment (Boëthius & Karlsson, 1996). A lot of low trafficked tracks contain regular gravel, not high quality macadam (Respondent 1, 2005). These are not studied in this thesis.
This sub-ballast material can contain gravel and blasted materials from the project. The blasted material is often transported to a manufacturer and is refined there. This is done because the handling of the blasted materials when it is transformed into ballast materials produces a lot of noise, which can be a problem if the area is populated (Respondent 2, 2005). This may therefore vary between different stretches.

Another reason that the ballast material from the site is not used directly is that it commonly has not the sufficient quality. It is however fairly common that blasted materials are used to fill up and to make the building area flat, or to build temporary work roads for the project (Respondent 3, 2005).

The material is purchased by the contractors for the different railway projects (Svensson, 2005). The ballast material has no surveyed environmental pressure during its operation phase (Boëthius & Karlsson, 1996).

2.1.2 Cables

Cables are used both to lead electricity and to deliver signals, and they can be located both under and above ground. Both electricity supporting cables and signal cables are reconsidered in this thesis. Only cables of copper are reconsidered in this study, since these are the most frequently used at the tracks outside the station areas. The cables are surrounded by a coat of lead, aluminium or plastic. The lead coats are now phased out, of environmental reasons. The cables put in use today at the Norrköping track area are the ones with a plastic coat (Respondent 4, 2006).

2.1.3 Contact wire system

The contact wire system provides the trains with electricity. It consists of a contact wire, which is connected to the electricity taker at the trains when they run. The contact wire is hanging in several carrying wires, which in turn are connected to a carrying line. They all consist of copper. Copper are spread from the contact wire, depending on the wearing (Boëthius & Karlsson, 1996). The wearing is however lower today, depending on new technology (Respondent 4, 2005) (see Chapter 5.4). The carrying line may also be an alloy with bronze and the contact wire can be alloyed with silver, with the purpose to increase the strength (Respondent 5, 2005). This is however not favourable because of environmental reasons, since material recycling gets more complicated (see Chapter 7; Reuse and recycling).

The cross section area of the contact wire is about 100 mm$^2$, and the cross section area of the carrying line is about 60 mm$^2$ (Respondent 4, 2006). The carrying line is twined, while the contact wire is founded in one piece (Boëthius & Karlsson, 1996).

Regional tracks are often not electrified, which means that the products of the contact wire system are often not used on those kinds of tracks (Respondent 6, 2005).

2.1.4 Rails

The rails are the steel strips at which the trains run (see Figure 1). They contain iron, manganese, silicon; small amounts of sulphur and phosphorus and in some cases also chrome (Boëthius & Karlsson, 1996).
There are different sorts of rails, and the difference is depending on their weight per meter. Often used weights are 43-, 50- and 60-kg per meter. The heavier rails are used on the busiest tracks with the heaviest traffic (Respondent 10, 2005). 60-kg rails are used on the main line railway in Sweden, but also on less busy tracks. This is therefore the weight of rails that is used in this thesis. The 43-kg rails are not available as new any longer (Respondent 7, 2005).

2.1.5 Railway ties

The railway ties are functioning as a foundation for the rails, and they also fix the rails and transfer the forces further down in the embankment (Boëthius & Karlsson, 1996), see Figure 1 for visualisation. Only concrete railway ties are studied in this thesis. This is because this is the most common railway tie, except at the marshalling yards, where wood railway ties are more common (Respondent 8, 2003). There exist concrete with different properties, i.e. waterproof concrete, light weighted concrete and concrete with increased strength (Grus- och makadamföreningen, 2001). There is however only one sort of concrete railway tie used in Sweden when it comes to ordinary tracks. There are two different suppliers in Sweden though, but they are very similar (Respondent 9, 2005).

Railway ties are produced in several places in Sweden. The concrete ties are founded in forms. The materials are cement, additive chemicals, natural gravel, crushed material, water and reinforcement bars of steel (Engberg & Eriksson, 1998). The concrete contains about 80 % ballast material, 12 % cement and 8 % water (Grus- och makadamföreningen, 2001). The tie is attached to the rails with an attachment appliance, which is constructed in different way for different types of railway ties (Engberg & Eriksson, 1998). The type of attachment appliance used in this study is the so called pandrol attachment appliance. This is because this is the most used one, depending on a widespread understanding that these achieve the best durability of the railway ties. No railway ties with FIST-attachments have been bought in as new since 1977 in Sweden (Boëthius & Karlsson, 1996). They may serve as reused material though.

The total weight of a concrete railway tie is 250 kg. The environmental impact from a concrete railway tie derives mostly from the production phase (Engberg & Eriksson, 1998), mainly from the production of cement, which is a very energy demanding process, and it causes emissions of Carbon Dioxide (CO₂), Sulphur Dioxide (SO₂) and Nitrogen Oxides (NOₓ). The energy derives mainly from fossil fuels (Gillberg et al., 1999).

The environmental impact would also be reduced if the railway ties were produced by recycled material, depending on that the energy-consuming first steps of the life-cycle, extraction and refining of materials will not be repeated. This is however depending on that the usage of recycled materials do not demand very long transport distances (Engberg & Eriksson, 1998).

2.2 Recycling potential

To reach a sustainable development a cyclic usage of materials is needed (Regeringen, 2003). This is achieved by recycling, which is a generic term used for different types of recycling, for example reuse, material recycling and combustion of materials. The term recycling is sometimes used synonymous with material recycling, but to avoid confusion, the term
recycling is only used as a generic term in this thesis. The term reuse is in this thesis used when products are used again in the same function and without being treated in any other way than by some small adjustments, such as e.g. grinding of the rails in order to regain the accurate profile (see Chapter 7; Reuse and recycling).

The main reason to recycle is to save energy and other resources. By making accurate decisions when choosing materials recycling is rendered possible (Fröst, 1995; Thormark, 2001). The most energy efficient way to make use of an old product is to reuse it. If this is not possible, material recycling is the second best alternative, and combustion of the product the last recycle alternative. When a product is recycled in a way that makes it loose its original form, which means that not all energy is taken care of, a down-cycling occurs (Thormark, 2001).

Recycling is achieved in the building sector through selective demolition, which means that the materials are separated and sorted during the demolition to make recycling possible (Fröst, 1995). The sorting of materials ought not to be a mayor problem in the railway infrastructure sector. A lead word to facilitate material recycling is to use as clean materials as possible, for example not to use alloys (Fröst, 1995), to use as few materials as possible and to standardize those (Signal, 1996).

Materials is likely not to be recycled if there are no market for them (Härle et al., 1994). This means that if no purchasers buy recycled materials, these materials will not be promoted in the future. The logistics of the used materials is often the factor which decides whether the materials can be made competitive on the market. The costs are reduced if the materials are used on the same site. Waste fees can facilitate the trade with recycled materials, which has been shown in Denmark. The transports also decide whether it is environmentally favourable to recycle the materials. The transports are very important for heavy materials as concrete and metals (Fröst, 1995). The environmental pressure can in fact be higher in a recycling scenario – if the transports are not handled well (Thormark, 2001). Other prerequisites for establishing a market for recycled materials is quality demands, capacity demands (i.e. the right amount of material at the right time) and a functioning management system for the materials. Economic factors that also have an impact are costs for the eventual treatment of the materials, the cost if the material instead were put on a landfill and the costs of new materials (Hartlén et al., 1999).

The environmental pressure becomes less per year if the service lives of the materials used are made as long as possible, at least if the prolonging process does not bring about an environmental pressure which increases the total environmental pressure per year (Thormark, 2001). To design the materials in a way which facilitates the maintenance of the railway track is a form of green design (also called design for sustainability) which extends the service lives of the products (Signal, 1996).

2.2.1 Materials suitable for recycling in the railway infrastructure

Here materials that are suitable for recycling in the railway infrastructure are presented. Parameters to reconsider when settling if a material is reusable is the quality, appearance and need for reparation or other measures (Fröst, 1995). The purchasing of materials which are possible to recycle when their service lives are finished is also a part of making the material use cyclic, as well as the avoiding of materials which complicates recycling (Thormark, 2001).
Design for sustainability is advancing in the building research area. This implies that it becomes easier to find recyclable materials and products. Which ways of recycling that is possible is often determined already in the designing phase (Thormark, 2001). The production process is sometimes in need to be adjusted in order to make recycling possible or easier. A lead word is to reduce the number of material used, but also to label materials such as plastics, to facilitate material recycling (Engström et al., 1993). To influence producers of railway products may be an important way to increase the recycling potential. For the railway sector to retain its good environmental reputation the development of green design is of great importance (Signal, 1996).

Concrete is one of our most dominating building materials, and concrete products can sometimes be suitable for reuse. Concrete can be examined to discover eventual fractures for example by using ultrasound. It can also be examined whether there is corrosion on the reinforcement bars, for example by using a polarisation resistant method (Fröst, 1995). These methods can be used to be able to decide whether a railway tie can be reused. The material can also be crushed to concrete gravel. This crushed material can be used in asphalt (Fröst, 1995), or to produce new concrete (Gillberg et al., 1999). The concrete products of interest in this thesis are the railway ties. Crushed concrete is in Sweden often used as filling material and to cover landfills, which may be a way to make use of broken railway ties (Fröst, 1995). The material can be used within Banverket or be sold.

The production of metals is in general very energy demanding. Metals are also limited resources, although it may be difficult to settle how much there are left of them in nature (Thormark, 2001). These are important reasons to economize with our metals. Products of metal are often suitable for reuse. They are also easy to material recycle, if they are not alloys (Fröst, 1995). The metal products of interest in this thesis are the rails, the cables and the contact wire system. There are examples where rails are reused as stair rails (Fröst, 1995).

Rock material is a necessary building material in buildings and infrastructure. Ballast is a generic term naming all rock material used in the building and construction sector. The raw material of ballast is crushed rock, natural gravel and recycled material. Natural gravel have traditionally been the dominating ballast material in Sweden, but the proportion of crushed rock in Sweden have increased to about half of the ballast material the last decades (Grus- och makadamföreningen, 2001). Natural gravel is also a finite resource; it may have to be produced in the future. The resource is calculated to be finished in some regions in Sweden in 10-30 years (Thormark, 2001). Because of energy demands in the future’s possible production of crushed aggregates the reasons for recycling of natural gravel is obvious. Other causes to decrease the usage of natural gravel are to conserve gravel ridges and ice river deltas; geological formations which will not recreated within a foreseeable future. Gravel ridges purify drinking water for half of all population centres in Sweden (Grus- och makadamföreningen, 2001). It may also be important to carefully economize with the high quality natural gravel labelled macadam, used as the over-layer of the railway embankment, and only use if where it is absolutely necessary. Natural gravel is in the railway sector used as macadam and sub-ballast. The quality of the raw material is depending on the geological origin of the rocks (Grus- och makadamföreningen, 2001). A prerequisite for recycled material to be used more frequently as ballast material is that its quality can be assured and approved by the purchaser (Grus- och makadamföreningen, 2001).
2.2.2 Recycled material to use for the railway infrastructure

To obtain and promote a cyclic material use in the railway sector a purchasing of non-virgin materials is also desirable; in order to promote the market for recycled materials. Of course, Banverket can use all those products suitable for reuse mentioned above and some of the materials suitable for material recycling.

Crushed bricks can be used as ballast material in concrete, but the concrete may be more sensitive for frost (Fröst, 1995). Crushed bricks may therefore be used as ballast material in the railway ties.
3 Method

This master thesis is a part of the research areas environmental management and environmental system analysis. Important theories within this large research area are e.g. *Factor 4 and 10 and Industrial Ecology*.

Industrial Ecology is a research area and a strategy to obtain a sustainable development in the industrial system by being inspired by the biosphere. The term stands for an attempt to reach a sustainable development, which means that ecological, social and economic aspects are all important factors to consider. The confidence in technological development during the transfer from the unsustainable industrial system of today to a sustainable one is strong in this theory (Erkm an, 2003). Industrial Metabolism is an area within Industrial Ecology which stands for an attempt to imitate the circulations of materials the nature and applying this in the society, for example by making use of all the waste products (Fisher-Kowalski, 2003). Factor 4 and 10 stands for calculated factors which several environmentalists claim we have to decrease our environmental pressure with, given different conditions, for example the population growth (Ammenberg, 2004). To investigate how it is possible to reduce the environmental pressure deriving from the railway infrastructure is a part in reaching these visions of a sustainable society.

To investigate the environmental pressure of the railway infrastructure, energy is used as indicator, mainly because this is a common indicator that mirrors environmental impact and because this is a suitable indicator for this particular situation (see Chapter 3.1).

To settle the service lives and reuse of the studied products, interviews are performed with employees at Banverket and at VTI; the Swedish National Road and Transport Research Institute. The present state service lives of the products are settled for different types of railway tracks (see Chapter 3.2 for information about the interviews). The empirical material is analysed in a system analytical perspective (see Chapter 3.3 for information about system analysis) and scenarios are created to decide how the material-related energy utilization is affected if the service lives of the products are changed. The scenarios are created in order to mirror situations occurring in reality (see Chapter 3.4 for information about the scenario creation). The estimations made at the interviews are the basis for the scenarios. The allocation of the materials makes it more difficult to connect specific energy requirements with a specific stretch. This is also a question which is addressed in this thesis, together with the transports and construction connected with the allocation. For information about the allocation, see Chapter 3.4.1.

It is also investigated which hindrances and possibilities that are connected with an optimization of the service life of the products, and it is investigated how the different scenarios correspond to these hindrances and possibilities, in other words; how the scenarios, which are supposed to represent different ordinary situations, work in reality.

The studies made by Svensson & Eklund, within the ongoing project *Possibilities and obstacles to reduce the environmental impact from the railway infrastructure by working in product systems* forms the foundation for this master thesis.
3.1 Energy as an environmental indicator

Environmental indicators are used to illustrate environmental pressure in several contexts, both on the business and the scientific arena. The utilization of environmental indicators has become common in environmental research and management, because they simplify complex issues, which in turn makes it easier to make accurate decisions (Smeets & Weterings, 1999). It is however very important to choose the indicator or indicators carefully, because the selection strongly affects the focus of the results (Svensson et al., 2006) The indicator or indicators that is chosen should cover as many environmental aspects as possible; particularly the aspects of interest for the study. It should give easy understandable information about the present situation in the studied system (Smeets & Weterings, 1999).

If too many indicators are used several problems arise; for example may the collection of data be impossible to perform within a reasonable time-frame and the results can be more difficult to adopt. There is a balancing act between having too much information for the decision-makers to handle, and too little information; so that the results do not mirror the reality in an accurate way, which in turn would lead to bad decisions (Svensson, 2005). It is also important to note that an environmental indicator always is a simplification of a complex reality. There is a risk when choosing a single indicator that the indicator does not cover all the environmental aspects that are expected. There are however many benefits with choosing only one or a few indicators; for example does a few indicators make it easier to study the chosen topic (Smeets & Weterings, 1999; Svensson et al., 2006).

The usage and handling of energy in society affect the environment heavily (Statistiska centralbyrån, 2003). The European Environment Agency (2001) ascribes energy to be the basic driving force behind both the climate change and a number of other air pollution problems. The energy consumption is unfortunately still increasing, mainly depending on a growing demand in the transport sector (European Environment Agency, 2001). Different sorts of energy indicators are common. Svensson et al. (2006) shows that a number of studies in for example the research areas of energy systems, transportation systems and building have used energy indicators. The authors also show that energy indicators are recommended in the ISO 14 031 standard, the EMAS regulation and by the World Business Council for Sustainable Development (WBCSD). Bouwman & Moll (2002) point at a number of previous studies that have used energy consumption of different means of transport as an environmental indicator. Statistiska centralbyrån (2003), the Swedish authority responsible for all statistics on e.g. the environment and the population, use gross supply of energy, divided into the different energy sources, as an environmental indicator mirroring the state in Sweden.

In this thesis the system is not as big as a whole country but rather energy within the rail infrastructure managing system. Thormark (2001) uses almost exclusively an energy indicator, for the reason of the easiness to get hold of data and because it mirrors many important environmental problems. She also shows that numerous studies point out that the usage of energy brings about undesirable environmental effects, and that these will be even bigger in the future (Thormark, 2001).

However, Svensson et al. (2006) holds that the reason why energy indicators are relevant seldom is questioned and discussed. It seems that the relevance of the indicator is considered obvious. The authors suggest that the indicators that are utilized and considered as relevant vary over time, something that is depending on which environmental problems that the society is focusing on at the moment. The reason why energy is viewed as a relevant indicator now may be a result of the present focus on global warming (Svensson et al., 2006). Society
is on the other hand likely to remain dependent on fossil fuels in a foreseeable future, and therefore global warming is also likely to continue being a problem (European environment agency, 2001).

Environmental pressure and energy use is strongly connected in many ways, for example are the material flows in society depending on energy. This makes energy indicators relevant, although the indicators naturally do not include all environmental impacts completely. Energy indicators can be regarded as obvious indicators in a wide sense, since all human activities demand energy, and the energy is in turn created within an energy system that generates environmental impact. There are however some environmental impact categories that are more affected by the utilization of energy than others (Svensson et al., 2006).

When utilizing an energy indicator it is also important to reflect on the existing energy system, for example which energy sources that is used in the specific region under focus (Svensson et al., 2006). The environmental pressure deriving from the use of energy is different in countries where the energy mostly is produced by hydro power, compared with countries which produce energy from coal and oil combustion. When using an energy indicator it is also important to mention which energy source that is used for producing the energy. Therefore it will as long as it is possible be indicated which energy source that is utilized. If the environmental impact of the rail system in the operation phase would be under focus, the choice of energy as indicator would not be as suitable, because electricity is the main fuel for the train traffic in Sweden today. The electricity in Sweden is mainly produced by hydro- and nuclear power (Stripple, 2001). The rail systems’ infrastructure is more energy-intense than the road infrastructure, and the energy derives almost exclusively from non-renewable energy sources. Those fuels have in turn a major impact on the most alarming environmental problems of today, for example global warming, acidification and toxicity aspects. If the studied system would include many toxic chemicals, not deriving from the utilization of fossil fuels, an energy indicator would not alone be suitable (Svensson, 2005).

There are different types of environmental indicators (see Smeets & Weterings, 1999). The energy indicator is an indicator which reflects the pressure on the environment, which means that it describes the situation in a system. Other pressure-mirroring indices are emissions of substances and usage of materials (Smeets & Weterings, 1999). By looking at the present pressure in a system you can compare with other systems or improve and measure once again to see the improvement. The energy indicator leads to many different other possible indicators, such as CO₂ emissions. The reason why emission indicators are not used in this study is because the energy indicator used (see below) includes many emissions, together with that there are many benefits with using only one or a few indicators, mainly to make the results easy to adopt (see above).

It is relevant to use an energy indicator in those cases where the energy use has a dominant environmental pressure. In other cases, where other environmental pressures are more dominating, energy as a single indicator may not give an accurate picture of the total environmental pressure (Svensson et al., 2006). By this follows that when choosing one or more indicators it is of great importance to reflect on the aim with the study, and the factors that are of importance for the study. When using an indicator, it is necessary to have an apprehension of the most important environmental impacts within the studied system, to make sure that the chosen indicator covers the desirable impacts (Svensson et al., 2006). The indicator used in this study is not meant to be seen as a fixed number; instead it is meant to compare environmental pressure in an easily understandable way.
3.1.1 Embodied energy

The kind of environmental indicator that is utilized to mirror environmental pressure in this thesis is *embodied energy*, an indicator mainly used in the building-, energy- and transport sector, depending on these sectors’ considerable environmental pressure connected with their energy-consumption (Svensson, 2005). Embodied energy can be seen as an environmental indicator that can have its application on technological systems.

By using embodied energy it is possible to calculate and evaluate the environmental pressure of the infrastructure of the railway system. Embodied energy stands for all the energy that is needed to produce a product, from extracting the raw materials to the usage phase (Thormark, 2002). Another term for embodied energy is material-related energy use. The reason why this particular energy indicator is used is because it is suitable to use when studying these types of systems, together with that the energy deriving from the phases up to and including the production phase stands for the differentially largest part of the energy requirements in the studied system (Maibach *et al.*, 1997). The indicator is in this study calculated from primary energy use, which means all energy needed to produce the products is included, including the energy losses.

3.2 Qualitative interviews

Qualitative interviews have been performed with employees at Banverket and at VTI. The interviews were made in order to map the present state concerning the use (the service lives) and reuse of the studied railway products in Sweden today. The estimations of service lives were used to create scenarios representing how the products are used in Sweden today. The interviews also gave information about the administration of used materials and actions of maintenance.

The choice of respondents is of high importance for the result, and this has therefore been made very thoroughly, and with great respect of the aim with the study (Ejvegård, 1996). Qualitative interviews involves a direct communication between the interviewer and the respondent, which means that there is less risk for misunderstandings and also that there are a possibility to put resulting questions. A qualitative interview can be either structured or unstructured. In a structured interview all questions are decided beforehand, as well as the question sequence. In a totally unstructured interview no questions are decided beforehand, the only thing decided is the theme of the interview (Carlsson, 1997).

The interviews made for this thesis was structured, but there was also room for resulting questions. A question manual was made before the interviews. The questions were however not the same for every interview, since the respondents have different areas of profession. The questions are formulated as clear as possible, to reduce the risk for false interpretations (Carlsson, 1997). If an answer to a question was either hard to interpret or vague, resulting questions were put in the interview situation or afterwards, to minimize the risk for misunderstandings.

The interviews have been taped on a voice recorder. The taping was performed to facilitate the interview situation for the interviewer, so that she was able to overview the interview as a
whole, instead of being busy writing. The taping also reduces the risk of misinterpretation already in the interview situation, which is possible when the answers are written down rapidly.

The answers from the interview are put down on paper principally word for word. The text is however not written in spoken language, of respect for the respondents. The purpose with the interviews is not to analyse how the respondents answered but what they said. The interviews are used to gain more knowledge about the studied area, but they are not analysed in a way to obtain values and differences in reasoning, because this is not the purpose with the interviews in this study. The interviews are instead made to obtain facts about service lives and reuse in Sweden, together with actions of maintenance and administrative issues concerning use and reuse.

The interview process started with an interview with one employee at the main office of Banverket. This is a person who, according to the supervisor of the thesis, possesses much knowledge in the given area. During this first interview all questions were asked, and when the respondent could not answer a question, he was asked to suggest one or more persons that might be able to answer the unanswered questions instead. In this way the respondent also becomes an informant in the interview process. To find the right persons to proceed in the interview process, the key informant or informants are essential for the success of the study. It is preferable not to build up the study only on the opinions of one single person (Yin, 2003). This study has therefore been performed by first interviewing this first person, and where gaps of knowledge have occurred, new respondents have been asked for. This has been done in every interview, and when the gaps were filled and when the same names were given in several interviews, the information was assumed to be sufficient. This method is sometimes called the snowball method, since the empirical material increases by every interview, in the way a snowball increases as it rolls down a hill (Halvorsen, 1992). The total numbers of respondents are 16, of which 3 of the interviews were made for Swärd (2005) and 2 for Svensson & Eklund (2003a).

3.3 System analysis

System analysis is a methodological science, and contains methods and techniques to describe, analyse and plan a complex system of any kind. A system analysis can be both quantitative and qualitative, and it can be performed in many different ways, from only describing a system in words, to utilize schematic models and creating computer models (Gustafsson et al., 1982).

This thesis have a system analytical perspective, which represents that the energy use that is needed – from the cradle to the gate – is seen as a system, where different variables influence the final energy amount that is needed for a railway stretch. The concept from the cradle to the gate symbolizes the environmental pressure deriving from all processes from the extraction of the material to the usage of it. Compare with the more commonly known concept from the cradle to the grave, which describes all processes within a product’s or a service’s life-cycle (Ammenberg, 2004) (see Chapter 3.5; System boundaries and delimitations). System analysis is used to describe the system, and calculations are made in order to analyse it. The system is described in both words and in figures.
3.4 Creating scenarios

Three or four different scenarios are created for each product, in order to visualize how the embodied energy per year is affected by the on the interviews estimated service lives. The scenarios are created based on the information gained at the interviews.

The reason why four scenarios are created for some of the products is that the estimated service lives in those cases diverged a lot between the respondents. The scenarios are created to visualize real situations as much as possible, i.e. the Best-Case Scenarios are supposed to mirror how long time it is possible that the products are used in reality, according to the respondents. The scenarios represent how long the products can last on the main line track. The main line track is the lines with the heaviest load in Sweden, except for some freight traffic tracks. The main line track is the frame of the railway infrastructure, and it is here that the main part of the traffic passes. The track in Sweden with the heaviest loaded is Malmbanan, a railway stretch with heavy freight traffic. These types of tracks are not considered in this study, since it is rather an exceptional case than a normal type of track.

All the different scenarios are supposed to represent actual situations, e.g. the Best-Case Scenario may be applied at one track, while the Realistic Scenario is applied at another track. It is important to represent real situations, in order to mirror how service lives and reuse affects the environmental pressure in reality. The scenarios are presented more thoroughly in Chapter 8.1, and it is explained which situations the different scenarios represent.

Stretches where it may be suitable to use already used materials are for example industry tracks, marshalling yards and less busy regional tracks (Hedström, 2002; Respondent 7 & 6, 2005). All these tracks have a considerably lower load than the main line track (Respondent 1). Not all of the materials are suitable for reuse. The products that can be and which are reused in the usual way, according to the respondents, are rails and railway ties. The macadam-ballast is in one sense reused at the same stretch, at the ballast cleaning process (see Chapter 6.1). The cables and the contact wire system are not reused at all (Respondent 10, 11 & 12, 2005). These products are however also put in scenarios, since their service lives affect the environmental pressure.

The reuse of rails and railway ties can be said to take place in three steps (in a favourable case). The first halt for the products are the main line tracks. The second halt can be a regional track, and the final halt a sidetrack at a marshalling yard. If a product will be used at all these different types of tracks, it has to be taken from the main line track in time, so that it is not too worn out, and the load on the regional track should not be too heavy. The earlier a product is taken from the main line track, the longer can it be used at less trafficked tracks (Respondent 1, 7 & 6, 2005). It is however not very usual that products are reused twice (Respondent 10, 2005).

3.4.1 Allocation

The embodied energy for the reused products has to be divided between the different stretches on which they are used. Allocation is a term that derives from the life cycle assessment area, and which explains methods to divide environmental pressure between for example different products or processes in a system (Ryding et al., 1995; Thormark, 2001).
Different allocation methods are suitable in different situations, and there is not one commonly accepted method to use. The environmental pressure can be allocated for example in proportion to the quality of the products, the economic value of them or to their usability (Ryding *et al.*, 1995). Reused material can also only be given the pressure from the eventual upgrading process and from the transports associated with the allocation (Thormark, 2001). This does not give a fair picture in this situation though, since the products may be moved from on track to another when they were still well-functioning on the first track.

The allocation method used in this study is based on the load factor on the different stretches. This is because the load factor is many times higher at the main line tracks than on the regional tracks, and the load on the different tracks affects the service lives that the products have on that specific track. The allocation factor that is used is based on the load factor, calculated in tonnes per year; which is the total yearly tonnage that runs on the different types of tracks.

The load on the main line track in Sweden varies between 7-10 million tonnes per year, at least on the western main line track. This means that the mean load, and hence the weight of the trains passing at each track belonging to the western main line track is somewhere between 7 and 10 million tonnes. The load factor is a bit higher on the southern main line track (Respondent 1, 2006). 10 million tonnes is therefore used as allocation factor for the main line track. The load on the regional tracks in the western Sweden varies between 0.5 and 3 million tonnes per year (Respondent 1, 2006). The factor used is the average load, which is 1.75 million tonnes per year. The allocation factors are used when it is calculated how big proportion of the embodied energy that are subscribed to each type of track (see Appendix 3 for details on the calculations and Chapter 8.2; Presentation of scenario calculations with comparison between the products).

To be able to calculate the remaining years which the products can be used on regional tracks when the different scenarios are applied on the main line track, an estimated total load possible for the products to manage is used. The total load for the use of the products on both types of tracks is estimated to 650 million tonnes (Respondent 10, 2005). This is an estimate, and if this total load would be put bigger or smaller in reality the remaining years at the regional tracks would be either more or less, which in turn would affect the calculated embodied energy per year at the regional tracks. This would however not affect the calculated energy per year at the main line track.

Since the load on the marshalling yards and similar types of tracks is extremely low, these types of tracks are excluded from the scenario calculations.

### 3.4.2 Presentation and comparison of scenarios

The environmental performance is calculated and presented as the indicator embodied energy per year. This is done to be able to show how the environmental pressure decreases or increases as the service lives get longer respectively shorter. This is hence the value indicating the environmental pressure in the results and conclusions.

It is in several figures in the result chapter shown how the embodied energy per year varies, depending on the applied scenario. The figures are created in a way which shows how much embodied energy that is added for every scenario, when the scenarios are shown in the order of how much energy they consume (where the least energy-consuming scenarios are
presented first, i.e. to the left or in the bottom in the bar). This is done to visualize the span of improvement that is obtained depending on which scenario that is used. Hence, the total bar represents the shortest scenario (the New-Technology Scenario), since this scenario has the biggest amount of embodied energy per year, the bar up to and including the second shortest scenario (The Low Realistic Scenario) shows the embodied energy per year if this scenario is applied, and so on. The improvement span is also presented as a percentage in the result chapter. An example of how the figures are created in the results is shown in Figure 2.

![Figure 2. Exemplifying figure showing how the embodied energy per year changes, depending on applied scenario.](image)

### 3.5 System boundaries and delimitations

The production of machines used for extraction, production and transportation of the materials is not included in the study. Neither is the construction of industry buildings etcetera included in the studied system. Transports and other energy consuming work needed to reuse the materials are not included in the calculations, although it is discussed how this can affect the results.

The system boundaries are visualised in Figure 3. The embodied energy is specified as the energy deriving from the extraction and the refining phases in the life-cycle and the transports in between these phases. The energy deriving from production of the products is not included in the data on embodied energy.

The reason why data from for example the production phase is not included is that the data collection for these additional data would be very time consuming, and therefore not viable within this project. The main part of the environmental pressure is also connected to the early stages in the life-cycle (Clift & Wright, 2000; Svensson & Eklund, 2003b). Transports made to and after the production phase are also excluded, as well as energy needed in the construction of the railway and in the maintenance work. Transports of materials from the producer to the project site would not add very much embodied energy if they would have
been included in the study, at least if the transports are performed by electricity driven trains. These transports may however add a lot of additional embodied energy if the transport distances are very long and if they are performed by truck (Swärd, 2005) (see Chapter 9 for further discussion). These factors are however difficult to take into reconsideration when it comes to the scenario calculations in this study.

Figure 3. Description of the studied system; what is included and not.

Economic considerations for the scenarios are not taken into account; economic issues are only discussed briefly in the thesis. This is because the aim with the thesis is to evaluate the environmental pressure, and not the economic consequences that the scenarios have. The adjustments between economic and environmental reconsiderations are left to Banverket and the other actors in the railway sector. Though, in many cases environmentally sound solutions also reduce costs, e.g. it is likely that long service lives and reuse is favourable also from an economical angle (Respondent 10, 2005).

When it comes to ballast material only the macadam-ballast and sub-ballast layers are considered. Ballast materials are also used as complementary foundation and pressure banks, depending on the geological conditions (Respondent 16, 2005). This does though vary a considerably between different stretches, and is therefore difficult to consider in this type of study.
4 Background values and information

In this section information about material use per km railway is presented, together with the embodied energy values used for every product. It is also presented how the embodied energy values, presented in MJ/tonne, correspond to how much material that is used on a km railway.

4.1 Material used per kilometre railway

Here it is presented how much material that hypothetically is used on a regular single-track railway (see Table 1). For calculations, see Appendix 2. The amounts of the studied products on a km single-track are visualised and compared in Figure 4, in order to show how important the different products are when it comes to weight. Compare with the results when it comes to embodied energy, and the picture is turned.

Table 1. Data on amounts of materials used per every km railway.

<table>
<thead>
<tr>
<th>Amounts of materials used on a km railway (tonnes/km)</th>
<th>Ballast materials</th>
<th>Cables</th>
<th>Contact wire system</th>
<th>Rails</th>
<th>Railway ties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macadam-ballsant Sub-ballsant</td>
<td>0.605</td>
<td>1.447</td>
<td></td>
<td>120</td>
<td>384.5</td>
</tr>
<tr>
<td>2052</td>
<td>3564</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Weight-percentage of materials on a mean 1 km railway stretch.

As shown in Figure 4 the most important material when it comes to weight is the ballast material, which stands for about 92 % of the total weight of the studied products, while the
percentage of the rails and railway ties is about 6 and 2 % respectively. The cables and the contact wire system stands for less than 1 % of the weight. These products are though shown to be important when it comes to embodied energy.

The weight of the materials is important when it comes to the transports, which can be very energy consuming (Swärd, 2005).

4.2 Embodied energy in the products

Here the embodied energy values for the different products are presented. It is also presented how much embodied energy that is calculated per km for the different products. For calculations, see Appendix 2.

The embodied energy values per tonne used in this thesis for the different products are presented in Table 2. The data values are taken from a life cycle inventory of railway ties (Engberg & Eriksson, 1998), and the life-cycles assessments of different building materials made by Stripple (2001) and Uppegren, (2003). For details concerning which data that are used for each products, see the following sub-chapters. As shown, the embodied energy per tonne is considerably higher for the cables, the contact wire system and for the rails than for the other materials, especially compared with ballast material. The embodied energy per tonnes is so low, compared with the other materials; the embodied energy in the ballast material is not even visible in Figure 4, where the embodied energy per tonne in the studied railway products is shown. This depends on the energy-intense production phase of steel and copper.

Table 2. Comparison of the embodied energy for the studied materials, energy deriving from the production phase (Engberg & Eriksson, 1998; Stripple, 2001; Uppenberg, 2003). Decimals are only used in those cases the data values are so small that they otherwise would have been equal to zero.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Embodied energy (GJ/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fossil fuels</td>
</tr>
<tr>
<td>Railway ties</td>
<td>1</td>
</tr>
<tr>
<td>Rails</td>
<td>21</td>
</tr>
<tr>
<td>Ballast materials</td>
<td>0.02</td>
</tr>
<tr>
<td>Cables</td>
<td>14</td>
</tr>
<tr>
<td>Contact wire system</td>
<td>14</td>
</tr>
</tbody>
</table>

The distribution between different groups of energy sources shows that the main part of the energy for concrete railway ties and all the energy embodied in the rails derive from fossil fuels. In the case of ballast materials, the distribution in renewable energy sources and nuclear power are at the same (or even at a higher) level. The main part of the energy needed in the production of copper derives from fossil fuels, but a considerable part also derives from renewable resources.
4.2.1 Ballast material
The embodied energy value used in this thesis, 0.07 GJ per tonne, describes the energy
needed in the production of crushed aggregates, which is the same as ballast materials.
Divided into different energy categories, the embodied energy from renewable energy sources
is 0.01 GJ, from fossil fuels 0.02 GJ, and from nuclear power 0.03 GJ (Stripple, 2001).

The embodied energy in the macadam-ballast used on a km single-track is hence calculated to
135 GJ/km, and the corresponding number for sub-ballast is 235 GJ/km. Taken together, the
embodied energy is calculated to 371 GJ/km.

4.2.2 Cables and the contact wire system
The value used for embodied energy in copper, which are used in both the cables and in the
contact wire system is 24 GJ/tonne (Uppenberg et al., 2003). This gives 14 GJ/km for the
cables and 34 GJ/km for the contact wire system.

4.2.3 Rails
The embodied energy value used in this thesis representing the production of steel is in total
21 GJ/tonne. All the energy derives from fossil fuels (Stripple, 2001). There are, as things
stand today, no longer a producer of rails situated in Sweden today. The rails in newly built
stretches in Sweden are commonly produced in Austria. The weight of the rails used per km
railway is hence calculated to 120 tonnes per km, and the embodied energy to 2466 GJ/km.
4.2.4 Railway ties

The embodied energy for concrete railway ties is calculated to 1 GJ per tonne (calculated for
the tie for the protection rail) (Engberg & Eriksson, 1998). About 92 % of this energy derives
from fossil fuels, 5 % of the energy derives from electricity produced by renewable resources,
and the resting 3 % derives from nuclear power (Svensson & Eklund, 2003b).

The embodied energy for the railway ties used per km railway is hence calculated to 1 060
GJ/km.

4.2.5 Embodied energy per km

The embodied energy per km for each railway product is presented in Figure 6. As visible, the
rails are the strikingly most important product when it comes to embodied energy per km
railway; it stands for about 75 % of the energy (deriving from the studied products). The
railway ties stands for about 12 % of the energy embodied in a km railway and the ballast
materials for about 11 %.

Although the embodied energy value per tonne was highest for copper, as pointed out above,
the cables and the wires and lines in the contact wire system are not very differential
compared to the other products; they only stand for about 1 % of the total embodied energy
each. This depends on that the adopted amounts on a regular railway track are relatively small
compared with the other materials. This does though not mean that these materials are not
important to work with considering service lives.
Figure 6. Embodied energy per km ordinary railway track, divided into the studied products.
5 Present service life estimations

The service life estimations deriving from the interviews are presented here. Note that the service lives also affect each other.

If the service lives of the products are extended, the environmental pressure decreases per year. An extended service life for e.g. a railway tie will not reduce the embodied energy in the product, but the environmental pressure per year will be smaller. In other words; the embodied energy would in this case not be put into the system as frequently. The durability of a product is an important factor to consider when reducing the environmental pressure per year – but the extension of the service life of a product should not be made on the cost of the possibility to recycle the product (Thormark, 2001).

The meaning of the term service life used in this thesis is the technical service life, which implies how many years a product is technically possible to use. Other meanings of the term can be economic- and aesthetic service lives (Thormark, 2001).

The service lives are also depending on the maintenance work (see Chapter 6), the geology and the climate (for example cold, heat, damp and salt, the latter depending on closeness to the sea) (Respondent 10, 2005).

The service lives pertain to how long the products can last at the main line track.

5.1 Linkages between the service lives of the products

The quality of one product may affect the service life of another product. This pertains to the rails, the railway ties and the ballast material, and in some cases also the contact wire system. If the embankment is not stable and well-drained, the rails can start to move vertically as the trains pass, which not only pulls in more water in the embankment, but also creates a bigger stress on the rails and railway ties. Waves and other unevenness makes the trains move up and down as they pass, which in turn creates forces further down in the track, which affect the railway ties, the attachment appliances and the ballast material. These forces may also create an increased wearing of the contact wire system (Respondent 10 & 13, 2005).

The products are also often exchanged simultaneously, to save money. For example are the ballast cleaning often made when the rails and railway ties are exchanged (Respondent 1, 6 & 7, 2005).

5.2 Ballast material

The service life of the ballast material is more difficult to settle than it is for the other materials (Respondent 6 & 7, 2005). This is because the macadam-ballast is seldom exchanged fully; instead it goes through a ballast cleaning process (Boëthius & Karlsson, 1996). The sub-ballast does not go through a cleaning process, instead it may be exchanged fully at rearmaments of stretches, but this only happens at very long intervals.

The level of exchanged material in the ballast cleaning process varies depending on how contaminated and worn the material is. It also depends on if the depth of the macadam-ballast is sufficient or not. If the depth is not sufficient, the exchanged material can be about 30 %,
while in other cases the amount of exchanged material can be about 5-10% of the total amount of macadam-ballast (Respondent 7, 2005). Another respondent at a track region estimated the exchanged level of macadam-ballast about 20-40% today, but he thought that the level possibly can increase with increasing speeds and loads, maybe to as much as 60-70% of the macadam-ballast (Respondent 1, 2005).

The macadam-ballast cleaning process is by economical reasons not a prioritized measure, (Respondent 1, 2005), and it is seldom done alone. In most cases it is done simultaneously with other measures such as exchanging rails and/or railway ties (Respondent 1 & 6, 2005). The persons employed at the Norrköping track area says that they have never only performed ballast cleaning without performing another measure in the track simultaneously, such as exchanging rails and railway ties. They have though sometimes performed a cleaning process when the macadam depth was not enough or when the embankment was exposed to frost damages (Respondent 6 & 7, 2005).

The opinions on when it is necessary to clean the macadam-ballast diverge, the interval goes from 20-25 years (Respondent 1, 10, & 13, 2005) (with an absolute minimum at 15 years, but this is only done by practical and economic reasons, when another measure is done simultaneously (Respondent 10 &13, 2005)) a to 40 to 50 years (Respondent 6 & 7, 2005). It is though difficult to settle when it is motivated to clean the ballast. The material usually looks the same at the surface – samples are therefore made in the embankment. The material usually gets worse and worse down in the embankment (Respondent 6 & 7, 2005).

The intervals of macadam-ballast cleaning processes are as close as you can get in determining the service life of the macadam-ballast material. The interval is though likely to be shorter as the embankment gets older (Respondent 1 & 13, 2005). The intervals seem also to be longer in practise than expected by the respondents at the main office or at VTI.

The durability of the macadam-ballast is of course depending on the load; which means total tonnage and axle loads. The material gets worn down, and the sizes of the stones get smaller and smaller. The stones also get rounder, which reduces the stability of the embankment (Respondent 14, 2005). The service life of the macadam-ballast is also affected by the surrounding environment. Railway tracks which pass through a highly vegetated area get a higher amount of leaves and other organic material in the embankment, which makes the macadam slide. This in turn affects the friction between the stones, and the wearing becomes higher (Respondent 13, 2005). Ballast cleaning may also be necessary in case of a flooding (Respondent 1, 2005) or accidents, such as pollution from the trains (Respondent 14, 2005). The start quality of the material is also of importance. It has occurred that macadam have had a lower quality than expected, with the consequence that it were worn down quicker. This has also happened for the sub-ballast. If the quality of the macadam-ballast is sufficient, blasting depending on frost in the embankment should not be a problem (Respondent 14, 2005). To avoid these problems is another reason to clean the ballast in time.

The sub-ballast is usually not maintained at all, except when a stretch is totally renewed. The estimated service life of the sub-ballast is about 100 years (Respondent 14, 2005).

5.3 Cables

There are a lot of problems with old, not longer used, cables in the ground. The cables are also difficult to localise since they are moving both horizontal and vertical in the ground. They
have in some cases moved in under the track, although they were put beside it originally, a fact which makes it difficult for Banverket to take of them. The metal prices are though rising, so it might be profitable to take care of the cables (Respondent 10, 2005).

The durability of the cables used today is estimated at an average of 30-40 years (Respondent 4 & 11, 2005), but they may last as long as 50-60 years. There are cables which were put in use in the 1940’s, still used (Respondent 12, 2005). The cables localized above ground are most vulnerable, since they are exposed to the sunlight, to wind, temperature and other climatic conditions. This part of the cables does therefore limit the service lives of the total cable (Respondent 4, 2005). The service life is also affected by the treatment (exposed forces and bending radius) of the cables. The temperature during the construction is also important, and ought to agree with the temperature given in the demand specification (Respondent 12, 2005). It is difficult to settle the service life of the cables under ground; the wearing is very low if the cables are untouched. Cables under ground are though often broken or worn during other actions made in the embankment (Respondent 4, 2005). Water may also be a problem, it penetrates the cables and destroys them (Respondent 12, 2005), as well as pollutants. Vibrations may also affect the service life (Respondent 11, 2005).

The suppliers of cables estimate that the durability of the cables is longer than estimated by the respondents. This is though difficult to know today (Respondent 4, 2005). Cables may be put in pressure to avoid dampness and hence prolong the durability. This can be done with all cables, but Banverket has chosen to only use this method on strategically important communication cables of metal (Respondent 12, 2005).

A factor which affects the exchange of cables, besides the durability, is technical development and technical/environmental shifts. It is not very common that cables are exchanged depending on new technology, but some cables containing lead are phased out depending on environmental reasons or demands. The cables put in use today will probably be used their whole service life, no other development can be seen today (Respondent 4, 2005). Metal cables are seldom exchanged depending on technological shifts, but some metal cables are exchanged or complemented with fibre optical cables. The development is heading towards more and more fibre optical cables, in order to be able to make use of new technology. The service life of optical cables is estimated to 40 years (Respondent 12, 2005).

The amounts of cables used have increased depending on intensified electricity safety demands. The intersection areas have been bigger and the electricity and signal system have been more and more separated (Respondent 11, 2005).

5.4 Contact wire system

The estimated service life of the contact wire system diverges between different respondents. This depends on a technology shift on the electricity taker on the locomotives. The durability have increased since the electricity takers were changed from consisting of metal to consisting of coal at the 1980’s. This depends on that the electricity taker now is worn instead of the wire (Respondent 4, 2005).

The contact wire is mechanically worn extremely little (Respondent 5, 2005) or nothing at all (Respondent 11, 2005). No wearing has been measured at inspections since the new electricity takers took over. The wearing is mainly occurring on short sections, depending on for example punctual heating when too much electricity passes through the wire, and the wire is
stretched out (Respondent 4, 2005; Respondent 5, 2005). The durability is also affected by climatic conditions, such as closeness to the sea, and pollution (Respondent 5, 2005).

The estimated service life is today about 50 years (Respondent 15, 2003; Respondent 5, 2005) or even 50-60 years (Respondent 4 & 5, 2005). There are contact wire systems in use today that were put in use before 2nd world war (Respondent 5, 2005), but this is of course depending on how busy the track is. The service life of the contact wire was 10 years ago estimated to about 40 years in normal cases (Boëthius & Karlsson, 1996). This difference depends probably on the new technology used today.

The durability will increase with larger diameters of the contact wire (Respondent 5, 2005). This though demands more copper, and hence a larger proportion of embodied energy.

The carrying line is not worn mechanically by the trains, but it is stretched out eventually, depending on the weights that hang in its ends. It may though be worn and torn at maintenance work or by birds sitting on it. The service life is the same as for the contact wire (Respondent 4, 2005) or a little bit longer (Respondent 5, 2005). After about 50 years spontaneous ruptures emerge. The surrounding environment affects the line, e.g. pollutants (Respondent 11, 2005).

There is a risk of corrosion if the contact wire and carrying line are connected with materials which are not of copper. From a durability point of view it is therefore favourable to use copper material in the components connected with the lines and wires (Respondent 5, 2005).

The setting of the contact wire is important, so that the electricity taker on the trains pushes against the wire with the right pressure. A too high pressure wears the wire more than necessary (Respondent 10, 2005). Badly set contact wire systems affect the durability of the carrying line. This happened when the high-speed trains (X2000) were introduced in Sweden, and carrying lines had to be exchanged after only 30 years (Respondent 4, 2005).

If the speed is decided to be increased in the future years a new contact wire system may be needed. Newly built stretches are today are designed for 250 km/h. This might not be enough throughout the whole service lives of the new contact wires, and the contact wire system may have to be exchanged earlier than expected (Respondent 4, 2005). Contact wire systems have in the past 20 years been exchanged at a lot of stretches depending on higher speeds. Higher speeds needs contact wires and carrying lines with higher strength (Respondent 5, 2005).

5.5 Rails
Corrosion on the rails does not ordinarily affect the service lives of the product, other factors usually determine the durability instead (Boëthius & Karlsson, 1996). The wearing on the rails is not distributed evenly. The outer edges of the rails in curves are for example worn out very quickly, sometimes as fast as in 10 years time (Respondent 1, 6 & 7, 2005). This wearing depends on the radius of the curve (Respondent 1, 2005). Only the products used in a straight track are though under focus here. There are also rails in use that dates from the end of the 1900th century, at marshalling yards or low operated regional tracks (Respondent 1, 6 & 7, 2005).
The exchange of the thickness, and hence the weight, of the rails and also the types of railway ties used have affected the exchange of rails the past decades. Though, it will probably not be introduced any heavier rails than the 60-kg in Sweden within a foreseeable future, even if there exist heavier rails abroad. Hence, a rail exchange will therefore probably not be done by this reason the coming years (Respondent 6 & 7, 2005).

There are rails at the main line track still in use that is 40 years old. An estimation of the service life on the main-line track is 50 (Respondent 7 & Respondent 6, 2005) or 40 to 50 years (Respondent 1, 2005). The 60-kg rail has though only been in use for 20 years in Sweden, so the service life is difficult to settle. To obtain a service life of 50 years on the main line track, a prerequisite is the railway ties last as long (Respondent 1, 2005). The 50-kg rail can manage a total load of 500 million tonnes, while a 60-kg rail can manage 650 million tonnes (Respondent 10, 2005). This implies 30% more load for the 60-kg rails. If the 50-kg rails are assumed to last 40 years at the main track line, the corresponding time span would be 52 years for the 60-kg rails, if it is assumed that the same relationship is valid.

The rails can last 30 additional years at a regional track if they are taken from the main line track adequately early. All the rails that are usable are reused, at least if the remaining service life economically motivate the work invested. At a marshalling yard a rail can last a very long time, if the load is very low (Respondent 1, 2005).

5.6 Railway ties

Frost and corrosion on the reinforcement bars affect the durability of the concrete railway ties (Gillberg et al., 1999). This is though not a big problem if the reinforcement bars are not very exposed (Respondent 9, 2005). The railway ties are also sensitive to shocks and derailing (Boëthius & Karlsson, 1996). The products are worn against the ballast material, and they also get cracks (Respondent 9, 2005). The rubber article located in between the railway ties and the rails are important to increase the durability of the railway ties (Respondent 6 & 7, 2005).

The calculated service life for a concrete railway tie is today about 40 years, according to a LCA of concrete and wood railway ties. This life-time is calculated with the demand that some components can have been exchanged within this time-span. Wood ties have a shorter service life than the concrete ties; 25 years (Engberg & Eriksson, 1998). Wood railway ties are not studied further in this thesis, and the word railway tie is used synonymous with concrete railway ties.

There are today railway ties in use that are 40 years old. The concrete railway ties were first used in Sweden in the 1960’s, and it is therefore difficult to settle the service life of them (Respondent 6 & 7, 2005). A qualified guess is that they can last for 50 years (Respondent 6, 7, 9 & 10, 2005), but the service life depend also on the accuracy at the moment of construction (Respondent 10, 2005). The span of the estimated service lives is also notable. One respondent thought that the railway ties are the weakest link in a railway track, and that the durability at the main line tracks is 40 years (if the railway ties should be possible to reuse) (Respondent 1, 2005). Two other respondents thought that the railway ties with the pandrol attachment appliance will last at least 50 years, maybe as long as 60 to 70 years (Respondent 6 & 7, 2005).

The type of attachment appliance used affect the durability, and the pandrol attachment appliance appears to be one that provides the best durability for the railway ties and the rails.
(Respondent 6 & 7, 2005). The service life is of course also depending on the initiation quality. Banverket have had a big problem with railway ties of low quality, produced in the years 1995-96. They started to break already after 5-10 years, and they had to be exchanged a lot earlier than calculated, followed by great economic losses (Respondent 10, 2005). This kind of unforeseeable factors may happen also in the future.

Railway ties may be constructed with a larger intersection area in order to increase their strength. This will though probably have negative effects when it comes to the durability of the other products. The Swedish railway ties are amongst the lightest railway ties in the world. The design of the railway ties have been almost the same when it comes to size, and the have been made more durable through using more reinforcement iron (Respondent 9, 2005).
6 Maintenance of the infrastructure

Actions of maintenance are made both for safety reasons and in order to increase the service lives (Boëthius & Karlsson, 1996). If the maintenance work is optimized the durability is likely to be longer.

The rest materials from the maintenance work are recycled in most cases. The environmental pressure deriving from the maintenance work would be reduced if a larger proportion of the used machines were driven by electricity (Boëthius & Karlsson, 1996).

6.1 Ballast material

The cleaning process of ballast material and the so-called banquet cleaning is actions of maintenance which improves the stability of the track, which in turn enable higher axle load. This is only made on macadam tracks (tracks with relatively high quality) (Boëthius & Karlsson, 1996).

The cleaning-process of ballast material aims to clean the macadam-ballast from fine-material. The goal is to reduce the amounts of grains smaller than 31.5 mm (Banverket, 1998). A machine sifts the material, and the material which grain sizes big enough put back as track-macadam, while the remaining material is replaced with new macadam. An ordinary cleaning of the macadam-ballast is made at a breadth of 2.1 m measured from the middle of the track, and with a depth of about 30 cm measured from the lower edge of the railway tie. This area contains ordinarily all the macadam-ballast (track-macadam) (Hedström, 2002).

The banquet-cleaning is a relatively new maintenance process which is done to increase the drainage in the embankment and hence increases the axle load. The banquet-cleaning process involves that embankment material that is not required (from 1 m from the rail and outwards) is taken out in order to restore the original shape of the embankment. In the cleaning process of the ballast material about 0.5 m$^3$ is set free per every track-meter. In a banquet-cleaning process about 1 m$^3$ is set free per every track-meter (Hedström, 2002).

The sub-ballast is seldom or never made any maintenance work with (Boëthius & Karlsson, 1996).

There are signals indicating that there are uncertainties about how to handle this free set material (the fine fraction), the necessary knowledge are not held in all cases in the railway sector. The new environmental legislation in Sweden, Miljöbalken, which was introduced in 1999, has sharpened the demands for how to handle the surplus from the cleaning processes of the ballast material. The responsibility lies at Banverket since the authority is the administrator, and Banverket need therefore to be able to decide the level of pollution in the material (Hedström, 2002).

6.2 Cables

The cables are made to last longer by the exchange only of short and damaged stretches. Whole cable sections are normally not exchanged except as other materials are exchanged (Respondent 12, 2005).
6.3 Contact wire system

The parts that are movable can be lubricated in order to increase the service life of the contact wire system (Boëthius & Karlsson, 1996).

6.4 Rails

The rails are lubricated and grinded to increase their service life. The lubrication is made to minimize the wearing. The grinding is made to reduce unevenness such as grooves and waves, and it is made either manual or by a diesel driven grinding train (Boëthius & Karlsson, 1996; Respondent 1, 2005). The grinding may prolong the durability of the rails several years (Respondent 6, 2005). The rails can though not always be grinded, sooner or later the rails are too worn down, and the right profile is not obtained (Respondent 6, 2005).

The environmental pressure deriving from the maintenance work of the rails is depending on cutting, grinding and welding of rails. Dust is spread from the rails (containing iron, manganese, silicon and small amounts of sulphur and phosphorus, in some cases also chrome) and from the used machines and substances. The welding creates smoke (Boëthius & Karlsson, 1996).

The rails and railway ties are straightened to restore the desired geometry of the track. This is done with machines specially design for this purpose (Boëthius & Karlsson, 1996).

6.5 Railway ties

There are no actions of maintenance for the railway ties. You can though exchange parts of or the whole the attachment appliance (Respondent 10, 2005).
7 Reuse and recycling

For a market of reused products to be made possible in the building sector, both a supply and demand is needed. This creates a problem – what should come first? If no one is asking for used products, no supply is created, and if no supply is created no one knows that the possibility to ask for the products is there (Thormark, 2001). This problem ought not to be as a big problem within an organisation such as Banverket, as it could be in the building sector, since there are used products that otherwise would become waste. A prerequisite is though that the different track-regions want to buy the used material.

A long-term collaboration between Banverket and different actors in the recycling sector is needed to facilitate recycling in the future. Recycling and reuse of ballast materials and railway ties is a complex area including many different actors, as for example purchasers, track entrepreneurs, recycling entrepreneurs and environmental offices (Hedström, 2002).

It has to be a reasonable service life left to economically motivate a reuse (Respondent 1, 2005). The materials are sometimes sent to Materialservice in Nässjö to be tested before they can be reused (Respondent 11, 2005). They can though also be stored locally, as spare products which are used mostly in the maintenance work. Products are generally not thrown away if they are functioning, if the remaining service life is estimated as sufficient (Respondent 6 & 7, 2005).

A lot of respondents pointed at the administration as a problematic issue which could and should be improved. The risk is that it is not documented which product that are available and where they are stored (Respondent 6, 7 & 13, 2005). Knowledge about environmental issues and recycling needs to be rooted at all levels to reach the accurate treatment of the ballast material (Hedström, 2002). Tradition and routines are also hindrances in reaching a cyclic material flow. A higher degree of planning ahead is necessary, and people often find it difficult to think in new ways (Respondent 10, 2005).

Hedström (2002) shows that there will probably be economic benefits with employing reuse and other forms of recycling in the railway sector. The economic potential is though likely to be higher with a good planning of how to handle the material. It is economically preferable if the materials can be used by Banverket internally. This brings about other benefits, such as the possibility to deliver material to low-prioritized railway projects (Hedström, 2002).

If the material cannot be recycled in any way costs for landfill and transports will be generated to handle the material (Hedström, 2002).

7.1 Ballast material

The ballast-material that is sorted out in the cleaning process may be used further down in the embankment, if mixed with other material, in order to obtain the right grain sizes (Respondent 14, 2005). It may also be used at marshalling yards, where the material has to be of smaller fractions, or be used as for example filling material when constructing a road. A market is starting to develop in this area. The material is though often polluted, and may therefore by environmental reasons not be used (Respondent 10 & 13, 2005). The contamination level decides if and how the material can be reused (Respondent 14, 2005). If the material is not used on the site it can be taken cared of by a recycling entrepreneur. A good administration
and advance planning is needed to reach the accurate treatment of ballast material (Hedström, 2002).

Ballast material can be contaminated with heavy metals, such as arsenic, cadmium, lead and zinc, poly-aromatic hydro carbons and aliphatic and aromatic hydro carbons (Hedström, 2002).

7.2 Cables
Cables are not reused, but they are material recycled once they are taken care of (Respondent 10 & 12, 2005).

7.3 Contact wire system
The components of the contact wire system are not reused. Even if the wires are exchanged before they are finished, they get too worn as they are put down, and they cannot be used again. It cost too much to handle it as careful as necessary (Respondent 11, 2005). The carrying line gets damaged where they are pinned up (Respondent 5, 2005). The wires and lines are though material recycled (Respondent 5 & 11, 2005).

If the contact wire and carrying line is alloyed with bronze (carrying line) or silver (contact wire), which are sometimes made to increase the strength (Respondent 5, 2005), material recycling gets more complicated than if no alloys are used. This is because alloys in general make it more difficult to material recycle materials.

7.4 Rails
When rails are taken from one track they go through a quality control before they can be reused. They are x-rayed in order to find tendencies to fractures. The rails are if necessary grinded to regain the right profile. It is though not possible to regain the rails original condition, since the head of the rail gets smaller. There are standards on how much the head of the rail is allowed to be worn down (Respondent 10, 2005).

43-kg rails are not put into use as new anymore. Instead, old tracks with 43-kg rails are often shifted to consist of reused 50- or even 60-kg rails (Respondent 7 & 13, 2005).

Products not produced anymore, such as the 43-kg rails, are stored at the different track regions, in case they will be needed in the maintenance work (Respondent 6 & 7, 2005).

7.5 Railway ties
Railway ties are reused when it is possible, but the biggest quantities are though worn out when they are exchanged. It has to be a reasonable long service life left to invest work in the railway tie again (Respondent 1 & 9, 2005). Reuse of railway ties is most common when a stretch get a total rearmament (Respondent 9, 2005).
Reuse of railway ties will probably become more common in the future, as the new railway ties with the pandrol attachment appliances are more durable and hence also more frequently used (Respondent 6 & 7, 2005).
8 Scenario calculations

Here are the results deriving from the scenario calculations presented. The information of the present state concerning service lives are used when creating the scenarios, in order to make the scenarios as much based on reality as possible. The results are first presented for every product individually and after that the products are compared with each other. For details about the calculations, see Appendix 3.

8.1 Scenarios and results for every product individually

The scenarios are based on the estimated service lives which are one of the outcomes of the interviews (see Chapter 5; Present service life estimations) and other results from the interviews which indicate other possible situations that affect how long the products will be used. The scenarios of the different products also interact with each other. The scenarios are in this chapter presented for the studied products separately.

The scenarios mirror how long the products last at the main line track. The remaining service life at regional tracks, if the products are reusable, is calculated in relation to the load on the different types of tracks. The products can last a lot of years supplementary if they are put at a low trafficked track (Respondent 7, 2005).

Embodied energy per year shows the environmental efficiency of the scenario. The span of how much the embodied energy per year can vary shows how important it is to prolong the durability of the products. These spans are also presented as a percentage, which shows how much the embodied energy per year can be reduced if the scenario is shifted from the New Technology Scenario to the Best-Case Scenario, respectively from the Realistic Scenario to the Best-Case Scenario.

The spread of estimations of service lives and the final decision of scenarios for the different products is visualised in Table 3. The New-Technology Scenarios shows when the products by different reasons are exchanged before they are worn out. The contact wire system may for example be exchanged in order to manage higher speeds (Respondent 4, 2005). The Realistic Scenarios are based on the most common estimations of service lives. The estimations did in some cases diverge a lot considering the Realistic Scenarios. In these cases two realistic scenarios are made; one Low Realistic Scenario and one Realistic Scenario. A mean value or a most frequently estimated value is used when creating the scenarios, in order to simplify the results. This simplification is also shown in Table 3.

Note that the New-Technology Scenarios are put as the worst estimated service lives, while the Best-Case Scenarios are put as the absolute best durability estimated. The Best-Case Scenarios are based on estimations on how long it is possible that the products last. In the case of rails and railway ties the Reuse Scenario is actually an environmentally better alternative than the Best-Case Scenarios, since when these products are reused they are made use of fully. The New-Technology Scenarios are put at the lowest estimated service lives, or at an estimated time span, based on the answers given by the respondents.

In some cases there is no span for the creation of a scenario in Table 2. This depends on that the estimations did not diverge according to this, or that the data are based on only one interview.
If the railway ties has to be exchanged the rails are commonly exchanged at the same time. The same scenarios are therefore used for both the rails and the railway ties. The railway ties seem, according to the interviews, to be the limiting product.

Table 3. Description of how the estimations of service lives for the different products varies, and at which durability the scenarios are put at for the different products.

<table>
<thead>
<tr>
<th>Product</th>
<th>New-Technology Scenario span (years)</th>
<th>Used number of years for scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cables</td>
<td>15-30</td>
<td>15</td>
</tr>
<tr>
<td>Contact wire system</td>
<td>15-30</td>
<td>15</td>
</tr>
<tr>
<td>Macadam-ballast</td>
<td>15-25</td>
<td>15</td>
</tr>
<tr>
<td>Sub-ballast</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Rails</td>
<td>20-40</td>
<td>20</td>
</tr>
<tr>
<td>Railway ties</td>
<td>20-40</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>Realistic Scenarios’ span (years)</th>
<th>Used number of years for scenarios</th>
<th>Low Realistic Scenario</th>
<th>Realistic Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cables</td>
<td>30-40</td>
<td>30</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Contact wire system</td>
<td>50</td>
<td>-</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Macadam-ballast</td>
<td>25-50</td>
<td>25</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Sub-ballast</td>
<td>100</td>
<td>-</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Rails</td>
<td>40-50</td>
<td>40</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Railway ties</td>
<td>40-50</td>
<td>40</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>Best-Case Scenario span (years)</th>
<th>Used number of years for scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cables</td>
<td>50-60</td>
<td>60</td>
</tr>
<tr>
<td>Contact wire system</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Macadam-ballast</td>
<td>50-60</td>
<td>60</td>
</tr>
<tr>
<td>Sub-ballast</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Rails</td>
<td>50-60</td>
<td>60</td>
</tr>
<tr>
<td>Railway ties</td>
<td>50-60</td>
<td>60</td>
</tr>
</tbody>
</table>

8.1.1 Ballast material

The sub-ballast is not very probable to be reused. Since it is so seldom exchanged it is probably too worn out to be used again, at least as sub-ballast. If the sub-ballast, as expected, is not reused the energy per year deriving from the calculations are shown in Table 4. This is also visualized in Figure 7, where it is shown that the embodied energy per year, and hence also the environmental pressure, increases when the sub-ballast is not used its entire service life. The improvement span is calculated to be 33 % if the New-Technology Scenario is applied and to 17 % if the Realistic Scenario is used, and the change goes to the Best-Case Scenario. For calculations, see Appendix 3; Calculations for results.
Table 4. Embodied energy per year for different service lives of the sub-ballast.

<table>
<thead>
<tr>
<th>Scenario (years)</th>
<th>Embodied energy per year (GJ/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New-Technology Scenario</td>
<td>2.94</td>
</tr>
<tr>
<td>Realistic Scenario</td>
<td>2.35</td>
</tr>
<tr>
<td>Best-Case Scenario</td>
<td>1.96</td>
</tr>
</tbody>
</table>

It is more difficult to give a simple picture of the embodied energy per year when it comes to the macadam-ballast. This depends on that the degree of exchanged material in the ballast cleaning process may vary a lot (see Chapter 5.2 and 6.1). The results of the calculations are shown in a table in Appendix 3 and in Figure 8. The exchange levels shown in the figure are based on the information obtained at the interviews. To avoid confusion; note that the steps between the exchange levels in the figure are not even, depending on the information they are based on.

The improvement spans is 33 % if the shift goes from the Realistic Scenario, and 75 % if the shift goes from the new technology scenario. The reason why the same percentage is calculated for all the exchange levels depends on that calculations of embodied energy per year relies on the same proportions, which is the embodied energy per km, divided into the service lives.

The more macadam-ballast that is exchanged, the more material has to be added, which gives a new energy investment and hence an even higher environmental pressure. This is though difficult to take into consideration in the scenario calculations, since the durability and exchange of this material in the future also varies.
8.1.2 Cables

Here the added embodied energy per year for the cables when the scenarios get shorter is presented. This is displayed in Figure 9. The improvement span in percent is calculated to 75 % if the New-Technology Scenario is applied, to 50 % for the Low Realistic Scenario and to 33 % if the Realistic Scenario is applied. Hence, although the cables are not that important when it comes to embodied energy per km, as shown above, the improvement span is considerable.
8.1.3 Contact wire system

Here the added embodied energy per year for the contact wire system when the scenarios get shorter is presented. This is displayed in Figure 10. The improvement span in percent is calculated to 75% if the New-Technology Scenario is applied and to 17% if the Realistic Scenario is applied. Hence, such as for the cables, although the contact wire system are not that important when it comes to embodied energy per km, as shown above, the improvement span is considerable.

Figure 9. Added embodied energy per year depending on which scenario that is applied for the cables.
8.1.4 Rails

If the rails are reused and used throughout their entire service life all the energy invested in the rails are made benefit of, at least the energy that can be made benefit of when the steel is used as rails, the material can of course be material recycled afterwards and hence reduce the need for new energy investments in other materials or in new rails. Energy needed in the transports and the work with assembling and disassembling the rails are of course added if the rails are reused. In this respect it is preferable to use the products at the main line track the entire service life. This is though not preferable in many other aspects, such as security, velocity and load. Issues concerning transports are discussed further in Chapter 9.

If the rails are not reused the calculated embodied energy per year will be as shown in Table 5. This is also visualized in Figure 11, where it is shown that the embodied energy per year, and hence also the environmental pressure, increases when the rails are not used their entire service life. The shaded area represents the additional energy per year which will be a fact if the rails are exchanged already after 20 years, depending on new technology. It is though very probable that these rails will be reused when they are exchanged this early (see Chapter 7).

The best possible scenario is of course if the rails are reused and hence made use for throughout their entire service life. A comparison is therefore made with this scenario in Figure 11. The reason why the embodied energy per year is lower in the Reuse Scenario is because the rails may still be reused in the Best-Case Scenario. Some of the embodied energy is allocated to the regional tracks in the bar showing the scenario when the rails are reused, but this allocated small part of the total energy is not shown in the figure. The energy allocated to the regional tracks is hence the reason why the bar of the Best-Case Scenario is a bit longer than the bar for the Reuse Scenario. The energy allocated to the regional tracks is

Figure 10. Added embodied energy per year depending on which scenario that is applied for the contact wire system.
shown in Figure 13 in Chapter 8.2.1, where the Reuse Scenarios for the rails and the railway ties are presented.

<table>
<thead>
<tr>
<th>Scenario (years)</th>
<th>Embodied energy per year (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New-Technology Scenario (20)</td>
<td>123</td>
</tr>
<tr>
<td>Low Realistic Scenario (40)</td>
<td>62</td>
</tr>
<tr>
<td>Realistic Scenario (50)</td>
<td>49</td>
</tr>
<tr>
<td>Best-Case Scenario (60)</td>
<td>41</td>
</tr>
</tbody>
</table>

Table 5. Embodied energy per year if the rails are not reused, in different scenarios.

The improvement span in percent is calculated to 69% if the New-Technology Scenario is applied, to 38% for the Low Realistic Scenario, to 23% if the Realistic Scenario is applied and to 8% if the Best-Case Scenario is applied (due to that the rails are not reused in this scenario).

8.1.5 Railway ties

As for the rails; if the railway ties are reused, and thereafter used throughout their entire service life, all the energy invested in the railway ties are made benefit of (see above). Energy needed in the transports and the work with assembling and disassembling the railway ties are of course added if the products are reused. In this respect it is preferable to use the products at the main line track the entire service life. This is though not preferable in many other aspects, such as security, velocity and load.

If the railway ties are reused, the embodied energy per year is calculated to about 16.3 GJ/year for every km at the main line track. The embodied energy per year at the regional tracks is calculated to about 2.8 GJ/year. The energy is allocated in relation to the load at the different types of tracks (see Chapter 3.4.1; Allocation). For details concerning the calculations, see Appendix 2; Calculations for the results.
If the railway ties are not reused, the energy per year is calculated to be as shown in Table 6. This is also visualized in Figure 12, where it is shown that the embodied energy per year, and hence also the environmental pressure, increases when the railway ties are not used their entire service life. The shaded area represents the additional energy per year which will be a fact if the railway ties are exchanged already after 20 years, depending on new technology. It is though rather certain that these railway ties will be reused when they are exchanged this early, at least if they are not damaged in any way. The reason why the embodied energy per year is lower in the Reuse Scenario is because the railway ties may still be reused in the Best-Case Scenario. Some of the embodied energy is allocated to the regional tracks in the bar showing the scenario when the rails are reused, but this allocated small part of the total energy is not shown in the figure. The energy allocated to the regional tracks is the reason why the bar of the Best-Case Scenario is a bit longer than the bar for the Reuse Scenario. The energy allocated to the regional tracks are shown in Figure 13 in Chapter 8.2.1.

### Table 6. Embodied energy per year if the railway ties are not reused, in different scenarios

<table>
<thead>
<tr>
<th>Scenario (years)</th>
<th>Embodied energy per year (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Technology Scenario (20)</td>
<td>52.98</td>
</tr>
<tr>
<td>Low Scenario (40)</td>
<td>26.49</td>
</tr>
<tr>
<td>Realistic Scenario (50)</td>
<td>21.19</td>
</tr>
<tr>
<td>Positive Scenario (60)</td>
<td>17.66</td>
</tr>
</tbody>
</table>

Figure 12. Visualization of how the embodied energy per year increases when the railway ties are used a shorter time period. The length of the scenarios shorter than the best-case scenario shows how many years this scenario adds. A comparison is made with the Reuse scenario.

The improvement span in percent is calculated to 69 % if the New Technology Scenario is applied, to 38 % for the Low Realistic Scenario, to 23 % if the Realistic Scenario is applied and to 8 % if the Best-Case Scenario is applied (due to that the railway ties are not reused in this scenario).
8.2 Presentation of scenario calculations with comparison between the products

This is where the products are compared with each other in order to see how important it is for each product to consider service lives when it comes to environmental pressure. The spans for how much the embodied energy per year can be changed depending on applied scenario are compared. This section is divided into three parts.

The first part describes the scenario where rails and railway ties are reused and hence made full use of. The second part describes when all the scenarios are included, which means that also the New-Technology Scenarios are included. The New-Technology Scenarios describe the situation where the products are exchanged before they are worn out, are included. The third part shows the span when the New-Technology Scenarios are excluded. This is done because this is the actual situation which is most probable for the products, at least as most of the respondents sees it today. This is therefore the improvement span which is important for the everyday work, although it is important to keep in mind how much energy that is not made use of when the New-Technology Scenario becomes reality or is discussed.

The scenario which is most probable for rails maybe also for railway ties is the Reuse Scenarios. These scenarios are therefore displayed in separate bars in all the figures below showing the scenarios where all the products are not reused. This also makes it easy to compare the different scenarios.

8.2.1 Reuse of rails and railway ties included

In Figure 13 it is shown how much embodied energy per year that is allocated to the different types of tracks when the rails and the railway ties are reused. No span is obtained, which means that all the invested energy is made use of (at least in the ideal case of making use of the products fully). This is therefore the in reality best environmental sound scenario.

For rails about 38 GJ/year is allocated to the usage on the main line track, while about 7 GJ/year is allocated to regional tracks. For railway ties about 16 GJ/year is allocated to the main line track, while about 3 GJ/year is allocated to regional tracks. The energy is allocated in relation to the load at the different types of tracks (see Chapter 3.4.1; Allocation). The reason why the embodied energy gets the same for every scenario is that the products, irrespective of applied scenario at the main line track, are assumed to be used fully. When the products are moved early in their service life a larger proportion of the embodied energy is allocated to the regional tracks. The number of years which the products can be used at the regional track is calculated in relation to the load on this type of track, which is lower at regional tracks than at the main line track. For details concerning the calculations, see Appendix 3; Calculations for the results.
Figure 13. Comparison of embodied energy per year and km railway for the rails and railway ties, allocated between the main line tracks and the regional tracks. The embodied energy per year is the same for every scenario, depending on the allocation method.
8.2.2 All scenarios included

Reuse of rails and railway ties are shown in separate bars, so that it can be compared with the scenario when these products are not reused. It is though very likely that rails and railway ties will be reused if they are taken out of use on a track very early in their potential service life. The comparison is though interesting to make, since it is shown how big impact a waste of the potential durability of the products have. In the case of reuse of rails and railway ties, the embodied energy per year pertains to how much energy that is allocated for the main line track.

Two different exchange levels are displayed for the macadam-ballast. 20 % represents a normal situation, while 100 % represents a situation where all the macadam is exchanged. For data values of additional exchange levels, see Appendix 3.

Total improvement spans are shown here, which means the improvement spans of embodied energy per year and km railway if e.g. the New-Technology Scenarios are applied for all products. The improvement spans are, such as above, calculated to an improvement to the Best-Case Scenario for all products except the rails and the railway ties, where the Reuse Scenario is considered the best possible scenario. The Realistic Scenario is used in the calculation of the improvement span from the Low Realistic Scenario for the products with no Low Realistic Scenario.

The total improvement span when the New-Technology Scenarios are applied for all the products (both when 100 % and 20 % of the macadam-ballast is exchanged) is calculated to 69 %. The corresponding improvement spans for the Low Realistic Scenario, the Realistic Scenario and the Best-Case Scenario are calculated to 39 % (100 % exchange of macadam-ballast) and 38 %, to 23 % (both exchange levels of macadam-ballast) and to 7 % (both exchange levels) respectively. The main part of the improvement potential is due to reductions in embodied energy per year concerning the rails, followed by the railway ties (see Figure 14).
8.2.3 New-Technology Scenarios not included

In this chapter the New-Technology Scenarios are excluded. The total improvement span of embodied energy per year if the scenario is shifted to the Reuse Scenario and the rails and railway ties are reused are calculated to 39 % (100 % exchange of macadam-ballast) and 38 % (20 % exchange) for the Low Realistic Scenario. The Realistic Scenario and the Best-Case Scenario are calculated to 23 % (both exchange levels of macadam-ballast) and to 7 % (both...
exchange levels) respectively. The main part of the improvement potential is due to reductions in embodied energy per year concerning the rails, followed by the railway ties (see Figure 15).

Figure 15. The added embodied energy per year and km depending on which scenario that is applied. The new technology scenario is excluded.
9 Eventual sources of error and factors that may affect the results

Here factors which may affect the results, such as transports, background data and service lives, are presented.

Rails and railway ties are in most cases the only products which are transported by rail. One reason why the other products seldom are transported by train is bad advance planning, but also that some products have to be transported directly and at a specific date. There are sometimes very small quantities which have to be transported, and railway is then not economically preferable. A possibility is to have several storages in different parts of the country, where the transports to the storages could be made by train, while the transport from the storage to the project sites could be made by truck (Respondent 10, 2005).

Ballast materials is mainly distributed on a local marked, depending primarily on high transport costs in relation to the total expense of the material, which is due to the weight of the ballast material. Ballast material is mostly transported by truck, and a calculation show that those transports constitute about half of the transports of all goods in Sweden (Grus- och makadamföreningen, 2001).

The transports of the materials are also an important energy consumer. A study of three newly built stretches in Sweden shows that the embodied energy deriving from transports can constitute as much as 20 % of the total embodied energy if the transports are not handled in an energy-effective way, i.e. by using electricity driven trains and by reducing transport distances. The transport-related energy may be reduced to as little as 1 % of the total embodied energy. Hence, the transport-related energy can be reduced by 97 %. Energy gains can even be made by increasing the transport distance but then being able to transport the materials on electricity driven trains instead of by truck (Swärd, 2005).

The transports of the ballast materials contribute to a large part of the transport-related embodied energy, since the material is very heavy. Improvements considering rails and railway ties may also reduce the transport-related embodied energy considerable (Swärd, 2005).

The data used for embodied energy and material use of course affects the results. The results might have looked different if they were based on other data. The same relationships would though probably been created, it is no question whether copper and steel are the most energy intense of the materials.

The estimations of service lives obtained at the interviews of course also affect the results. But since several different scenarios are used, this should not be a big source of error. If the actual Best-Case Scenario is better in reality than put out in this study, the improvement spans would be greater, and vice versa. But the same trend would in that case be shown. This study therefore gives an idea of how the service lives affect the environmental performance, even if the scenarios do not correspond exactly with reality.

The allocation method chosen also affect the results when it comes to the Reuse scenarios (for rails and railway ties), as well as the calculated remaining years at the regional tracks.
10 Discussion

It is important to take the resource perspective under consideration when choosing a new material, so that no waste problem is created. A big challenge is to balance between the technical development and the resource perspective (Respondent 10, 2005). The materials should preferably be reused, and thereafter material recycled. Though long service lives reduces the environmental pressure, new technology may also be beneficial for the environment, for example by reducing energy demands in the operation phase. This balancing act has to be done in each specific situation.

There are a lot of possibilities and benefits with creating a well-functioning reuse of railway products, as well as prolonging their service lives. The advantage shown in this thesis represents the possibility to reduce the need for energy and thereby reduce the environmental pressure. This ultimately reduces the pressure which is resulting in major environmental problems such as eutrophication, climate change and acidification (Rydén et al., 2003). To as much as possible make use of the materials in the infrastructure takes us one step closer to the vision of a total closing of all material cycles; the vision of Industrial Ecology (Erkman, 2003). To fulfil this dream entirely the material cycles has to be closed for all the products and materials used by the railway sector, as well as materials in machines and vehicles and fuels, not only the energy-intense materials treated in this study.

A factor which complicates the ambition to create cyclic material use is that the responsibility for the materials lies upon different parties (Thormark, 2001), together with that it is not well-documented which used products that are available, how many they are and where the used products are located (Respondent 6 & 7, 2005). This is though an administrative issue which can be addressed. Banverket has therefore, in order to reach the environmental benefits with reuse, to create an accurate and well-functioning administration of already used material.

It is interesting to note that the estimations concerning both the intervals between the times for ballast cleaning and the exchange levels of macadam-ballast diverge quite much between the respondents at the main office and at VTI on one side and the track areas on the other. The respondents working closely with actions of maintenance estimate that ballast cleaning is performed more seldom and with a smaller exchange level (see Chapter 5.2). The difference may have happened as a mere accident, but it might also be an indication that it theoretically is favourable to perform big-scale ballast cleaning processes often, but other causes explains why this does not occur in practice. These causes may e.g. be economical and practical ones.

The major total improvement span shows that there are, or at least may be, a lot to be done in order to reduce the environmental pressure. This can be a part in reducing society’s total environmental impact - although the total reduction does not go up to a factor 4 or even a factor 10 – the total reduction can at least go up to as much as a 69 % reduction (New-Technology Scenario applied) (Ammenberg, 2004). From an environmental perspective it is preferable to invest in products and materials with long durability, since this reduces the energy which needs to be invested in the assembling work and in transports. In this case it is though even more important that the products are reused and thereafter recycled. In particular it is crucially important that the products are not put out of use early in their service life, since this increases the embodied energy per year considerable.
The fact that the service lives of the products affect each other, in particular concerning the rails, the railway ties and the ballast material, complicated the management actions. Though it is shown in Chapter 8 that long service lives reduces the environmental pressure, it may be crucially important to e.g. perform ballast cleaning and grinding of the rails quite often, in order not to create negative wearing of the materials and hence reduce the service lives.

Another way of reducing the environmental pressure, without decreasing the energy consumption, is to shift the energy source used for the extraction, refining and production of the materials from fossil fuels to renewable energy sources. This would decrease the CO₂ emissions considerably (Swärd, 2005).

If ballast material is taken from the project site when constructing a railway stretch, the transports are minimized and the energy demand is hence reduced. The fact that the ballast material is taken from the site may though affect the quality of it, and hence the service life of both the ballast material and the other studied materials (see 5.1; Linkages between the service lives of the products). This is a difficult balancing act when using a strategy which is environmental favourable. The quality of the ballast material, and hence the durability of the products, has to be weighted with the transport distances to alternative ballast sources.

The benefit that follows with increasing the service lives of the railway products consist of that the investments in the very energy-demanding railway infrastructure, which stand for the biggest part of the environmental pressure of the railway sector (Maibach et al., 1997), are minimized. This means that the railway sector will reduce its total environmental pressure, by increasing service lives. It is of great importance for Banverket, as well as for the whole railway sector (including manufacturers) to focus on reducing the environmental pressure ascribed to the infrastructure, in order for the sector to retain its good environmental reputation. To improve the environmental performance of the railway is not only important for the railway sector, but also for the whole society, since a sustainable transport system is an extremely important matter in order to create a sustainable society.
11 Conclusions

The conclusions are presented by answering the research questions.

**How does the present state considering service lives and reuse in Sweden appear?**

The present state service lives varies between 25 and 100 years for the realistic scenarios for all the products. The estimated service lives varies between 15 and 80 years for the new technology scenarios. When it comes to the best-case scenarios the estimated service lives varies between 60 and 120 years, depending on railway product.

The products reused today are rails and railway ties.

**How can the environmental pressure be influenced through changed service lives?**

There are considerable improvements to be made by increasing service lives, and this pertains to all the studied products. The reductions in embodied energy per year go up to 75 % if the New-Technology Scenario is applied and to 33 % if the Realistic Scenarios are applied. If the Low Realistic Scenarios are applied the reductions goes up to 50 %. A great improvement potential exist for all the products if the New-technology Scenarios are applied. The products where the main improvement potential when it comes to the Realistic and the Low realistic Scenarios exist is the macadam-ballast, the cables, the rails and the railway ties.

If the New-Technology Scenarios are applied for all the products the total improvement span is as much as 69 % altogether. If the Low Realistic Scenario instead is applied, the improvement span is calculated to 38-39 % (depending on the exchange level of macadam-ballast). If the Realistic Scenario is applied, the improvement span is calculated to 23 % and if the Best-case Scenario is applied the span is calculated to 7 %, depending on that the most energy efficient strategy is to reuse the products possible to reuse. The main part of this improvement potential derives from the rails and the railway ties.

**Which measures are important to take for the different products groups?**

In reducing the environmental pressure it is important to make use of the products as much as possible, i.e. to reuse them and use them as long as possible. Since the rails and the railway have the largest improvement potential these are also the products most important to focus on. The products where actions of maintenance are possible should be maintained at regular intervals, in order to prolong the service lives of most of the products.

**Do the estimations diverge between different actors?**

The estimations concerning both the intervals between the times for ballast cleaning and the exchange levels of macadam-ballast diverge quite much between the respondents at the main office and at VTI on one side and the track areas on the other; the respondents working closely with actions of maintenance estimate that ballast cleaning is performed more seldom and with a smaller exchange level than the ones at the main office and at VTI.
The respondents where rather agreed when it comes to the service lives of the rails and the cables, while the estimated service lives diverged more when it comes to the contact wire system and the railway ties.

How do the actions of maintenance affect the service lives and the environmental pressure?

Actions of maintenance prolong the durability of the products, e.g. by increasing the stability in the embankment and hence reduce the wearing.

What can be done by Banverket?

If rails and railway ties are reused and made use of during their entire service life, all energy invested in the products is made use of. The most environmental sound alternative is to reuse the products which are reusable (rails and railway ties) and to use these products as long as they last. This gives an energy need of 16 GJ/yr and km for the railway ties and 38 GJ/yr for the rails on the mainline track. The energy allocated to the tracks where the products are reused is calculated to 3 GJ/yr and km for the railway ties and to 7 GJ/yr and km for the rails.

To work with increasing service lives for all railway products are an important step in reducing the environmental pressure of the railway infrastructure, as shown in this thesis. The products on which focus should be put today are the rails and the railway ties, since the main improvement potential exist for these products. This should be communicated to all employees who in their everyday life affects how long products are used and how often they are maintained.

The administration of the used material is the main problem in order to create a well-functioning reuse of railway articles. This includes transports, storage and documentation of products. Tradition and routines also stand in the way of creating a sustainable reuse of these products.

Other improvements which can be done are to make better material choices. To improve transports and the maintenance work is also a big source of improvement.

What can be done by the producers/suppliers of the products?

To improve the ability to reuse and recycle all railway products is an important step in reaching closed material cycles. To reduce the weight of the materials reduces both the embodied energy and the energy needed for transports. This will though probably reduce the durability, which is not preferable since the producers should strive towards creating products with as long service lives as possible. By using renewable energy sources in the extraction, refining and in the production, the environmental pressure is reduced because e.g. of reduced CO$_2$ emissions.
Acknowledgements

You would not have this master thesis in your hand if it was not for all the people who have with a great commitment kindly helped me with my questions. I would therefore like to thank all my respondents for your great support, for your time and willingness to contribute with the information so crucially important for this thesis.

I have had the great benefit of having two supervisors supporting me and answering all my questions. Thank you, Mats Eklund and Niclas Svensson, for your inspiration and motivation, for our discussions and for guiding me along the way. This thesis would not have been the same without you.

Finally I would like to thank Johan for being there for me and for painting my world in beautiful colours.

/Karin Swärd

Norrköping 09 June 2006
References


Interviews

Respondent 1 (2005). Track engineer; Gothenburg track area. Interview performed 2005-12-16.


Respondent 5 (2005). Design engineer, contact wire systems; Banverket’s main office. Interview performed 2005-10-12.

Respondent 6 (2005). Track administrator, Norrköping track area. The interview performed at the same time as the interview with Respondent 7; 2005-11-17.

Respondent 7 (2005). Track technician; Norrköping track area. The interview performed at the same time as the interview with Respondent 6; 2005-11-17.


Appendix 1

**Vocabulary of railway specific concepts**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast material:</td>
<td>The material used for the layer of crushed stone which the rails and the railway ties rest upon.</td>
</tr>
<tr>
<td>Carrying wires:</td>
<td>The wires that connects the carrying line with the contact wire.</td>
</tr>
<tr>
<td>Carrying line:</td>
<td>The line which is placed parallely with the contact wire, in which the contact wire hangs.</td>
</tr>
<tr>
<td>Contact wire:</td>
<td>The wire which connect to the electricity taker on the locomotives.</td>
</tr>
<tr>
<td>Contact wire system:</td>
<td>Concept for the contact wire, the carrying line and the carrying wires.</td>
</tr>
<tr>
<td>FIST-attachment appliance</td>
<td>Sort of attachment appliance to fix the rails on the railway ties. Not put in use as new today.</td>
</tr>
<tr>
<td>Macadam:</td>
<td>A type of ballast material with high quality demands. Usually used as the over layer of the railway embankment. The material in the over-layer is often called track-macadam. Macadam can also be used in other layers, but it is not necessary. The macadam can also be called macadam-ballast.</td>
</tr>
<tr>
<td>Pandrol-attachment appliance</td>
<td>Sort of attachment appliance to fix the rails on the railway ties. The most common attachment appliance today.</td>
</tr>
<tr>
<td>Railway tie:</td>
<td>Product of wood or concrete which the rails rest upon. They are placed at right angles to the rails, at a mean distance of 0.65 m in between each railway tie.</td>
</tr>
<tr>
<td>Sub-ballast:</td>
<td>Equivalent to the under layer of ballast materials. The same quality demands are not necessary on this layer.</td>
</tr>
</tbody>
</table>
Appendix 2

Calculations of background values and information

Ballast material

The ordinary use of ballast material per km railway is calculated after the drawings of a normal section of a newly built railway stretch in Stockholm, called Stockholm South – Ärstaberg (Banverket, 2000).

The depth of the macadam-ballast is on this stretch 30 cm, which is a usually used depth. The medium breadth is 3.8 m. Hence is the area of the cross section of the macadam ballast 1.14 m$^2$. The amount of macadam ballast per km is therefore 1140 m$^3$.

The depth of the sub-ballast is on this stretch 40 cm. The medium breadth is 4.95 m. Hence is the area of the cross section of the sub-ballast 1.98 m$^2$. The amount of macadam ballast per km is therefore 1980 m$^3$.

To transform amounts of ballast materials, given in m$^3$, to obtain the amount in tonnes, the amount is multiplied by 1.8 (Respondent 16, 2005). This is the transforming factor used in the railway project Stockholm South – Ärstaberg, and it is used for all the stretches in this study. The density is hence assumed to be 1800 kg/m$^3$. The amount of macadam ballast used on an ordinary km of railway is calculated to 2052 tonnes. The amount of sub-ballast per km railway is calculated to 3564 tonnes. Put together, the amount of ballast material is calculated to 5616 tonnes/km.

Cables

The amount of metal used in cables varies a lot between different locations. This is an estimation of the amounts of copper in low-voltage cables (used for electricity, telecommunication and signal). The weight of the cables is higher at the station areas. Here are also cables containing aluminium used (Respondent 4, 2005). The higher amounts of copper at station areas are only mentioned here; the amounts used in the calculations are the ones outside the station areas. The aluminium cables are not treated in this study, since they only exist on station areas. The coats of the cables are excluded as well.

Except the ordinary cables, copper is used in a wire which is used for electricity safety for conducting objects (for example posts, fences and bridges) within an area of 6 m from the contact wire. The objects are linked with the rails with a 6 mm pure copper wire, which is on average 3.5 m long and are estimated to be situated one per every 40 m track (Respondent 4, 2006). This gives about 99 cm$^3$ per wire and 2475 cm$^3$ in total.

The density of copper is 8.96 kg/dm$^3$ (Björk et al., 1990). The weight and the volume of the copper used in cables on a normal stretch of railway, on station areas and marshalling yards is presented in Table A. The amount presented for an ordinary single-track is the one used in the following calculations.
The weight and the volume of the copper used in cables on a normal stretch of railway are calculated to 67.5 dm$^3$, or 605 kg.

Table A. Estimation of amounts of copper used in cables on different types of tracks, calculated per km (Respondent 4 2005).

<table>
<thead>
<tr>
<th>Type of track</th>
<th>Amounts of Copper (Cu) per km (dm$^3$)</th>
<th>Total (dm$^3$)</th>
<th>Total (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cables</td>
<td>Electricity safety wires</td>
<td></td>
</tr>
<tr>
<td>Ordinary single-track</td>
<td>65</td>
<td>2.5</td>
<td>67.5</td>
</tr>
<tr>
<td>Marshalling yard (big)</td>
<td>300</td>
<td>-1</td>
<td>300</td>
</tr>
<tr>
<td>Station area (single-track)</td>
<td>105</td>
<td>-</td>
<td>105</td>
</tr>
<tr>
<td>Station area (double-track)</td>
<td>110</td>
<td>-</td>
<td>110</td>
</tr>
</tbody>
</table>

Contact wire system

The regional tracks are not electrified at the Norrköping track area, and therefore they do not have a contact wire system. There are though regional tracks that are electrified in some track areas, and those tracks are under focus in this study (Respondent 4, 2005).

The contact wire intersection area is normally 80-120 mm$^2$, and the main part of it is 100 mm$^2$. The intersection area used for the calculations in this study is 100 mm$^2$, since this size is the most ordinary one. 80 mm$^2$ contact wires are only used on old marshalling yards. The carrying line intersection area is normally 50 or 70 mm$^2$. A mean value of 60 mm$^2$ gives a fair picture of the actual situation, at least in the Norrköping track area (Respondent 4, 2005).

The contact wire system is assembled in a zick-zack pattern, in order to wear the electricity taker on the train even (Boëthius & Karlsson, 1996). This makes the contact wire and the carrying line longer than a km per km railway. The medium distance between to contact wire posts is 60 m. The wire varies its location +40 cm and -40 cm from a zero position, in the middle of the electricity taker. This pertains to a strait railway track, but will though mirror the reality in an accurate way (Respondent 4, 2005).

The length of the contact wire between two posts is hence 60.005333 m (which is calculated by using Pythagoras Theorem). The length of the whole contact wire on a km single-track is hence 1000.0888 m. The same length applies to the carrying line. The volume of the contact wire used on a km single-track is hence 100.00888 dm$^3$ and the volume of the material in the carrying line is 60.005 dm$^3$.

The area of the carrying wires is about 20 mm$^2$. About seven wires are used in between two posts. This gives that 117 carrying wires are used per km single-track. The lengths of the carrying wires vary between the following lengths: 383, 431, 544, 578, 703, 785 and 853 mm (Haglund, 2005). A mean value of 611 mm is hence used. The volume of the mean carrying wire is hence 12.22 cm$^3$. The total volume of the material used for the carrying wires is therefore 1429.74 cm$^3$.

The density of copper is 8.96 kg/dm$^3$ (Björk et al., 1990). The weight of the contact wire is hence 896.8 kg and the weight of the carrying line is 537.6 kg. The weight of the carrying wires is

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1 The amounts of electricity safety wires on marshalling yards and station areas is unknown, but not under focus in this study.
wires is calculated to 12.8 kg. The total weight of the studied products in the contact wire system is hence 1447.2 kg.

**Rails**

In a single-track of railway two rails are used, which implies that the total length of the rails used on a km railway track is 2 km. Since the weight of the rails is 60 kg/m, the total weight of the rails used on a km railway track is 120 tonnes.

**Railway ties**

Every kilometre of railway demands 1538 railway ties (0.65 m between each railway tie), at least in the ordinary cases. Since every railway ties weighs about 250 kg (Engberg & Eriksson, 1998), the total weight of the railway ties used on a km single-track is 384.5 tonnes.

The embodied energy value used in this study for a concrete railway tie is 689 MJ/tie. This value for embodied energy represents a concrete railway tie (article number 0290505) with 10 mm rubber layer, used for a protection rail. It is though admitted in this study that the other types of concrete rails have the same embodied energy. The embodied energy for a concrete railway tie is hence calculated to 1003 MJ per tonne railway ties (calculated for the tie for the protection rail).
Appendix 3

Calculations for the results

The calculations for the results which are not available in the thesis are presented here. For the calculations of embodied energy per km railway, see Chapter 4; Background values and information.

Macadam-ballast, embodied energy depending on exchange level

The embodied energy per year depending on the scenario used and the exchange level applied in the ballast-cleaning process is displayed in Table B.

The results are calculated in the following way. The energy embodied in the macadam-ballast used on a km railway is multiplied with the exchange level and the answer is divided by the number of years in each scenario.

Table B. Embodied energy per year for different intervals of making the ballast cleaning of the macadam-ballast. The embodied energy per year also varies depending on the exchange level.

<table>
<thead>
<tr>
<th>Scenario (years)</th>
<th>Embodied energy per year (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exchange level</td>
</tr>
<tr>
<td></td>
<td>100 %</td>
</tr>
<tr>
<td>New-Technology Scenario (15)</td>
<td>5,64</td>
</tr>
<tr>
<td>Realistic Scenario (40)</td>
<td>1,13</td>
</tr>
<tr>
<td>Best-Case Scenario (60)</td>
<td>2,26</td>
</tr>
</tbody>
</table>

Embodied energy per year in the sub-ballast, the cables and the contact wire system

The total energy embodied in each of these products (individually) on a km railway is divided with the years of the different scenarios, in order to obtain the embodied energy per year.

Embodied energy per year for the rails and the railway ties

The calculations of embodied energy per year on the mainline track are performed as follows. First the number of years are multiplied with the allocation factors, which are put at 10 for the main line track and 1.75 for the regional tracks (see Chapter 3.4.1; Allocation). This is divided with the estimated total load possible on a 60-kg rail, which is put at 650 million tonnes (see Chapter 3.4.1). The result of these calculations is then multiplied with the embodied energy per km for the different products, and finally divided with the years of each scenario.

The calculations of embodied energy per year allocated to the regional tracks are performed as follows. The remaining service lives on the regional tracks, depending on the applied scenario, are calculated in relation to the total load estimated, i.e. 650 million tonnes (see Chapter 3.4.1; Allocation). The results from the first calculations of in the paragraph above
(the number of years multiplied with the allocation factors and divided with the estimated total load possible on a 60-kg rail) are used to calculate the remaining percent on the regional tracks (1 minus the results from the calculations on the main line tracks outlined above). This result is then multiplied with the embodied energy in the products on a km railway. This is then divided with the remaining years on the regional tracks for each scenario.