Environmental evaluation of steel and steel structures

The Steel Eco-Cycle

Handbook for engineers, researchers and university students

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The first edition is based on experiences gained from the environmental research programme *The Steel Eco-Cycle*, which was carried into effect during the period 2004-2012.

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Foreword

Evaluating environmental performance will become ever more significant as societies strive to use natural resources more responsibly i.e. to become sustainable. Methods of evaluation are being developed and regulations at a political level are in view; all aiming to steer products, commodities and services towards a more efficient utilisation of natural resources.

Demands will steadily increase on manufacturers of products to submit information on their environmental impact and energy use from a life cycle perspective. This applies to the raw materials, production and use of products, their recycling, waste management and transportation.

Steel is, and will remain the world's most used and recycled material. In this context, it is crucial that the properties of high strength and more resistant special steels, increasingly used in products and structures, can be environmentally judged. This must be done in a way that serves both the business development of the companies concerned and the demands of society for stewardship of our natural environment.

As part of the environmental research programme, *The Steel Eco-Cycle* (www.stalkretsloppet.se), we have carried out a range of evaluations of environmental performance. These relate to changes in process technology and also to the structures that are upgraded with the advanced steel grades now available.

This book shows how environmental evaluations are carried out within the *Steel Eco-Cycle*. It also considers the future challenges that face companies in order for their operations to contribute to a sustainable social development.

Göran Andersson
Programme Director, The Steel Eco-Cycle
Jernkontoret

Main Content

How to start evaluating environmental impacts and performing Life Cycle Assessments (LCA):

- Read this handbook.
- Study examples in The Steel Eco-Cycle, www.stalkretsloppet.se
- Contact the specialist in this field at Jernkontoret, www.jernkontoret.se
- Participate in the activities of Jernkontoret's Product Ecology Council
- Take your own initiatives.

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1 Why Environmental Evaluation

1.1 Introduction

Industrial activities have as their goal to provide a return on input labour. It is the same principle that made the world's first farmers start to cultivate the earth and to raise livestock. A hundred fistfuls of planting seed could give a 50 000-fold return when the seed came to be harvested. This insight changed the way that mankind lived and the striving for an improved standard of living gradually laid the foundations for the society we know today. The most important driving force behind this development has undoubtedly been the ambition to increase consumption and raise living standards. With industrialisation, mankind has developed new possibilities for harvesting an ample return from input labour.

As the consumption of goods grows, so too does the impact on our environment. At the same time, economic activities become more global in scale and acquiring a proper overview of them more difficult. It is increasingly important, therefore, to be able to deal with environmental issues not only locally but from a global perspective. With the help of environmental assessments, the effect of consumption on the environment can be quantified and a factual basis for decisions on sustainable development be provided.

Steel, which is the world's most used and recycled material, has been developed over a long period and has been used by mankind for thousands of years. It might be thought that this material is fully developed; in fact, specialised steel grades are being developed all the time and at an ever faster rate. From a sustainability perspective, the steel grades of today and tomorrow offer considerable scope for improving the efficiency of energy and material use and for providing a longer lifespan for products and plants in contemporary society.

The increased costs of energy and raw materials, as a general rule, presuppose large-scale production and a copious market or else active specialisation with global leadership. For the steel industry, this means that its customers are to be found worldwide and that the products are frequently transported over long distances.

This book describes the environmental evaluation of both the production of steel and of its use in structures and products. It also examines how improved steel grades and new production processes can have a positive influence on the environmental impact value. Examples in the book are obtained from the environmental research programme "The Steel Eco-Cycle" (*Stålkretsloppet),* www.stalkretsloppet.se and pay due regard to the complete life cycle of steel.

1.1.1 Purpose of the book

The goal of this book on environmental evaluation is to show examples of how steel products, and improved methods of producing steel, can be assigned an environmental impact value from a life cycle perspective. Examples that show how one can develop quantitative

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data for decisions can provide inspiration to think along new lines where environmental issues to do with the steel industry, and the uses of steel in society, are concerned.

This book can be used for the education of engineers and researchers within the steel industry and also in the world of higher education and research institutes. Its goal is to disseminate knowledge about methods for environmental analysis and to enable the reader to make well-informed decisions when ordering services in the environmental area. The book is one step on the road towards sustainable development. You, the reader, are one part of this development and can affect its results in a positive way.

1.1.2 Challenge for the steel industry

In the early stages of industrialisation there were few who questioned how industrial operations would affect the environment. Just as when agriculture was developed, the return on labour was what occupied men’s minds. But now the picture has changed and all across the world there is an understanding that measures are needed to create long-term sustainable development. The environmental issues acquire an ever greater importance for industrial and social development.

Since the 1970’s, the steel industry in the Nordic countries has worked effectively on different environmental issues. Through targeted inputs to reduce emissions to air, land and water, Swedish companies now have a premier global position. Sweden’s steel companies have developed their plants- and the knowledge of their personnel- over a long period so they can produce steel with leading-edge performance in many applications.

But new challenges lie on the road ahead. In step with the emergence of concepts such as sustainable development, so the environmental field has been widened to embrace new areas: Life Cycle Assessments, biological diversity, ecosystem services as well as social and ecological footprints. All this implies an increased need to understand advanced materials and new production processes from new perspectives.

Sweden’s steel industry already has a strong position in the world market in several steel product areas. Correctly utilised, Swedish steel has great potential to enable its customers to manufacture more efficient structures with new steels that reduce the ecological footprint during the whole lifespan of the products concerned. All this delivers environmental savings that are frequently much larger than any environmental impact that the steel production causes in the first place. This possibility is frequently overlooked in the development of today’s sustainable society.

Sustainable development demands that we can demonstrate environmental improvements from a holistic perspective. In the current environmental debate this is frequently termed a life cycle or eco-cycle perspective. Various methods have been developed; the one to emerge as most significant is designated Life Cycle Assessment or just LCA. The scope of such an analysis is illustrated in Figure 1.1.

Common to Life Cycle Assessments is that, for each stage of a product's life cycle, a determination is made of the use of natural resources and emissions to land, water and air. Certain materials cannot be recovered but are used, for example, as energy feedstock for heating purposes. Others can be recycled several times before the properties are changed or undergo such deterioration that waste actually arises.

Steel in products has a unique characteristic: it can be recycled into steel scrap, time and again, to serve as the raw material for new steel. Through industrial scale recycling, one could say that steel is an infinitely recyclable material.

Figure 1.1 Life Cycle Assessments reflect a product's overall material and energy flows as well as the emissions to air, land and water, all from a life cycle perspective.

It is often hard to obtain a comprehensive idea of how an individual product or structure affects the environment. Take a motor car, for example. It is relatively easy to work out its airborne emissions during its estimated lifespan. But what picture emerges when we start to go backwards and forwards in the life cycle? Which raw materials are included in the car? How have these been produced and transported? How long will the car be operating on the roads? Is it possible to separate and recover the materials of which it is made? And what happens if certain parameters are changed? What would be the consequences, for example, if the bodywork were made of thinner steel that reduced the weight by 10-20 per cent, or if the corrosion protection were extended by 5-10 years?

To carry out environmental assessments from a life cycle perspective is a challenge, as much for environmental experts as for other researchers and engineers. At the same time, those who accept the challenge, learn the methodology and use it in their work gain significant environmental and commercial advantages.

1.1.3 Steel is the world's most used and recycled material

Steel is the world's most intensively used metallic construction material, figure 1.2. It is, therefore, especially important that it is assigned a quantitative environmental impact value that can gradually be improved. During 2010, almost 1,500 million tonnes of steel were produced for a range of products, structures and buildings across the world. Stainless steels comprised about 32 million tonnes of this total while all other metals together accounted for less than 80 million tonnes.

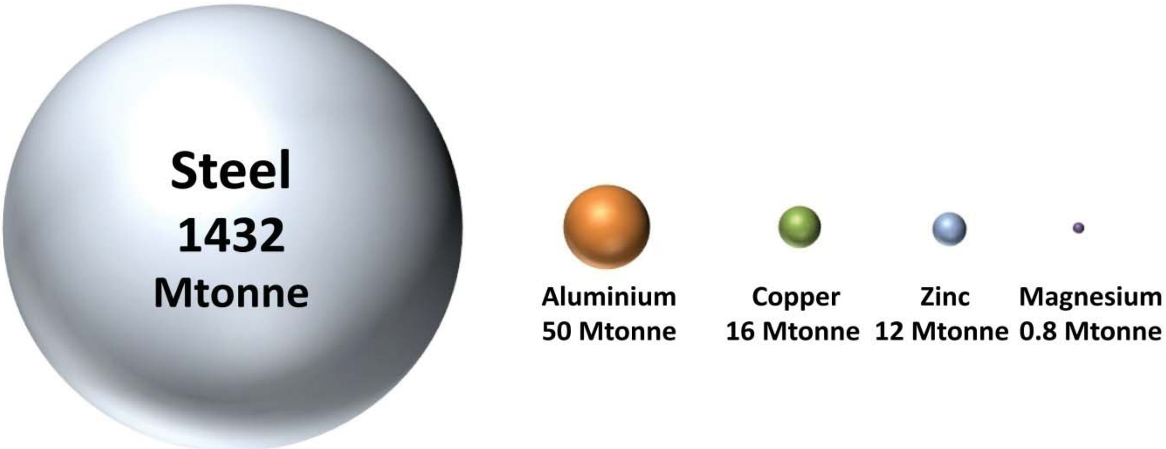

Figure 1.2 World production of structural metals in 2010, millions of tonnes

Several forecasts indicate that the world's steel consumption will increase by the order of 2,500 million tonnes up to the year 2050, figure 1.3. Consumption growth is so large that the supply of steel scrap, despite high recycling rates, is insufficient to meet more than 30 per cent of steel consumption globally and about 40 per cent in Sweden.

By the year 2050, the recycling of steel scrap will only suffice for about 50 per cent of the world's total steel production. To avoid a shortage of steel in society, the remaining amount must be produced from an increasing share of iron ore, even allowing for maximum rates of steel recycling.

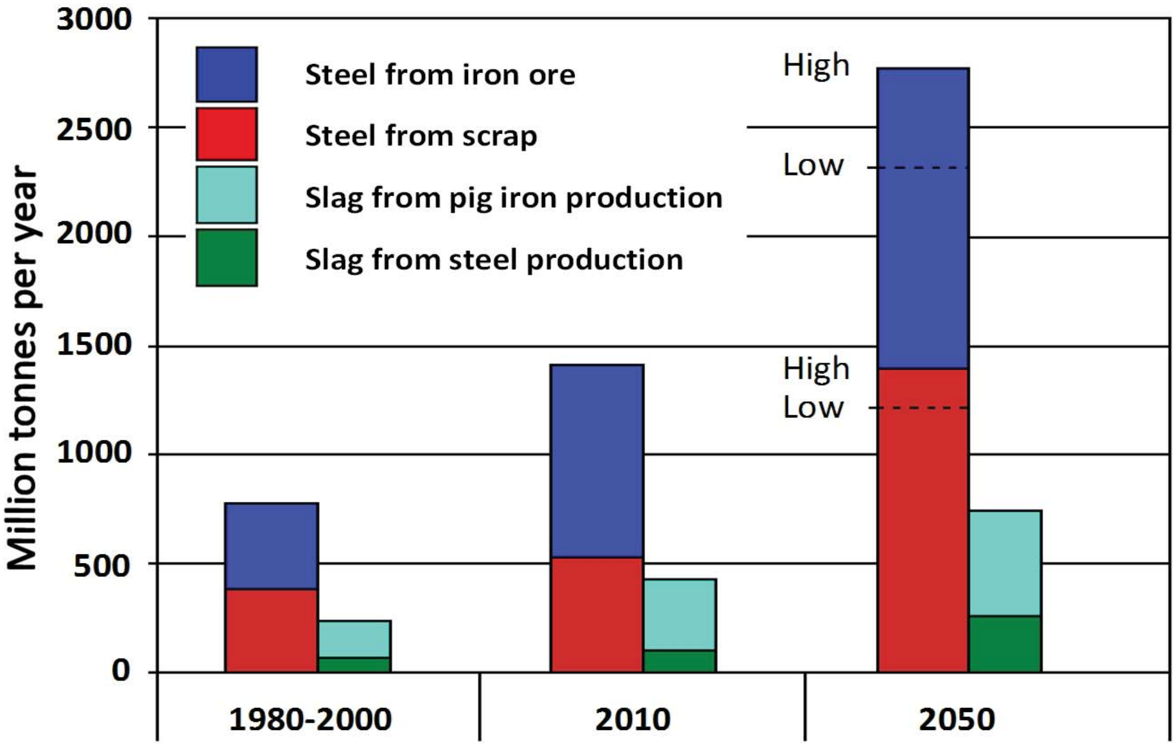

Figure 1.3 Historical development and forecast for total world production of steel and slag by year 2050

1.1.4 Steel becomes stronger and more resistant

The heavy demand for steel means that the requirement for alloying metals for steel production is large and increasing. These alloys are needed for producing base steel, but also for producing ever more advanced steel grades that are both stronger and more resistant, even though advanced cooling, quenching and temper rolling can limit the amount of alloys used.

Higher strength steels permit significant material savings in steel structures. A doubling of strength delivers a weight saving of about 30 % for those structural elements manufactured of high strength steel, according to the so-called root formula equation 3.3 (weight reduction is inversely proportional to the square root of the yield strength quotient), chapter 3.3.
This weight reduction, besides the lesser environmental impact through the need for a smaller quantity of steel for a particular function, also delivers substantial environmental benefits by economising on the use of natural resources and through more energy-efficient end products.

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Figure 1.4 shows how the steel strength, expressed as the yield strength of hot rolled steel, has developed over the last fifty years.

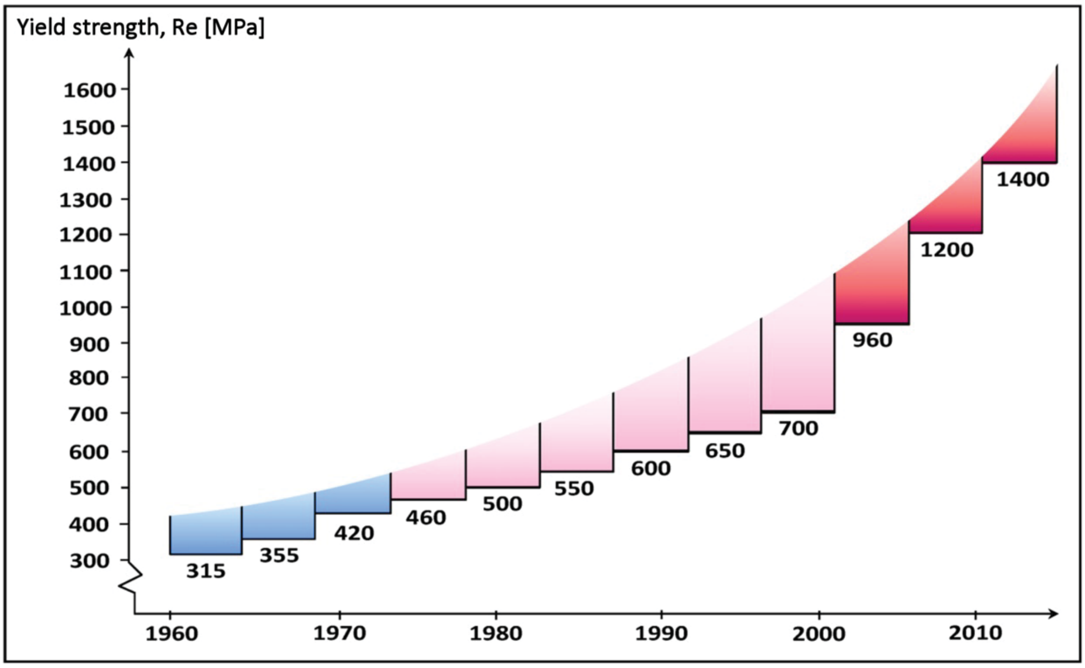

Figure 1.4 Development of strength of hot rolled carbon steel over the last fifty years

Even though the volumes of high alloy steel grades, widely known as stainless steel, only comprise about 2 % of all steel, the growth of this market segment is twice as high as for low alloy steel grades, often called carbon steel. Figure 1.5 shows this trend over the last 30 years. This also affects the demand for alloying metals.

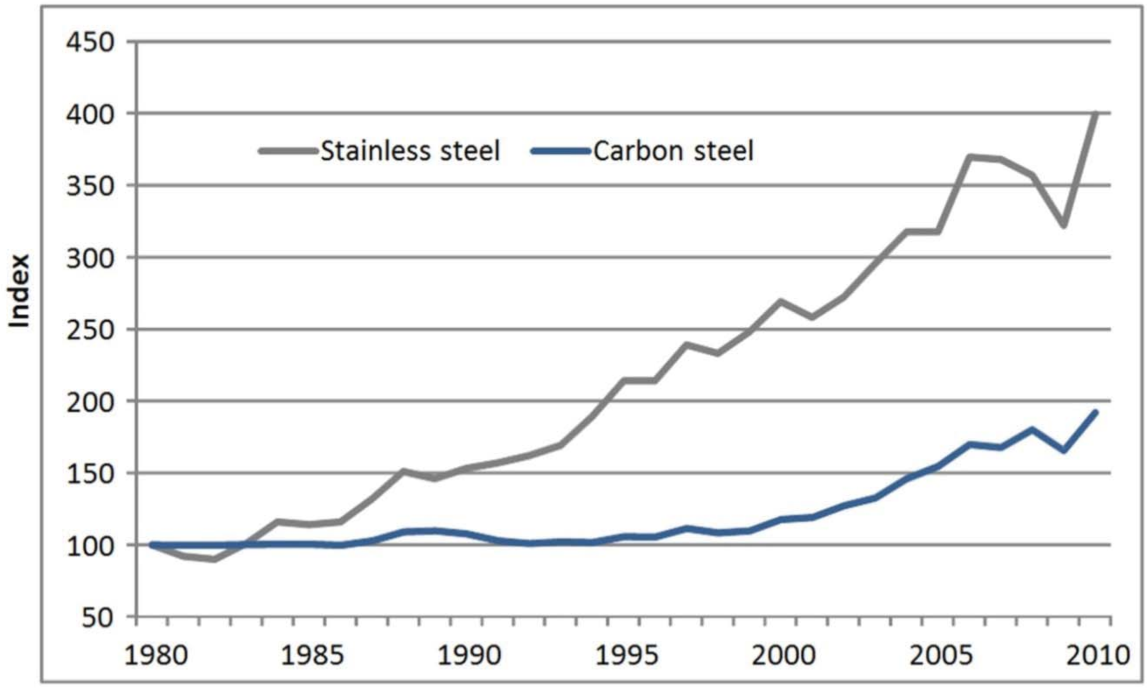

Figure 1.5 Growth of stainless steel compared with carbon steel

In the same way as for carbon steels, the strength of stainless steels has also increased. Stainless steels have been developed so that the austenitic steels have acquired a strong duplex complement within each corrosion resistance range, Figure 1.6.

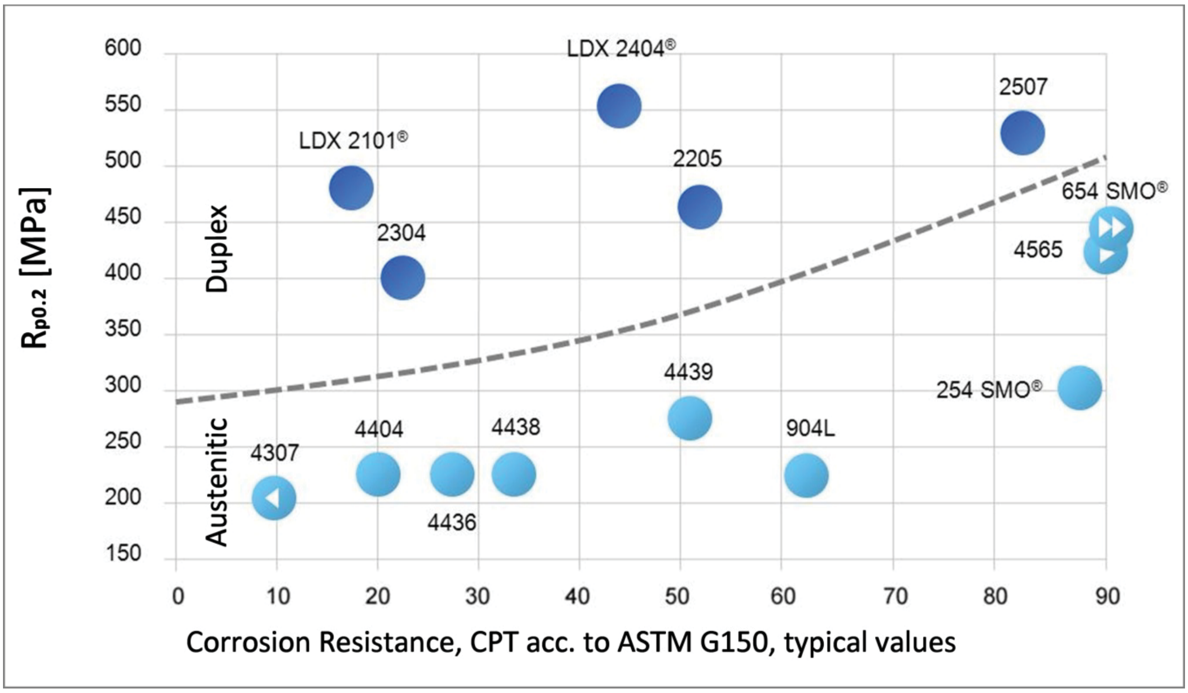

Figure 1.6 Duplex high-strength stainless steels complement the austenitic steels available

For stainless steel also, its strength, in terms of yield strengths above 1000 MPa, is utilised through the possibility of temper rolling. The technique is applicable to all steels but is most common for low alloy austenitic stainless steel since it is possible to combine very high strength with good formability. This is demonstrated in figure 1.7 below.

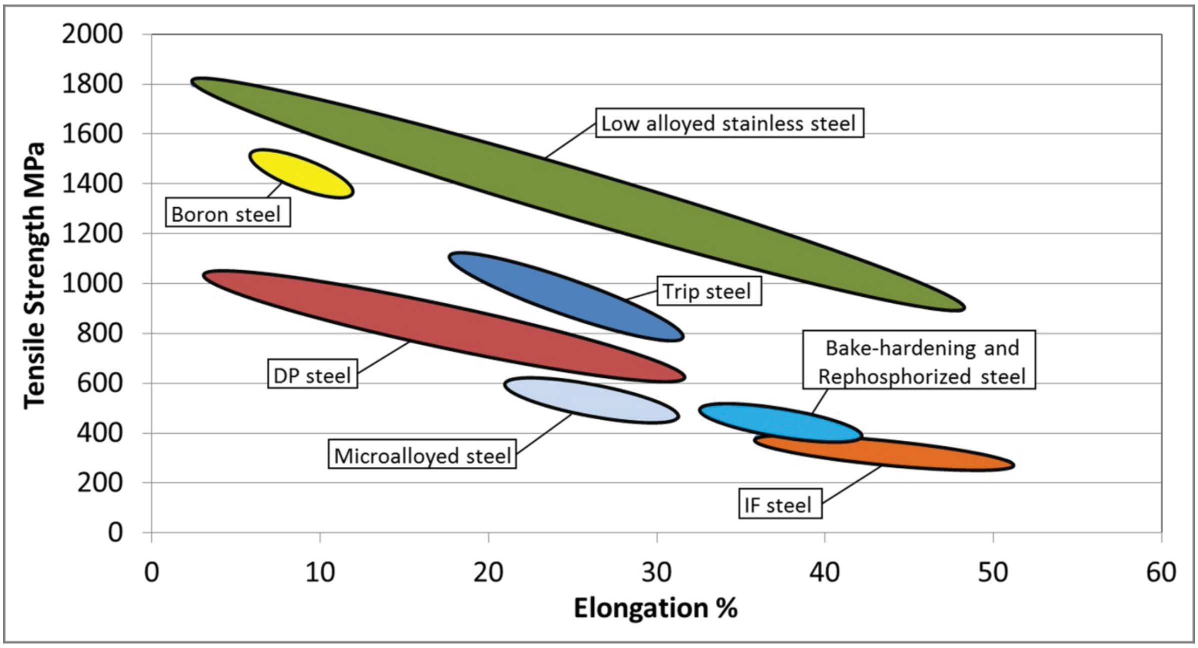

Figure 1.7 The combination of strength and formability of low alloy austenitic steels

Current research shows great advantages through reduced energy consumption during both the production and use of new steels in vehicles, for example. Steel producers and those that use steel have great possibilities of shaping sustainable outcomes for the environment, not least because the steel in products and structures is also a raw material source for the production of new steels when the existing products are worn out.

Environmental assessments enable the significance of new steel grades and recycling to be quantified and valued in connection with decisions concerning sustainable development.

1.1.5 The steel industry makes more than steel

Figure 1.3 above clearly shows that steel production also generates large quantities of residual by-products and that slag constitutes the major part of these. Slag is a valuable material since it can replace natural resources in, for example, the production of cement, as the base layer material in road construction and in asphalt mix.

Another aspect is that steel production generates large quantities of residual energy in the form of process gases and heating. The scope of this energy resource is so large that SSAB's operations in Sweden alone deliver 1 TWh of district heating to the steel towns of Luleå, Borlänge and Oxelösund. In addition, approximately 0.7 TWh of electric power is produced which corresponds to almost half of SSAB's total electricity requirement at the three sites. Figure 1.8 is an elevated view of the CHP (combined heat and power) plant in Luleå. This plant delivers the major part of the heating requirement, and a large part of the electricity requirement, to Luleå Municipality through utilising residual energy in the form of process gases from SSAB's steel production.

Figure 1.8 View over Luleå CHP, LUKAB, which supplies heat to Luleå

Where major changes to an industrial concept are planned, it is necessary to fully consider the supply and use of residual by-products and residual energy as an environmental impact value in a Life Cycle Assessment.

1.2 Environmental evaluation gives the full picture

Environmental evaluation, as we use the term here, describes how the environmental impacts of different steel grades can be assessed from a life cycle perspective. Besides forming a factual basis for different environmental comparisons, this data may also serve as a foundation for decisions on product development or process changes in the production of steel.

The great challenge is to be able to set the individual change within a larger perspective and to analyse the consequences that arise from a life cycle perspective. For steel, this means that the change needs to be quantified and analysed during steel's entire eco-cycle: from raw material to production of steel and steel products, transportation, manufacture and utilisation of end products and structures right up to the recovery of steel scrap and residual material. Figure 1.9 shows steel's life cycle, covering production and use as well as the recycling of steel scrap which becomes new steel in a wholly new product. This is a pattern that can be repeated time and again without loss of steel's special properties.

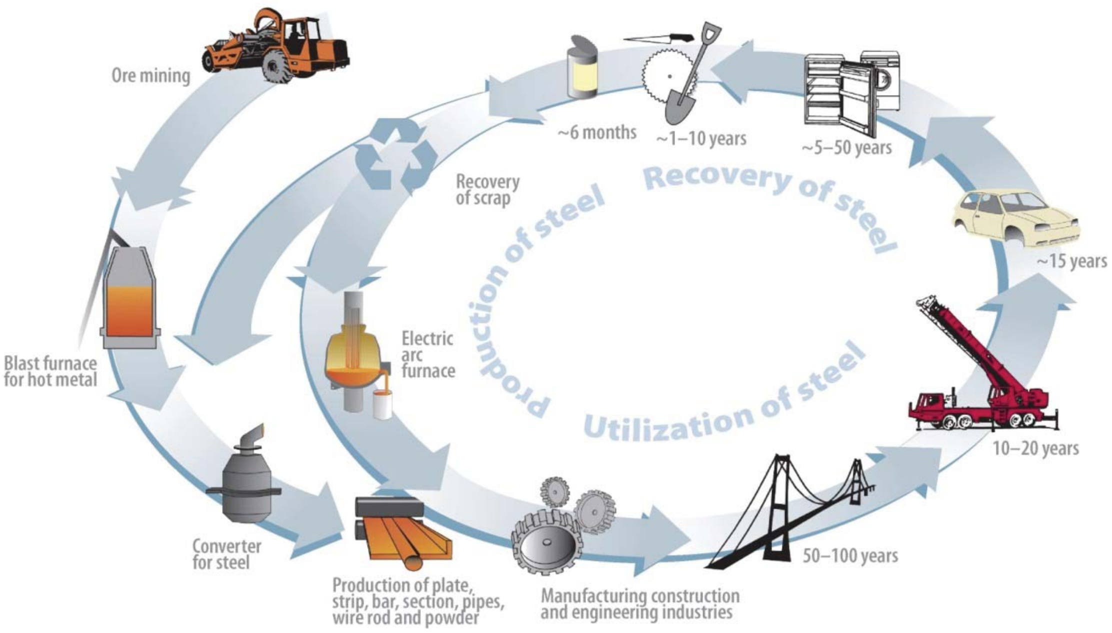

Figure 1.9 Steel's life cycle is a closed eco-cycle

Steel is, and remains, the material that is most used and recycled in the world today. The high level of recycling makes steel unique among modern materials.

Environmental evaluation is mainly based on the formalised Life Cycle Assessment (LCA) which is used within the steel industry today. The formal LCA methodology is complex and calls for detailed analyses by experts in the field, especially as the results shall be able to be scrutinised and quality assured both legally and from a customer perspective.

In their everyday work, many researchers and engineers focus on environmental evaluation and life cycle thinking without always using the strict, formal analysis methods. It is possible, nevertheless, to combine simple assessments with deeper analyses by experts; already, at an early stage, one can concentrate efforts on those areas that have the greatest influence on the environmental impact value and those measures that deliver the best effect. Subsequently, such a methodology builds up the knowledge needed to move towards sustainable development.

1.2.1 Working together is crucial for development

The saying "if one does as one has always done, then things will be as they have always been" is undoubtedly true. It is only by thinking in new ways that it becomes possible to see new opportunities. A minimal increase in the burden on the environment at the production stage may, for instance, create the conditions for environmental benefit with the end-users of a product through lower environmental impact during use.

To foster developments within the environmental area it is essential that the steel industry maintains forward-looking communication with stakeholders. This will help it identify the strengths and challenges of using advanced steel products from an environmental viewpoint. It is necessary that process and product specialists discuss new ideas and applications with environmental engineers, marketing personnel and, not least, the company's customers. Through discussing and analysing the environment together, new understanding of decisions and development requirements arise which may be crucial to the company's profitability. An ability to work together across technical and social borders is acquiring ever more importance in the development of products that are part of sustainable social development, figure 1.10.

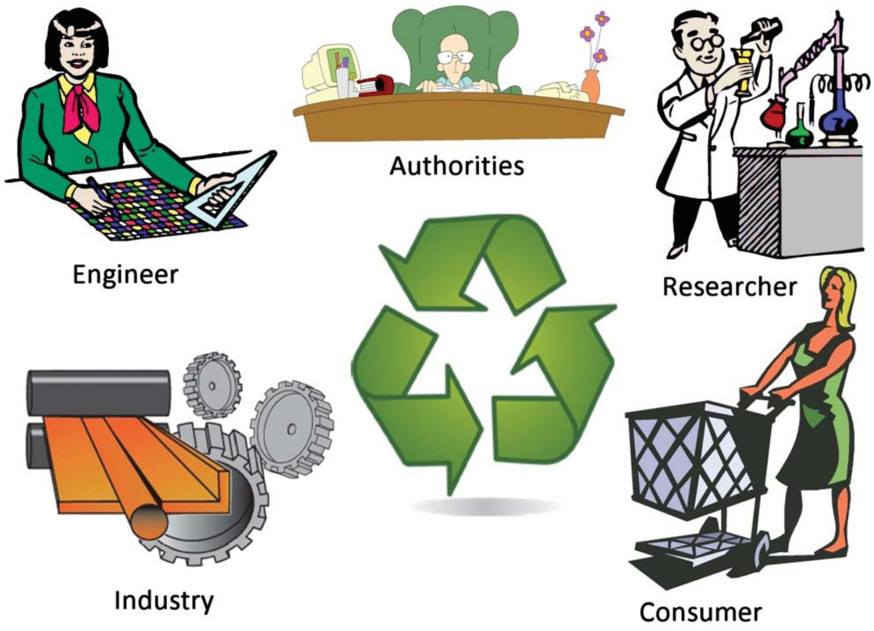

Figure 1.10 Working together across new frontiers is vital to ensure sustainable product development.

1.2.2 Steel Eco-Cycle programme shows the way to new opportunities

The environmental research programme "*The Steel Eco-Cycle*" (2004 - 2012) deals with all stages of steel's life cycle. A key to the success of this programme is found in the wide-angle lens it brings to the subject, the ability to see the overall picture in the interdisciplinary work. Researchers in different fields have been able here to acquaint themselves more closely with new ways of evaluating environmental issues and sustainable development in an environmental context. The clearest example of this is the use of advanced high strength steels within the automotive industry.

An analysis of the environmental impact value of high strength steel, the steel that today is supplied to auto manufacturers across the world, shows that the environmental load increases slightly when measured, for example, in terms of tonne carbon dioxide/tonne steel produced. There may be a modest need for more energy to produce the steel and, in certain cases, also a small increase in alloying elements to achieve the higher strength desired. This is more than compensated, in most cases, by the fact that products or structures can be made lighter. Since lesser amounts of steel are used in the construction, at the same time as the function is fully retained, significant environmental benefits are created through reduced emissions and economising on the consumption of natural resources and energy.

For vehicles of lighter weight, the environmental relief effects during use are also substantial; the longer that a vehicle of lighter weight is running, the more favourable the outcome for the environment owing to reduced fuel consumption. Reduced fuel consumption frequently comprises more than 90 per cent of the total reduced environmental impact.
Figure 1.11, taken from the environmental research programme *The Steel Eco-Cycle*, illustrates the potential environmental benefit where a million tonnes of high strength steel replaces 1.3 million tonnes of conventional steel in vehicles.

Life cycle phase	Carbon dioxide	Energy
Raw materials	-200 ktonne	-850 GWh
Steel production	-500 ktonne	-2 150 GWh
Use of application	-7 300 ktonne	-28 000 GWh
Total	-8 000 ktonne	-31 000 GWh

Figure 1.11 Potential for reduction of environmental impact when a million tonnes of high strength steel replaces 1.3 million tonnes of conventional steel in vehicles.

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The environmental benefits from fixed, so-called passive structures are less. However, the relative environmental relief may be significant all the same. This is shown by the results of a Life Cycle Assessment carried out on the Friends Arena in the Solna district of Stockholm, figure 1.12. By using 32 per cent high strength steel in the fixed roof structure, instead of conventional steel with 355 MPa in yield strength, the weight could be reduced from 4,584 tonnes to 4,000 tonnes (13 per cent). The newly constructed roof in high strength steel has a yield strength of 430 MPa (weighted average) through the different quantities of steels selected, with 355, 460, 590 and 900 MPa yield strengths. Owing to production and transportation of lesser amounts of steel, compared with a roof produced of conventional steel with 355 MPa yield strength, there is a substantial environmental benefit in terms of reduced carbon dioxide emissions.

Weight of fixed roof [tonne]	Weight reduction [tonne]	Weight reduction [%]	Environmental relief CO_{2e} [tonne]	Environmental relief CO_{2e} [%]
4 000	584	13	1 340	16

Figure 1.12 Weight savings and environmental benefits with high strength steel in the Friends Arena, Solna

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One example where the use of a high-strength duplex stainless steel has delivered considerable environmental benefits is shown in Figure 1.13. Here, the tank of a milk tank trailer is manufactured in duplex steel EN 1.4162 (LDX® 2101). Through choosing this steel, the tank's weight could be cut from 7 tonnes to 5 tonnes or by about 30 %. This, in its turn, means that emissions of carbon dioxide for each road milk tanker could be cut by 90 tonnes during the tanker's lifetime.

Figure 1.13 Milk tank trailer (permission from Officine Mecchaniche B.S. S.r.l)

Processes for manufacturing of steel

Within the environmental research programme *The Steel Eco-Cycle*, a number of technical methods for the production of steel have been developed, methods which also serve to reinforce steel's eco-cycle.

This development has helped to improve our knowledge of the supply and quality of steel scrap, increased the yield from raw materials during steel production and the recovery of slag, all this strengthening steel's eco-cycle. The technical processes developed have been environmentally evaluated from a life cycle perspective, showing reduced emissions of carbon dioxide and reduced energy consumption. The potential environmental benefits that these methods can deliver appear in figure 1.14. This shows that the environmental improvement from the technical changes increases by a factor of 3-6, when the environmental impact of the raw materials is taken into account. How the environmental impact value is estimated in process changes is shown in more detail in chapter 5.

Process	Carbon dioxide	Energy
Raw materials	-1 100 ktonne/year	-4 200 GWh/year
Steel production	-200 ktonne/year	-1 100 GWh/year
Total	-1 300 ktonne/year	-5 300 GWh/year

Figure 1.14 Potential for reduction of environmental impact on change of production methods for Swedish steel industry, ref. The Steel Eco-Cycle.

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2 Life Cycle Assessment – concept and background

2.1 General

There are many methods to evaluate products in environmental terms using a holistic approach. By far the most common of these is the Life Cycle Assessment, LCA, which takes into consideration the product's environmental impact from "Cradle to Grave". LCA also covers recycling when the product's useful life has come to an end or where it is used as the raw material for a new product.

Through carrying out a Life Cycle Assessment, where account is taken of raw material extraction, production, use, handling of residual products, transportation and end-of-life recycling, an understanding is obtained of both the larger picture and the smaller details. It then becomes possible to implement measures where they deliver the greatest environmental benefit.

The Life Cycle Assessment is also a tool that can identify scope for improvement and help to avoid the problem of sub-optimisation. There are many examples where the selection of a raw material or production process, with an inherently higher environmental load, leads to a significantly lower total environmental impact when seen over the entire life cycle. This is consequently a better choice from the environmental viewpoint. Life Cycle Assessments demonstrate such possibilities and lessen the risk of incorrect measures being taken from an environmental viewpoint.

2.1.1 Life Cycle phases – commonly used terms

The description of a product's life cycle normally covers those concepts shown in figure 2.1. Where steel's eco-cycle is concerned, however, it is common to speak of Cradle to Cradle instead of Cradle to Grave. This is because almost all steel undergoes recirculation (closed loop recycling).

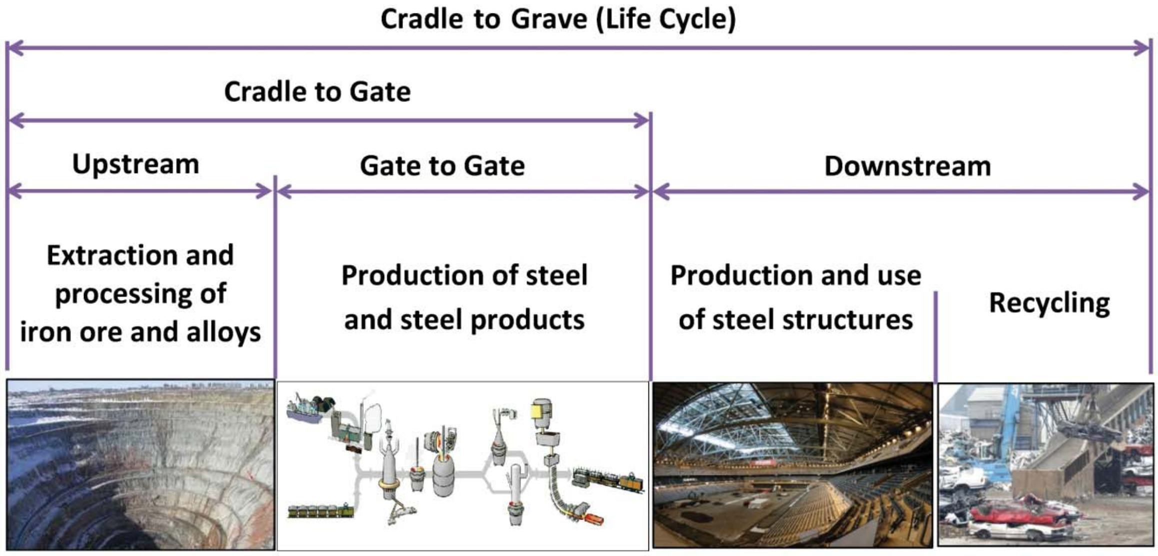

Figure 2.1 Generic terms for the phases in steel's life cycle.

2.1.2 The history of Life Cycle Assessments

LCA, Life Cycle Assessment, has its origins in energy analyses of products from “Cradle to Grave” from the 1960’s, although it started to be applied in its present form at the end of the 1980’s. Frequent early studies involved comparisons of different packaging materials. At an early stage, the LCA earned a reputation for being complex and costly while the results were not always seen as reliable. The basis of this reputation was the absence of a unified methodology and the lack of access to representative data for all stages of a product’s life cycle.

A first step towards a scientifically robust and unified methodology was taken by the scientific, not-for-profit, international organisation SETAC. It was in 1992 that it produced its “*Code of Practice*”. This document marked an important opening move in the work that the International Organisation for Standardisation (ISO) started shortly thereafter, on behalf of the standardisation of environmental management, ISO 14000. This included the preparation of an LCA standard, ISO 14040 series, and a standard for LCA based environmental product declarations.

The first LCA standard was published during the latter part of the 1990’s and introduced the structure that has been applied ever since. The most recent edition is SS-EN ISO 14044: 2006 “Environmental management – Life cycle assessment - Requirements and guidelines”.

According to this standard, a Life Cycle Assessment shall include the following elements:

- Definition of the study’s goal and scope.
- Inventory and preparation of a model that comprehends all parts included in the product’s life cycle, to enable the calculation of the material and energy flows including all emissions to air, land and water.
- Environmental Impact Assessment, where the emission’s contribution to different forms of environmental impact are assessed.
- Interpretation, where different tools such as sensitivity analyses are used to interpret the study’s results.

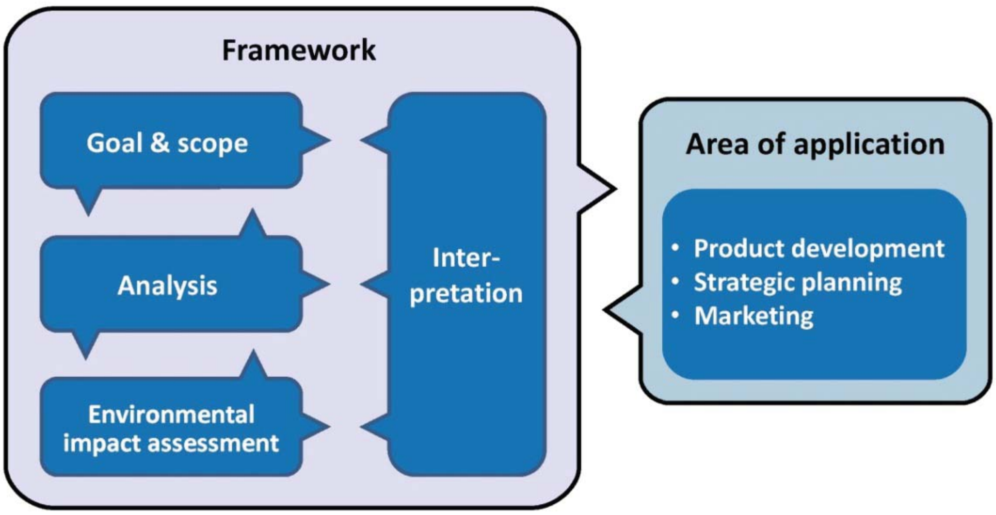

Figure 2.2 Schematic illustration of Life Cycle Assessment according to ISO 14040.

2.1.3 Life Cycle Assessments within the steel industry

The early use of LCA within the steel industry mainly involved seeing and learning. The view of environmental protection changed somewhat during the latter years of the 1980's – from a focus on air and water pollution caused by the production plants to a life-cycle perspective on the environmental effects of the products themselves.

LCA was viewed as a tool with great potential at the same time as it was complex and costly. There was a great need for an ISO standard that tightened up the methodology, but above all there was a shortage of data of good quality. This was the main reason why the then International Iron and Steel Institute (today World Steel Association) carried out a large-scale project to prepare representative data for steel products intended for LCA studies. The first version of this database saw the light of day in 1998, known throughout the LCA world as IISI 1998.

Eurofer (The European Steel Association), in connection with this, developed data for stainless steels. Many other materials were to follow. So it has continued, and nowadays there is much better access to data of good quality. This means that the cost of a LCA study today is about a tenth of what it was at the end of the 1990's. There is, however, still much to do in order to increase data accessibility and the quality of the information.

The EPD system (*Environmental Product Declaration*) was originally a Swedish programme for LCA-based environmental product declarations. It was launched in 1998, based on the work being undertaken within ISO. The standard for EPD, ISO 14025, only emerged however in 2006. The Swedish EPD system was converted, in 2008, to the now operative "International EPD system", which is the only EPD programme that is used globally.

Following the introduction of the EPD system, there are three main types of LCA:

- Comparative studies to assess variations in environmental performance.
- Declaration of a product's environmental performance from a life cycle perspective.
- Studies of product development work.

The different manuals, guidelines and handbooks that have then been produced are also categorised into these three main types. For comparative LCA studies, a set of rules apply the purpose of which is to be as flexible as possible in order to take account of the special circumstances that apply to each specific application. For environmental product declarations the reverse is applicable. In order to obtain as good comparability as possible all instructions are strictly formulated so that the data is comparable.

Today, the utilisation of LCA within the steel industry is very extensive, especially for products associated with consumers. There are, in this context, three types of applications:

- Internal company studies as support for, and documentation of, own product development studies.
- Major community-level system studies where, for example, different recycling processes, choice of fuel and so on are compared. This frequently has the purpose of informing the EU Commission and other public authorities. It may also describe how the environmental performance of type products is modified over time.
- Information on the product’s environmental performance and Environmental Product Declarations (EPD). This information is then narrowed down to a single environmental aspect, so-called “*footprints*”, such as “*carbon footprint*” and “*water footprint*”.

2.1.4 Life Cycle Assessments from an EU perspective

During the early years of this century, the EU Commission worked on developing an integrated product policy where LCA is concerned. The object was to shift the focus of environmental policy from production plants to the products themselves and to get producers to report the environmental performance of their products in a life cycle perspective. The idea was to stimulate life cycle thinking in product development. To support this development, the EU’s joint Research Centre JRC took the initiative to develop a joint LCA methodology and database structure for LCA data.

The result was seen in the so-called ILCD handbook, a far-reaching guide for implementing different types of LCA study, the last part of which was published in 2011. A summary of this is to be found in: *The ILCD Handbook in a Nutshell, IVL report B2020, 10/7/2012.*

There is a stated conviction within the EU Commission that the future competitiveness of European industry must be based on a better utilisation of resources throughout the product life cycle. Demands are therefore made that the environmental properties of a product are shown from the viewpoint of its entire life cycle within many different areas. Examples are the so-called “Ecodesign Directive” and the new Construction Products Regulation (CPR).

In January 2012, the European standardisation organisation (CEN) stipulated a test method standard for EPD construction materials (SS-EN 15804:2012). It is assumed that this will have a major impact; there is a clear link to the new Construction Products Regulation (CPR) instruction for EPD to be used for communication of the environmental properties of construction products. The EU Commission published a first draft of the LCA manual for *Product Environmental Footprints* (PEF) during the latter part of 2011. The stated goal is to develop a harmonised and stringent LCA methodology for work on policy measures and for trade and industry’s own environmental work.

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The signal is unmistakeable.

The environmental performance of products will be measured in future from a life cycle perspective within the EU's different policy areas. Industry is required to develop products with the same line of approach. Those who fail to take this on board risk losing the market's confidence.

Steel has great possibilities for following the pathway marked out. The advanced steels of today and tomorrow will be able to extend the useful life of structures. This will be done by increasing corrosion resistance, reducing structural weight through higher strength while disclosing also the positive environmental effects that arise through economising on material and natural resources. Furthermore, it is possible to recycle steel more or less as many times as one wants and with a low energy input. That is why steel is frequently described as being an infinitely recyclable material.

2.1.5 Working procedure with a Life Cycle Assessment

Regardless of the scope of the environmental assessment, it is essential to establish the framework conditions for the evaluation that must be carried out.

Whether it relates to a rough estimate of the environmental consequences of a minor change in a product or production process, or indeed the start of a wholly new production run, a structured working method contributes to simplifying the analysis of the project's consequences for the environment.

A formal LCA shall generate a list of the resources, emissions, residual energies and residual products created during a product's life cycle. Here a standardised methodology is a prerequisite to enable results to be used for comparisons and conclusions. The method frequently used for advanced Life Cycle Assessments is that which was standardised by ISO and which counts as the Swedish standard.

Where the purpose is only to analyse a small number of environmental aspects, for example the greenhouse effect and energy, it is recommended to limit the environmental analysis data inventory to those parameters that are relevant. Where environmental analyses of industrial processes are concerned, one often gains most from selecting individual key factors, such as carbon dioxide, energy and material flows; these give clear signals of how a change may affect the aforementioned factors.

The scope of a Life Cycle Assessment, in the way we describe it in this book, appears in easy-to- grasp form in figure 2.3, while the working procedure is shown in more detail in Ch. 3 and Ch. 4.

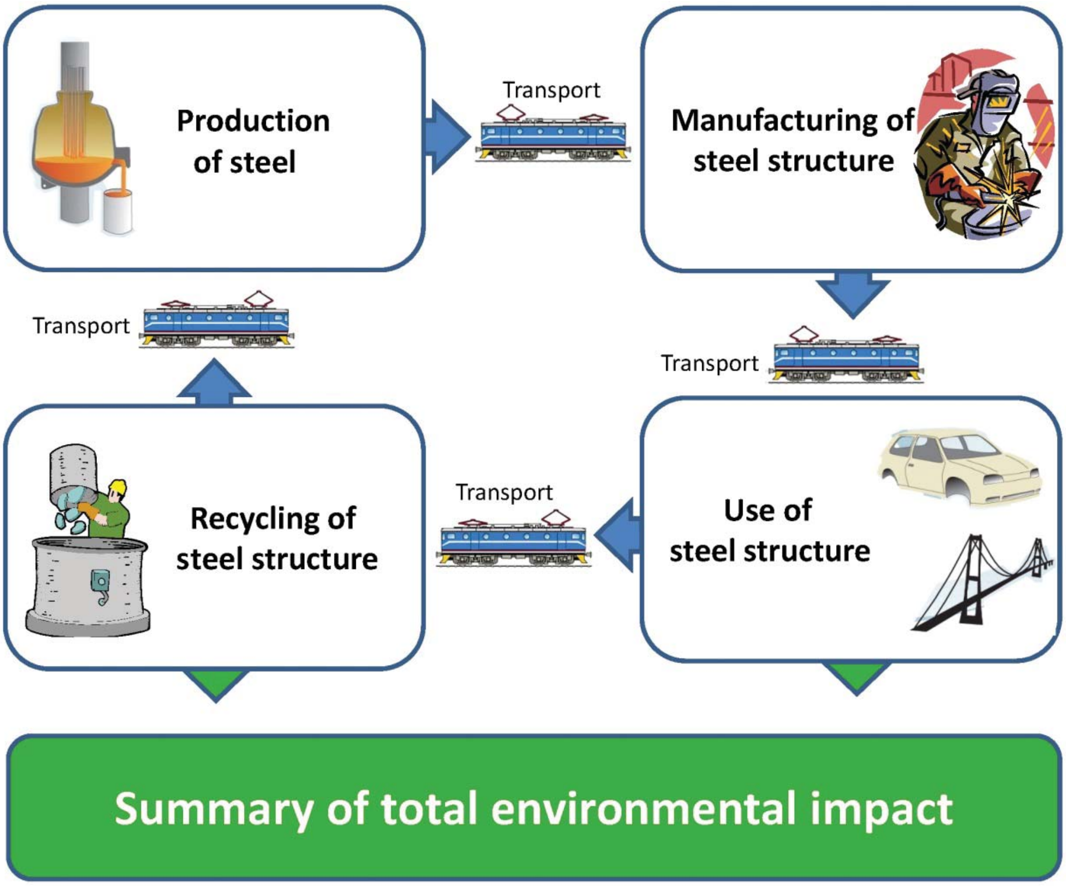

Figure 2.3 Easy-to-grasp description of a Life Cycle Assessment for production of steel as well as the manufacture, utilisation and recycling of steel structures and related transportation.

The environmental evaluation of new steel processes is normally conducted as a Life Cycle Assessment; here the analysis can be limited to comparing the existing production process with the new proposed one.

In the LCA work the data collection, above all, is an extensive component part. It is normally carried out as an iterative process. To start with, one relies on easily accessible, but possibly rough data, in order to obtain a picture of which data will be most important for the results. Having collected further data, especially relating to those factors that are most significant for the end results, the calculation is repeated until such time as the desired level of accuracy is achieved.

2.2 Goal and Scope of Life Cycle Assessment

2.2.1 Purpose, goal and system boundaries

The establishment of the goal and scope is a very important part of the LCA. It is here one describes why the assessment is being carried out, for whom it is intended and how the results shall be actually used. It is also determined how the life cycle should appear and what shall be included and what may be left out of the assessment. All delimitations and simplifications are indicated as well as the quality of the data that is aspired to. At this stage, the entire planning of the analysis is carried out; this frequently means that one must go back and modify the preconditions in the course of the work. This is what makes LCA studies into an iterative process.

An important point in this context is the choice of the Life Cycle Assessment's functional unit. This is a measure of the utility delivered by the product studied.

It is the environmental impact per functional unit that is the subject of environmental evaluation in an LCA, not the impact per kg of material or such like.

A clear example comprises new advanced steel grades which normally have a slightly higher environmental impact per kg than conventional steels. However, a smaller amount of high strength steel is required in different applications for the same function. In an example with typical stainless steel, a lower corrosion allowance is required with a higher addition of alloy and thereby a smaller quantity of metal. Compared with carbon steel, surface treatment is avoided as well as the maintenance of the same. Reckoned per functioning unit, the environmental impact is thus lower. It is a basic rule in LCA studies to always relate the environmental load to the benefit the product delivers; this is termed functional unit in LCA terminology.

Another issue having a great influence on the LCA results is how material recovery shall be evaluated. To what degree should the steel scrap's environmental burden from the earlier life cycle be included in the calculation? To what extent should future environmental relief be allocated a credit because the steel product will be recycled in future? Here are several different lines of approach and a single standard is lacking.

In the different EPD systems and, for example, the CEN standard for the environmental declaration of construction products (EN 15804), the use of scrap raw material is, so to say, "free from environmental burden". On the other hand, one is not entitled to a credit owing to the fact that the material in the end-of-life product can be recycled. In the EU's PEF guide, the environmental impact from previous life cycles is debited against corresponding material losses in its own life cycle. The first case favours use of recycled material; the second favours production of those products that can be recycled.

2.2.2 Choice of environmental impact categories

To be able to reformulate the inventory flows of materials, energy, emissions and such like in terms of environmental impacts, the relevant environmental impact categories need to be chosen. There are a large number of such categories and which ones are chosen depends on the purpose of the LCA study.

For example, if one wants to know how much a product contributes to climate change it is, in principle, only necessary to make an inventory of greenhouse gas emissions since the only environmental impact category relevant is the greenhouse effect. This means, however, that one knows nothing about other environmental impacts and cannot draw any conclusions about the product's overall environmental properties. It is, therefore, common for several environmental impact categories to be included, even if these only account for e.g. climate change, energy consumption or water use. For standardised analyses such as environmental product declarations, a number of impact categories are specified and these must then be included in the evaluation.

In the section of the EU's ILCD handbook published in November 2011, 14 indicators are specified, of which three relate to different forms of toxicity. This is a gross list and it is not intended that all items shall always be present. The selection shall be confirmed and justified in the LCA study's "Goal and Scope". The standard for the EPD relating to construction materials specifies seven environmental categories as well as no less than 21 resource categories.

The most common list of mandatory impact categories includes the five classic categories:

- climate change
- acidification
- eutrophication (over-fertilisation)
- ground-level ozone
- ozone depletion.

The latter is a declining environmental problem and is therefore seldom taken into account. The quantity of residual products of different types is always shown. Also included on occasions are some summary measure of toxic discharges as well as a number of indicators for resource utilisation such as water use, land use and non-renewable energy raw materials and input raw materials.

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2.3 Data collection (LCI, *Life Cycle Inventory*)

2.3.1 Sub-process analysis data

Data is collected for the sub-processes that have been defined in Goal and Scope, figure 2.4.

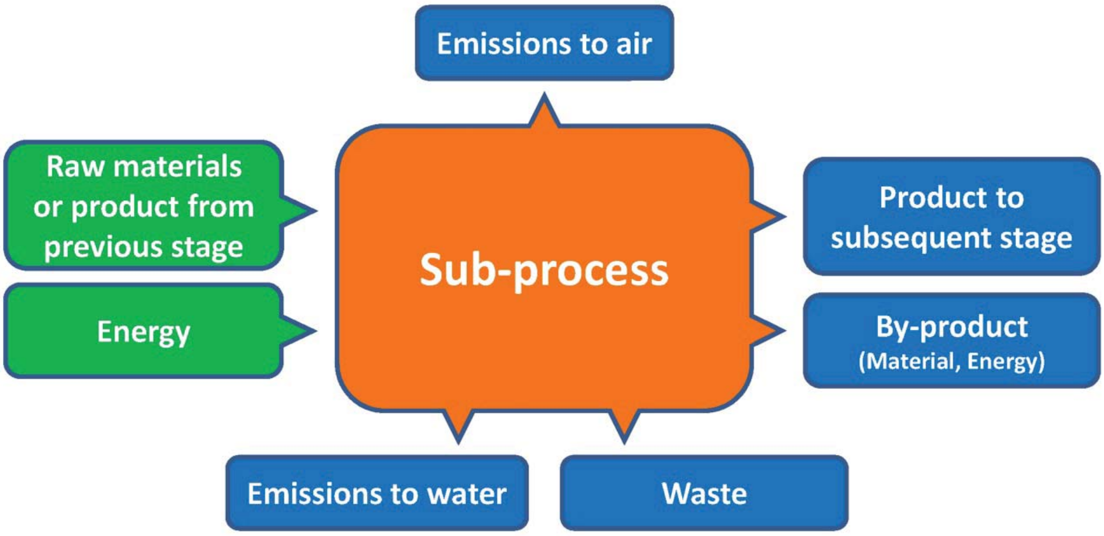

Figure 2.4 Example of data collected for the respective sub-process.

The sub-processes may correspond to individual process stages or summarise the entire production processes, depending on the level of detail required for the description or in which aggregated form (aggregation level) the data can be collected most easily. On production of steel, the categorisation is as follows: steel production, hot rolling including possible hardening and tempering, cold rolling including annealing, pickling and coating. The processes shall thus include all supply chain and supplementary processes as well as residual product and energy flows involved in making the end product. Where a more detailed analysis is required, the metallurgical steel production process for carbon steel can be divided up into coke oven, blast furnace, converter and continuous casting. The production of stainless steel can be divided into the production stages of electric arc furnace, converter and continuous casting.

The core processes are modelled in as detailed form as possible whereas other processes are described in more summary form.

An important aspect for all processes is to calculate the yield of raw materials and the energy efficiency since this directly affects the end result. As the level of processing increases so the yield becomes increasingly important to take into account.

2.3.2 Raw materials and energy

For raw materials and energy bearers, so-called generic data is available in different LCA databases. The LCA software tools used for environmental calculations are normally delivered with this type of database. Other data sources include the EU’s public ELCD database, or the Ecoinvent database developed by a number of parties within the Swiss

Centre for Life Cycle Inventories. The different global trade bodies, *International Molybdenum Association* (IMOA), *Nickel Institute,* among others, frequently publish LCA data based on studies conducted among member companies. It is also possible to seek data in different types of literature, technical reports, articles and environmental reports; in that case special knowledge is required to interpret and rework the data so that it becomes usable. Data is often published in consolidated (aggregated) form, where the entire production process is described as a “black box”. This data frequently encompasses the whole process chain from natural resources to finished product (so-called cradle to gate data). This data does not always tally with the chosen scenario and must then be adapted.

Appendix 2 includes a list of different data and information sources.

Raw materials

Examples of raw materials are iron ore, carbon (C), coke, ferrochrome (FeCr), ferronickel (FeNi), ferrosilicon (FeSi), and ferromanganese (FeMn).

Examples of input goods are welding wire, chemicals such as sodium hydroxide (lye), lime, and calcium oxide.

Data for production of raw materials is obtained, as a rule, from databases as generic data. It sometimes happens that one does not find what one is looking for in accessible databases. In that case there occur so-called data gaps. In section 2.3.4, there are examples of how to handle these.

Fuels

Examples of fuels are coal, coke, natural gas, LPG and oil.

Where fuels are concerned, data is required relating to the production and transportation of the fuel as well as the emissions that arise when the fuel undergoes combustion in the specific process. Where emission data is lacking for the particular use then general information is available in public databases.

Electricity

Data for different types of power source

Environmental data relating to the production of hydropower, nuclear power, coal power and so on is obtained as a rule from databases as generally applicable data.

Different regions generate electric power from different types of primary energy sources. Sweden’s electricity needs are mainly met with nuclear power and hydropower, in roughly equal parts. Norway relies predominantly on hydropower; France has a large share of nuclear power whereas Europe, on average, has substantial components of both coal and nuclear power energy sources. The mix of energy types, that is to say how much is hydropower, nuclear power, coal power and so on can have a considerable effect on the LCA analysis results.

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Average data for a nation or region

If one wishes to analyse a new process technology, one must assess how the new process will affect electricity use. Where the electricity use may be considered to be part of the normal electricity use of a country or region, and the new process will not thereby significantly increase the total electricity consumption, we can assume that the electricity is average electricity. Since electricity is both imported and exported to and from a country, the consumption mix in the grid may differ from the production mix. In this book, however, it is the consumption mix that is referred to when we speak about average electricity. Statistics concerning the composition of produced and consumed electric power in different countries can be obtained from *The International Energy Agency*, see Appendix 2.

Where analysis of a single plant only is intended, then perhaps not even average data is the most appropriate selection. In that case, data should be selected that represents the electricity purchased through a contract with a power supplier.

If one wishes to have a wider perspective than one single plant, then a European average, for example, may be preferable.

Data for marginal electricity

Where the process has a significantly higher electricity use than the reference scenario, where it is so extensive, for example, that it influences the infrastructure for electricity production in a country, it may be justified to assume that that one must make use of marginal electricity, at least in the short term.

Marginal electricity is calculated in Sweden today on the electricity production in a natural gas combined cycle power plant (NGCC). There may thus be a great difference in the environmental impact between average electricity and marginal electricity.

Data used in the Steel Eco-Cycle

The Steel Eco-Cycle environmental research programme relies on data that represents a Swedish average (based on the consumption mix) for Swedish produced electric power. For electric power consumed outside Sweden, an average for Europe as a whole has been used. In the upstream data, such as on production of alloying elements, electricity production is already included. In that case, average data is included for the country where the material is produced.

2.3.3 Data for transport journeys

Environmental data for different forms of transportation is available as generic data in modular form, like data for the production of fuels. Examples of databases are the Network for Transport and Environment (NTM) and the LCA databases (e.g. Gabi software), see Appendix 2. As a rule, these contain data for different means of transport such as private cars, trucks, buses, ships, passenger trains and freight trains of different sizes, load capacity and types in respect of fuel and motor. Environmental data is frequently specified per tonne of load and kilometre travelled (tonnekm).

For freight transportation, it is essential to ascertain if the freight carrier is weight-limited or volume-limited. Weight-limited transportation is where the carried goods have high density and can be loaded efficiently. In this case the vehicle achieves its maximum permitted weight before the volume is fully utilised. Many transport journeys of raw materials and steel are weight-limited transport journeys. This means that one can count on a high load factor, see also section 3.4.3.

When the goods are voluminous or cannot be loaded efficiently then one has volume-limited freight transport. The vehicle then becomes fully loaded without achieving the permitted payload. Transportation of a steel structure is normally volume-limited whereas transportation of steel products is most often weight-limited. For volume-limited transport journeys, one needs to calculate the load factor (LF) through relating the quantity of freight to the vehicle's maximum load capacity as set out below.

$$\mathbf{LF} = \frac{\text{Quantity of freight [tonne]}}{\text{Maximum load capacity [tonne]}} * 100 \qquad [2:1]$$

This means that the transport data used to calculate the environmental impact of truck journeys must correspond to the calculated load factor.

Where information is lacking for calculation of the load factor but it is adjudged that the transportation is volume-limited, one can assume a load factor of 50 - 70 per cent, a figure that is normally on the safe side.

The distance for transport journeys by land and sea between two places can be calculated with the aid of different web pages, see Appendix 2.

2.3.4 Handling of LCA data gaps

In steel production a large amount of different types of raw materials, chemicals, water vapour, gases and so on are used and the relevant LCA data is not always found for all these. If all these are used in small quantities, and where it is known that the production has low energy use or generates low specific emissions, then the data gaps may be considered to be negligible.

If one considers this not to be the case, then one can attempt to assess the environmental impact with data for the production of equivalent material. If an estimate should produce much too large an impact it is appropriate to carry out sensitivity calculations that refine the end results.

Data can also be obtained from process descriptions in handbooks relating to process engineering or by carrying out rough calculations based on the stoichiometric ratio (quantitative relationship) between raw materials and product.

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There is also data available on the energy conversion in chemical reactions. All this requires that one has LCA data for input raw materials.

The data gaps that cannot be considered negligible shall be recorded quantitatively so that this can be included qualitatively when the results come to be interpreted. Where LCA data is lacking it is important that the material flows are shown in the compilation of results.

2.4 Modelling of the LCA system

2.4.1 General

A common feature of LCA software tools is that they combine a graphic interface for the flow charts with a module that balances the mass and energy flows in the system, figure 2.5. Data for the integral sub-processes, relevant transport journeys as well as for production of raw materials and energy is compiled and managed most simply by an LCA software program.

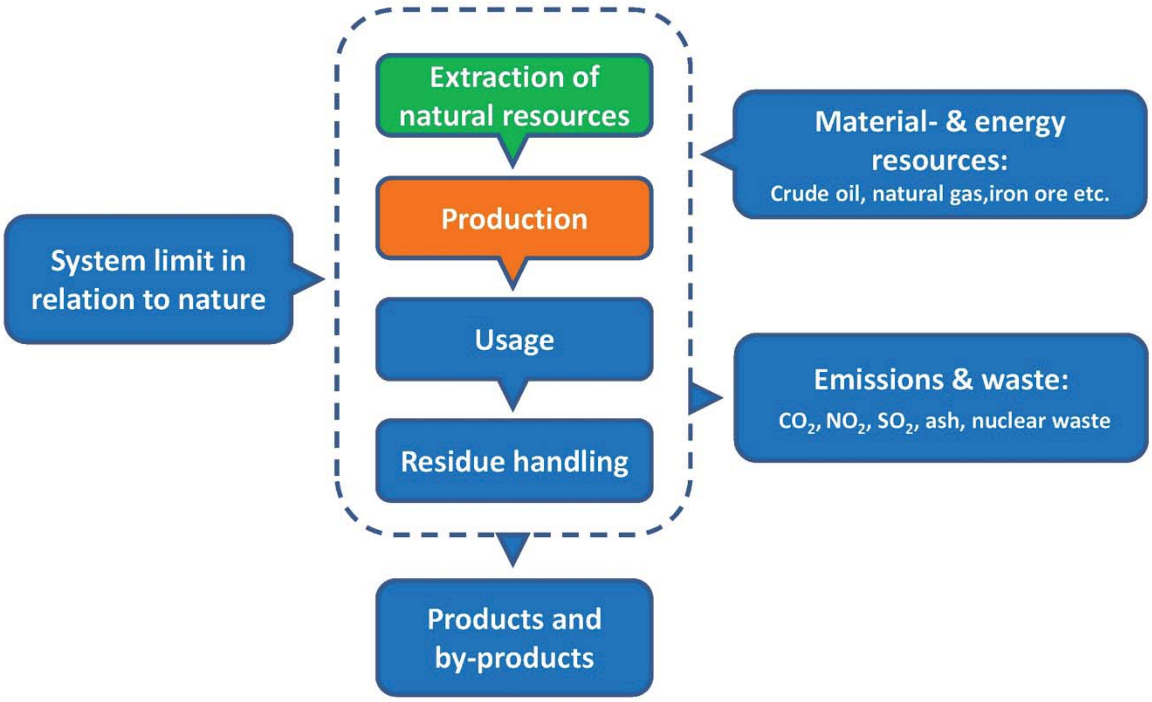

Figure 2.5 Example of interface for mass and energy flows.

Such software programs commonly contain data to calculate the potential environmental impact from the estimated emissions from the system, for example the greenhouse effect and acidification.

2.4.2 Software for Life Cycle Assessment

Access to LCA software facilitates the modelling and calculation work. Some software programs are relatively good value and easy to use even for those who do not have knowledge of LCA analyses. Others are more advanced and demand both experience and more profound LCA knowledge.

For simpler systems, however, one can also use Microsoft Excel. The process modules may then be represented by spreadsheets which are linked to one another. For more advanced mathematical modelling, programs such as MatLab can be used. The disadvantage with Excel and MatLab, however, is that one does not then have direct access to LCA databases.

The LCA software programs GaBi (PE International, Germany), and SimaPro (Pré, Holland) are prominent in this market.

A number of companies within the steel industry use the software program GaBi, which for example has access to extensive databases and more mathematical functions than most other LCA software. GaBi enables modelling of even complex processes with non-linear relations between processes. SimaPro is commonly used for the preparation of environmental product declarations (EPD). The Steel Eco-Cycle project has been analysed with the help of GaBi.

2.5 Interpretation

Interpretation is the fourth part of a formalised Life Cycle Assessment. It is, however, carried out in parallel with other parts of the LCA. As stated above, simplifications and assumptions are necessarily made. One is obliged to use data that is not always exactly correct. Consequently, there are a number of deviations from a wholly perfect LCA. In the interpretation, a sensitivity analysis is carried out to assess how these assumptions and deviations affect the results of LCA studies. An assessment is then made concerning whether there is sufficient background material to draw conclusions or whether one must go back and complete the study. It can happen also that one has to revise the objective that was set up for the analysis.

2.5.1 Interpretation of a first inventory result

When the LCA system’s flow chart has been put together, an initial inventory result is calculated which is then interpreted in terms of one or two key factors, an example being carbon dioxide emissions. The overall picture and the supporting details are identified and attempts are made to assess how different assumptions or data gaps affect the results. This can be carried out with the help of sensitivity analyses.

2.5.2 Sensitivity Analysis

In an LCA analysis a series of different assumptions are made. These include the choice of data for electric power production, choice of system boundaries (i.e. what is included and excluded), choice of allocation methods (e.g. how one distributes the environmental impact for different processes between primary products and by-products). They may also include approximations that have been made in connection with a data gap or assumptions concerning a recovery rate.

The sensitivity analyses are a good tool for acquiring an idea of the significance of such assumptions for the results. Where a data gap is concerned, it is possible to test by adding an approximation based on a similar material in order to assess if the data gap is serious or not. For example, it is possible to use another allocation method to see the effect this has.

2.5.3 Uncertainty Analysis

Environmental estimations for large systems with complex processes and long supply chains are normally associated with major uncertainties. A downright miscalculation is often not possible; however, one can test the conclusions through sensitivity analyses for important parameters as well as through computing different scenarios. To be considered significant, the numerical difference in a differential analysis must be on a level with the uncertainty.

Raw material use is well documented as a rule. The carbon dioxide emissions are not usually measured but calculated from the consumption of carbon bearers such as fossil energy. This method offers relatively good precision.

For the production of steel, the greatest uncertainties are to be found in the data used for production of the alloying elements. Such base data is frequently aggregated and comprises the entire chain from cradle to gate. This can make it difficult to assess if the data is representative from the point of view of technology, used production data for generation of electric power etc.

For analysis of the entire life cycle of a steel structure, the greatest uncertainty lies in the steel scrap's environmental impact value which is credited in connection with the structure's end-of-life recycling, see also chapter 3.5.

Where new and older process technology is subject to comparison, the greatest uncertainty probably lies in the description of the new process, particularly where the data is based on laboratory trials and any data from full-scale trials is non-existent.

2.6 Results and Conclusions

When one has compiled the results of the inventory, estimated the contributions to the selected environmental impact categories and acquired knowledge from the interpretation, one can then draw conclusions according to the goals that have been set for the study. In connection with the reporting of the results and conclusions, it is a good idea to discuss how secure these are, based on the interpretation and on knowledge of the flow systems studied.

The numerical results shown shall be reasonable bearing in mind the technical preconditions. The difference in carbon dioxide emissions, for example, shall correspond to the difference in fossil energy used (coal, crude oil, natural gas). Where this is not the case, then there must be a reason; for example the fossil energy bearers have not undergone combustion but instead are used as material in the life cycle (coal in steel, crude oil in plastics and chemicals).

The conclusions are most often relevant where all environmental impact categories point in the same direction; for example, if the greenhouse effect, acidification and consumption of energy resources quantitatively show that case A is better than B.

On many occasions, however, one is compelled to weigh one environmental effect against another. An example of this approach is indicated below:

Case A implies increased use of nuclear power compared with case B, whereas case A delivers a reduced climate change effect. There is no scientific method, however, for evaluating the impact of nuclear waste and increased extraction of the finite resource that is uranium in terms of climate change effect. It is consequently not possible to draw any objective conclusion concerning this question, based on the Life Cycle Assessment. Such complications shall be reported in the conclusions.

3 Environmental evaluation of steel and steel structures

3.1 Introduction

This section describes the environmental evaluation of a steel structure and clarifies the principles and working procedure for determining the environmental impact value of different steel grades in steel applications.

The challenge for today's product developers is to develop new steel grades and to fabricate products with these so that chemical composition, steel production, use of the steel in structures, recycling and handling of residual products are all optimised from an eco-cycle perspective.

To evaluate a steel structure's environmental performance during its entire life cycle, it is best to divide up the analysis into a number of sub phases. These different phases are illustrated in figure 3.1 and described in more detail in this chapter.

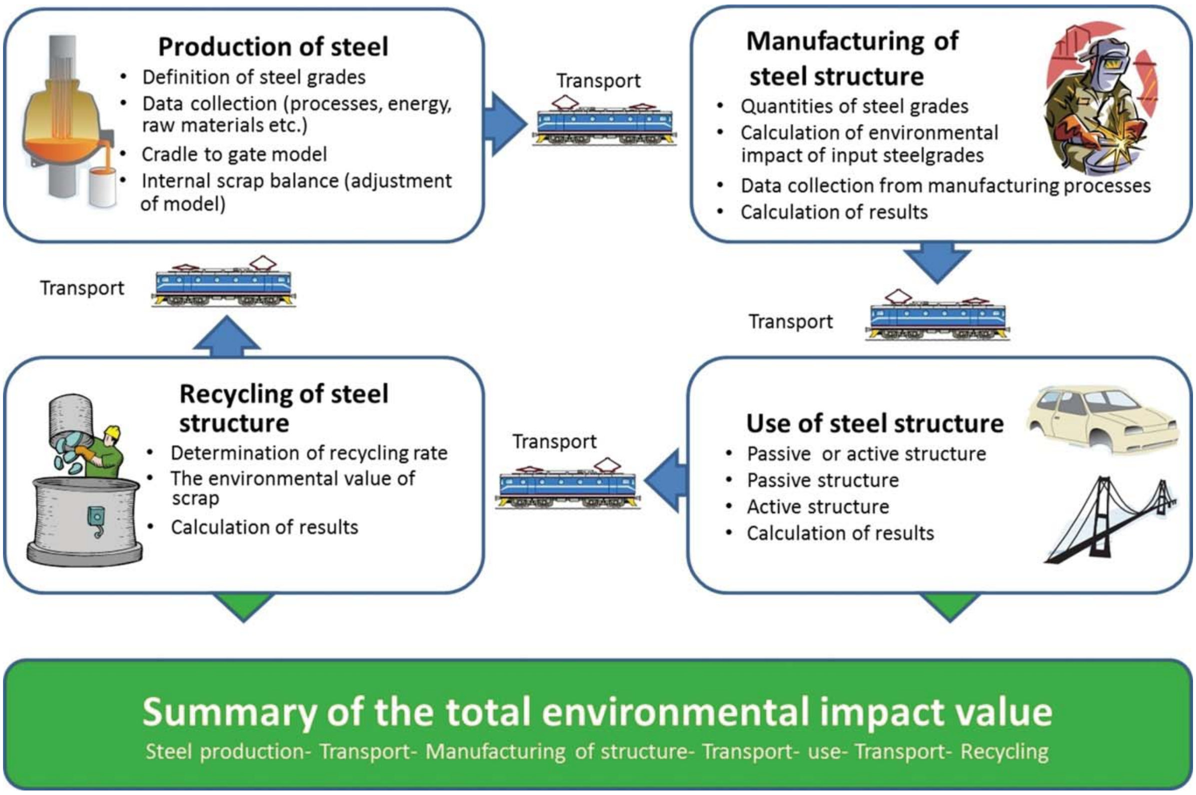

Figure 3.1 Important stages in the Life Cycle Assessment of a steel structure.

3.1.1 Development of steel

The development stage of steel is not normally included in the environmental evaluation of a particular structure. From the environmental viewpoint, however, it may be of crucial importance to incorporate the environmental dimension already at the product development stage. To develop steel for sustainable products, the environmental impact of the raw materials and the alloying elements must be environmentally evaluated already at the development stage, in combination with those advantages that advanced high strength steel, stainless steel and hardened steel, for example, deliver to the end product.

Through the use of advanced steel grades it can be shown that alloys which, in the production stage have a greater environmental impact, actually deliver significant environmental benefits when viewed from the perspective of the product's overall life cycle. On development of new steel grades (high strength steel, stainless steel), it is therefore especially important to so "compose" the steel that the combination of raw material, production method and area of use delivers the lowest possible environmental impact from a life cycle perspective, in relation to the intended product characteristics and product functions. For example, accelerated cooling processes during hot rolling of steel can be an alternative to the addition of alloying elements.

When alloying the steel, it is generally a good idea to choose the alloying approach that delivers the lowest environmental impact. However, one should accept a higher alloy content where it is compensated by the ability to make a lighter structure and one with less material consumption and/or with more corrosion/wear-resistant steel, thereby delivering lower environmental impact from a life cycle perspective.

An example is the choice of duplex stainless steel instead of high-alloy austenitic stainless steel; the duplex steel combines higher strength with an alloy composition that ensures a lower environmental impact.

3.1.2 Alloy composition

Alloys have a major effect on the environmental impact value of steels. The diagram in figure 3.2 provides guidance in the choice of alloying element so as to ensure the lowest possible environmental impact. With the help of such data, the alloying concept of the steel can be environmentally evaluated and an adjustment can take place to achieve the intended properties and range of applications. The diagram shows emissions of greenhouse gases for different alloying elements. A greenhouse gas is a measure of the potential effect that the gas has on global warming potential (GWP), the so-called greenhouse effect.

The greenhouse gases are expressed as CO_2 equivalents (CO_{2e}). This value mainly comprises carbon dioxide, but emissions such as methane and nitrous oxide (laughing gas) also contribute.

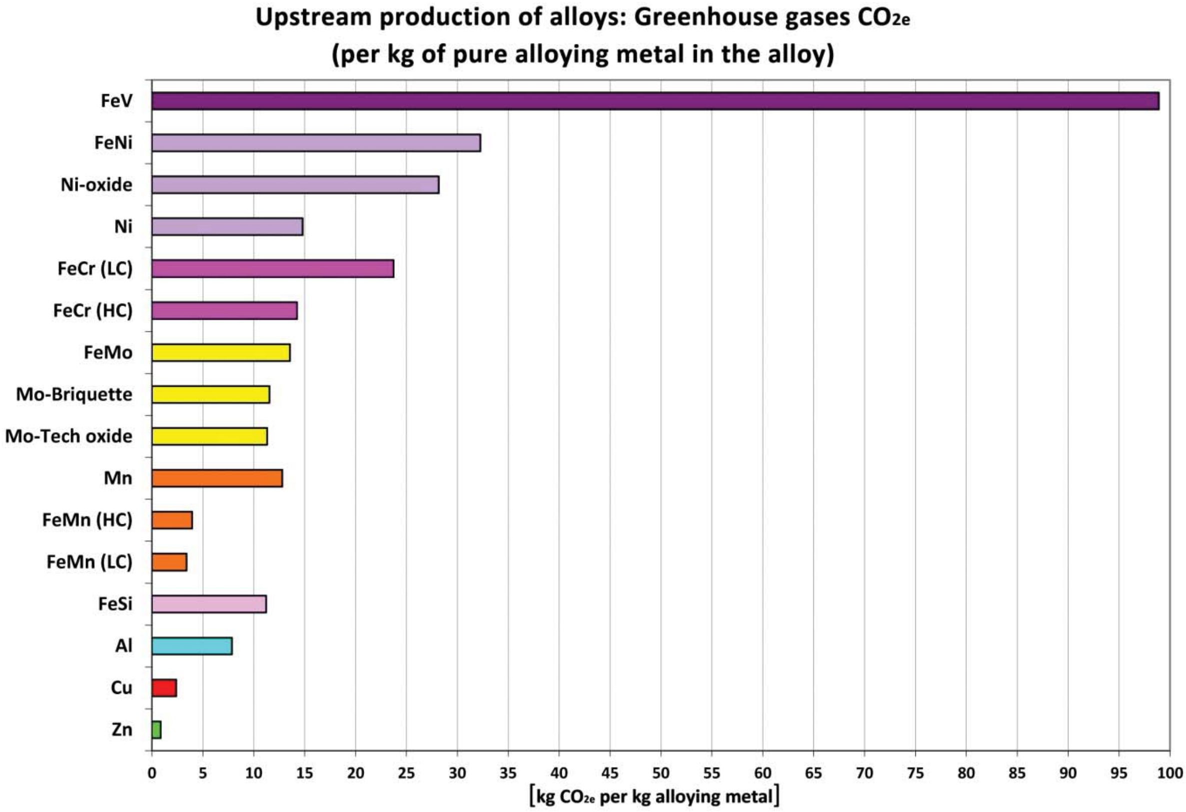

Figure 3.2 Example of total emissions of greenhouse gases on production of different alloying elements, (kg CO_{2e} per kg alloying element).

3.1.3 Production method

The production method that delivers the lowest possible environmental impact value should be chosen. The processes are developed or modified to achieve the best possible material yield. Here too the choice of alloying elements has a role to play.

To improve the yield on production of steel influences the steel's environmental performance very positively, since a high yield rate means that less quantity of steel needs to be produced in the prior process stages. The steel scrap is recycled, it is true, as a raw material for production of new steel, but the environmental credit this delivers is normally less than the environmental gain that results from an increased yield in the steel production process.

3.2 Production of steel

3.2.1 Definition of steel grades

The environmental evaluation is commenced by choosing the steel grades and thickness range that shall be included in the structure. The latter is important since different thicknesses may demand different alloy contents in order for a specific strength to be achieved.

The production process for the relevant steel grades is then defined. Examples may be: steel plant, continuous casting, hot rolling including possible hardening and tempering, pickling, cold rolling, annealing, coating etc. The sub-processes are identified for those parts of the process where there is access to relevant data. It is not always necessary to collect data for all sub-processes but one can combine sub-processes at suitable levels and collect data for this level. This is termed the aggregation level in the LCA methodology.

3.2.2 Data collection for the LCA system process stages

Plant-specific sub-processes

To begin with, data is collected for the specific sub-processes, normally the most essential production stages in the production process. The data is related to the produced amount of product in the respective sub-process, for example a tonne of continuously cast slabs. In order for the data to be representative, it should cover a longer period, for example one or two years. The period of time chosen should not include exceptional events.

The following data is collected for each sub-process:

- **Consumption of raw materials such as iron ore**, coal, coke, alloying elements and chemicals. It is important to identify the percentage share of the respective alloy composition and to calculate the environmental impact value, even where such data may be difficult to obtain from the alloy producers. The same applies to chemicals.
- **Consumption of steel scrap** divided into internal and external scrap respectively and stainless and carbon steel respectively. Find out the percentage analysis for the respective scrap inflow in respect of the most important alloying elements, for example nickel (Ni), chromium (Cr), molybdenum (Mo), manganese (Mn), titanium (Ti), copper (Cu) etc. Calculate an average for the relevant time period since the scrap inflow in practice consists of many different scrap fractions.
- **Consumption of energy raw materials** (electricity and fuels), for example coal, FeSi, oil, natural gas, LPG and bio fuels. Note that water vapour or compressed air is not an energy raw material. Find out instead how much fuel or electricity is consumed in order to produce the medium.
- **Emissions to air and water.** The emissions that derive from supporting processes in the form of compressed air, water vapour, gases etc. are normally approximated with the help of general databases or plant data. For example, data for combustion of fuels and possible resource recovery shall be taken into account.
- **Residual products and residual energy.** If the flow is changed in connection with the choice of steel grade, the volume shall be identified and the consequences analysed.
- **Sub-processes after the steel plant**, i.e. further processing of the steel into the intended product. Determine the material yield for the relevant steel grade in each sub-process and enter the yield loss divided into relevant outflows, for example internal steel scrap, slag, oxide scale, etc. The yield is calculated by dividing the outflow of “steel” by the inflow of “steel”, in tems of hot rolled steel (tonne) per tonne of cast slabs.

Production of raw materials and energy

This involves collecting data relating to iron ore, alloying elements (FeV, FeCr, FeSi, calcium oxide), LPG, oil and electricity, for example. For raw materials, such as alloying elements and chemicals, there is often consolidated (aggregate) environmental data (Cradle to Gate) for the production of these. Normally, data is used from different existing LCA databases. See Appendix 2 – Data sources for environmental evaluation.

Transport of raw materials

Where data for transport journeys in respect of raw materials, chemicals and other input goods used in steel production is concerned, the relevant freight carrier is specified e.g. truck, ship or train as well as total weight, maximum load capacity and fuel. In the analysis are included the distance for transport of raw materials to the steel plant as well as possible transport of steel slabs, where rolling is carried out at another geographical location.

Estimate the environmental impact for transport of a specific raw material through totalling up the product of the environmental impact value, the raw material quantity and the transport distance for each freight carrier, according to the equation 3:1.

$$M_{\text{Trp Raw material, x}} = \sum (Mn * \text{Quantity}_{\text{Raw material, x}} * \text{Distance}_{\text{Raw material, x}})_n \qquad [3:1]$$

$M_{\text{Trp Raw material, x}}$ = *Environmental impact value for transport of respective raw material [per tonne product in relevant sub-process]*
M_n = *Environmental impact value for transport mode "n" [per tonne km]*
$\text{Quantity}_{\text{Raw material, x}}$ = Quantity of raw material x [kg/tonne product in relevant sub-process]
$\text{Distance}_{\text{Raw material, x}}$ = Transport distance for raw material x [km]
n = *Number of transport modes*

For freight transport, it is important to know whether the transport in question is weight-limited or volume-limited. Raw material transport is frequently weight-limited and, in that case, one can count on a load factor of 90-100 per cent. This means that transport data for the truck transport journeys (where M_n in the formula above is truck transport) should correspond to a load factor of 90 - 100 per cent. If the truck partly travels empty, then the load factor is reduced by the amount corresponding to the empty journeys. This means, for example, that if the truck always travels empty on the return journey then the load factor is 50 per cent.

In this case, one uses transport data from e.g. NTM or GaBi databases.
See also Appendix 2 – Data sources for environmental evaluation.

3.2.3 Modelling of the LCA system from cradle to gate

The production stages from cradle to gate, that is to say from raw material to saleable steel product, are put together to form a model. This work is facilitated if one uses a ready-to-use LCA software tool. The finished model consists of the primary sub-processes as well as complete modules for raw materials, energy and transport. Figure 3.3 provides an example of the flow chart for a main system and a subsidiary system for a specific steel grade produced in an integrated steel mill.

As reference unit for the model, the functional unit (estimation base) uses one tonne of finished steel product from the system.

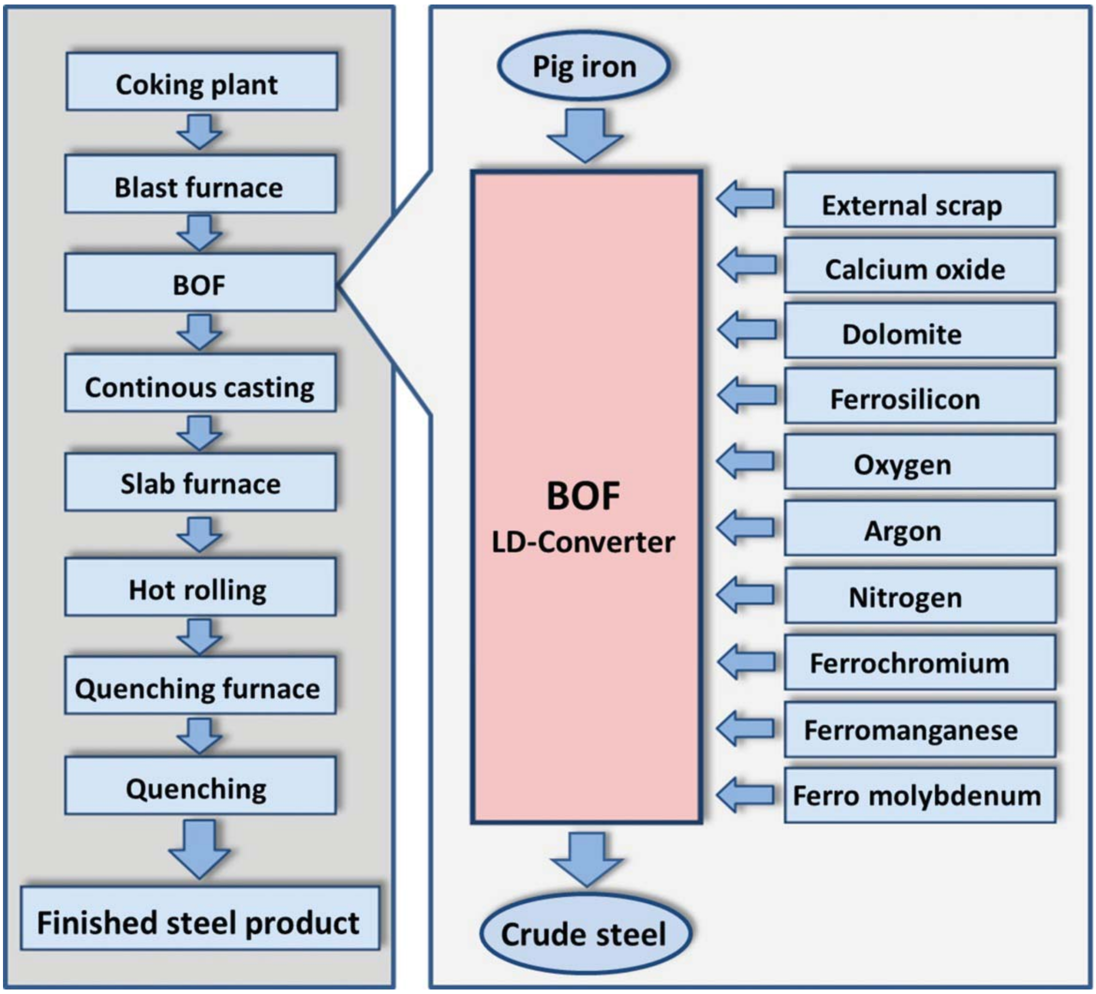

Figure 3.3 Example of a main system for production of carbon steel (right) and a subsystem for the LD process (left), both for a specific steel grade.

3.2.4 Determining a first inventory result

A first inventory result for the cradle to gate summary shows consumption of natural resources, emissions to the surrounding environment and residual products.

The inventory result may, for example, appear as in table 3.1. Results are calculated per functional unit (FU), for example per tonne saleable steel.

INFLOWS	Unit/FU	Value
Non-renewable resources		
Iron ore	kg	1 700
Chromium ore	kg	1
Uranium	kg	0.02
Crude oil	kg	66
Coal	kg	1 050
OUTFLOWS		
Emission to air		
Carbon dioxide (CO_2)	kg	2 000
Sulphur dioxide (SO_2)	kg	2.9
Nitrogen dioxides (NO_x)	kg	0.42
Methane	kg	6.9
Nitrous oxide	kg	0.01
Hydrocarbons	kg	7.2
Emission to water		
COD*	kg	3 E-04
Phosphorous	kg	5 E-05
Nitrogen	kg	2 E-04
Chromium (+III)	kg	9 E-06

**) Chemical oxygen demand*

Table 3.1 Example of inventory results for certain selected parameters (per tonne saleable steel product).

A suitable approach may be to carry out an initial analysis of the results for e.g. carbon dioxide (CO_{2e}) and fossil fuels, in order to see which parts of the process have the greatest effect on the end result. The results of the analysis may also provide an indication of the need to supplement the data collection. If a hypothesis made has a large effect, then a new estimation is made in order to produce better data. In this circumstance one may also need to carry out sensitivity analyses for different data gaps. Where data for a raw material is lacking, one can try to enter an approximation based on a similar material in order to assess the significance of the data gap. See also section 2.3.4 – Handling of data gaps.

3.2.5 Analysis of steel scrap's environmental impact value

Even where steel is recycled and forms part of a closed eco-cycle this does not mean that use of steel scrap is "free" from an environmental viewpoint. There are different ways of estimating the scrap's environmental impact value in Life Cycle Assessments. Here we are using a method that is recommended by the World Steel Association (the international trade body for the iron and steel industry).

Steel scrap's environmental impact value is thus calculated as the impact value for steel produced from iron ore minus the corresponding value where the steel is made from steel scrap. This difference is multiplied by the yield from the electric arc furnace process. This yield is presumed by the World Steel Association to be 95 per cent as a general rule. The environmental impact value varies with steel grade, whereby the share of alloys and also the processes are of significance for the environmental impact value.

It is important to analyse the scrap balance for each steel grade, with regard paid to external and internal scrap and distribution between stainless steel scrap and carbon steel scrap.

How the environmental impact value for use of steel scrap in the production of a steel is applied, depends on whether it is external or internal steel scrap and whether the production of stainless steel or carbon steel is involved in each case.

For carbon steels, the external steel scrap on steel production, in a cradle to gate analysis, is considered as being free from environmental burden. But this steel scrap will be assigned an environmental impact in connection with the recycling of the steel structure. On the other hand, a so-called "internal scrap compensation" is performed for carbon steel already in the cradle to gate analysis as set out below.

For stainless steels, all scrap inflows (external and internal) on steel production are also considered as free from environmental burden in a cradle to gate analysis. This is due to stainless steels having a much more complex scrap balance; consequently, the scrap's environmental impact is taken into account only when a steel structure is recycled. As mentioned in Section 2.2.1, there is at present no standard for how the scrap's environmental burden shall be allocated. In the *Steel Eco-Cycle* environmental research programme, and in this book, we have chosen to use the method recommended by the *World Steel Association* (WSA or *worldsteel*).

External steel scrap

For each steel grade, it is decided how much external steel scrap (commonly called bought scrap) is added per tonne of end product, distributed between carbon steel scrap and stainless steel scrap.

Internal steel scrap

Internal scrap is that which falls away during production and is returned to the process as raw material.

The total amount of internal scrap from fallen away material is identified. This information will also be used in connection with estimations of the environmental gains on recycling.

For carbon steel, an “internal scrap compensation” is carried out which is a balancing for the internal steel scrap per tonne of end product, i.e. how much internal scrap is added and how much is generated on yield losses, all calculated per weight unit of finished steel product.

The difference between inflow and outflow of scrap is given an environmental impact value for the internal steel scrap, as per figure 3.4.

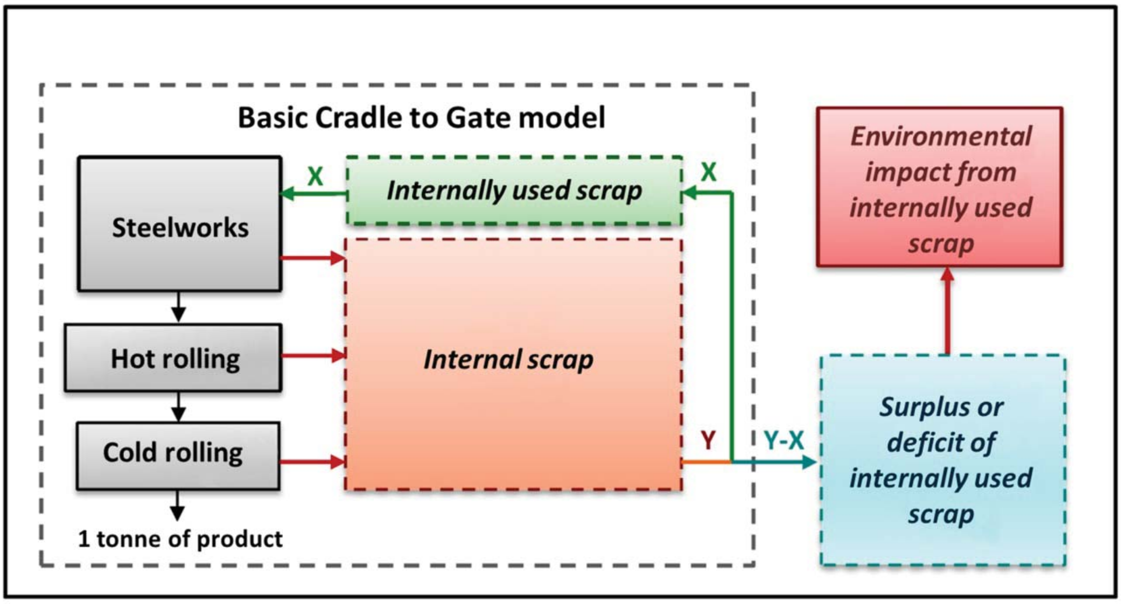

Figure 3.4 Cradle to gate model for carbon steel with compensation for internal steel scrap.

This environmental impact value becomes a burden in case of deficit (Y-X<0), that is to say where the inflow of internal scrap is greater than the outflow. Conversely, an environmental gain is obtained on surplus (Y-X>0), where the inflow of internal scrap is less than the outflow. In the latter case, the steel grade has thus generated more internal scrap than it uses in its own production. This means that the scrap may be used in the production of other steel grades and the steel grade is thereby allocated a credit.

A surplus or deficit of internal scrap is credited or debited in the model system for the production of slabs in the steel plant. This environmental impact value for internal scrap varies depending on the steel grade.

Credit allocation takes place already here in the cradle to gate analysis in order to even out the internal differences between different steel grades which can be ascribed to different yield losses. This enables one to obtain a fairer comparison of the same function, namely production of one tonne of steel as well as generation of the same amount of internal scrap for all steel grades which are analysed. This takes place only for carbon steel, due to the production of stainless steel being much more complex. In this case the scrap balance is handled later in the analysis, on estimation of the steel structure’s recycling.

3.2.6 Steel production's cumulative environmental impact – from cradle to gate

For evaluation of the environmental impact on steel production, the following environmental impact categories (environmental effects) are commonly taken into account

Greenhouse effect (CO_2-equivalents (CO_{2e}))

Acidification (AP - Acidification Potential)

Europhication (EP - Eutrophication Potential)

Photo Oxidant Creation (POCP - Photo Oxidant Creation Potential)

Natural resources are commonly limited to energy resources (renewable and non-renewable) as well as material resources (ores, limestone etc.).
To be able to interpret and draw conclusions from the environmental analysis, these resources should be presented divided into different stages in the production process, e.g. coke oven plant, steel plant, processing and production of alloys.

To facilitate the interpretation of the results, it is important to divide up the environmental impact so as to identify how much is "upstream", i.e. the production of raw materials and energy as well as transport, and what is attributable to the individual plant's environmental impact (gate - gate). In order for the report not to become too extensive, this can be illustrated through several complementary diagrams where the results are shown per functional unit, in this case per tonne of steel.

Figures 3.5 and 3.6 show examples of the greenhouse effect on production of ore-based saleable steel, on the one hand for the total cradle to gate system and, on the other hand, specifically relating to production of alloys for different steel grades.

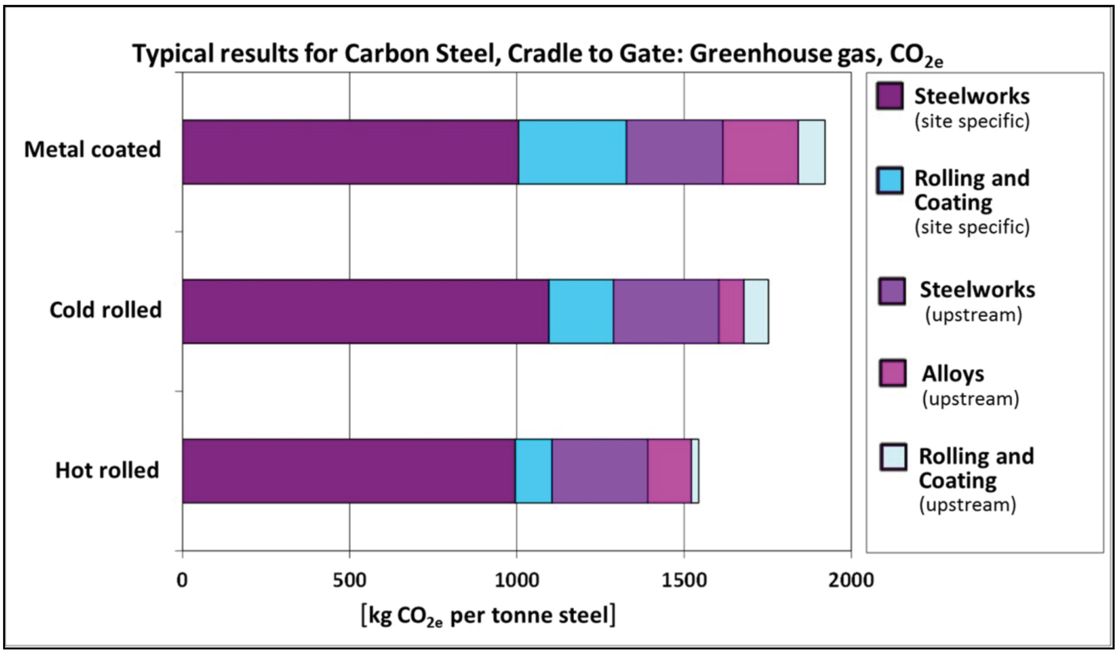

Figure 3.5 Total greenhouse effect of the steel products, including raw material preparation (kg CO_2-equivalents per tonne ore-based saleable steel).

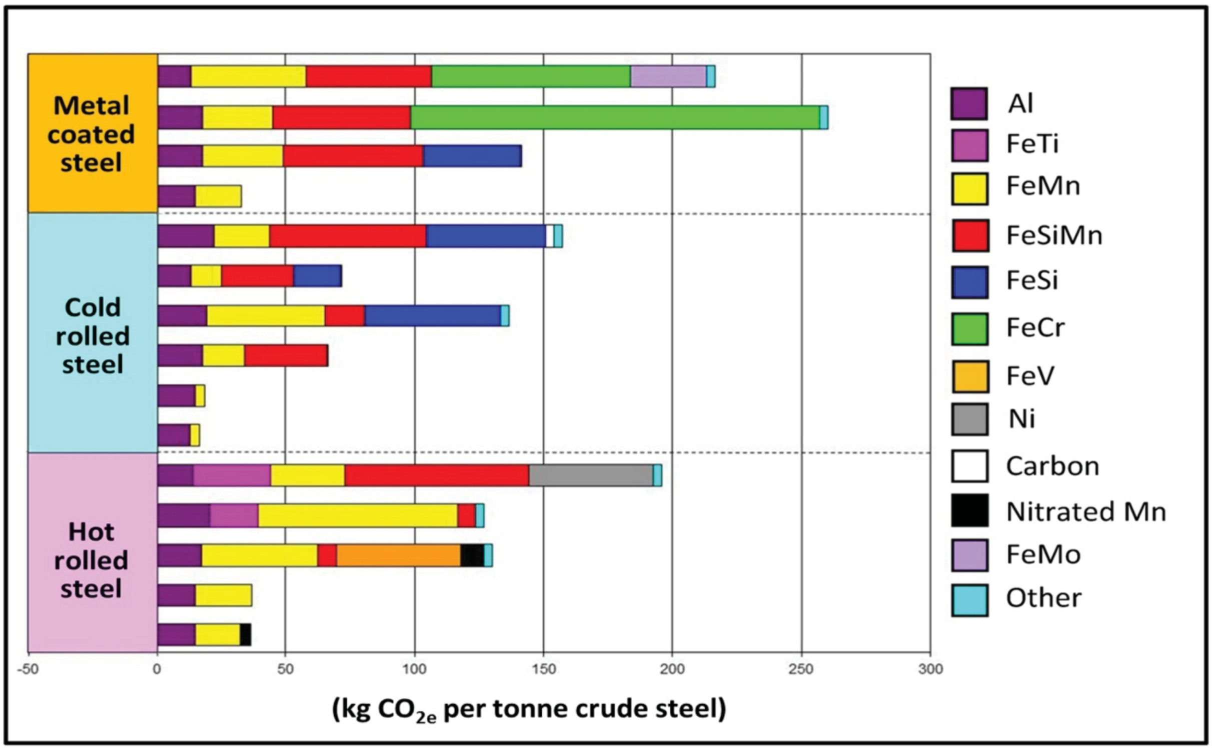

Figure 3.6 Total greenhouse effect of alloying elements on preparation of alloys (kg CO_{2e} per tonne ore-based crude steel, carbon steel).

Experience from the *Steel Eco-Cycle* environmental research programme teaches us that there is a link between the environmental impact value for different steel grades and the steel's yield strength or chemical analysis. These links have been determined through regression analysis of the environmental impact value, carbon dioxide equivalents [CO_{2e}], per tonne of steel and the yield strength [MPa] for carbon steel and the percentage content of alloying elements for stainless steel.

Figures 3.7 and 3.8 show the connection between environmental impact values expressed as greenhouse effect (carbon dioxide equivalents [CO_{2e}]), Cradle to Gate and yield strength. Examples here relate to steel grades of carbon steel, as investigated in the *Steel Eco-Cycle* environmental research programme.

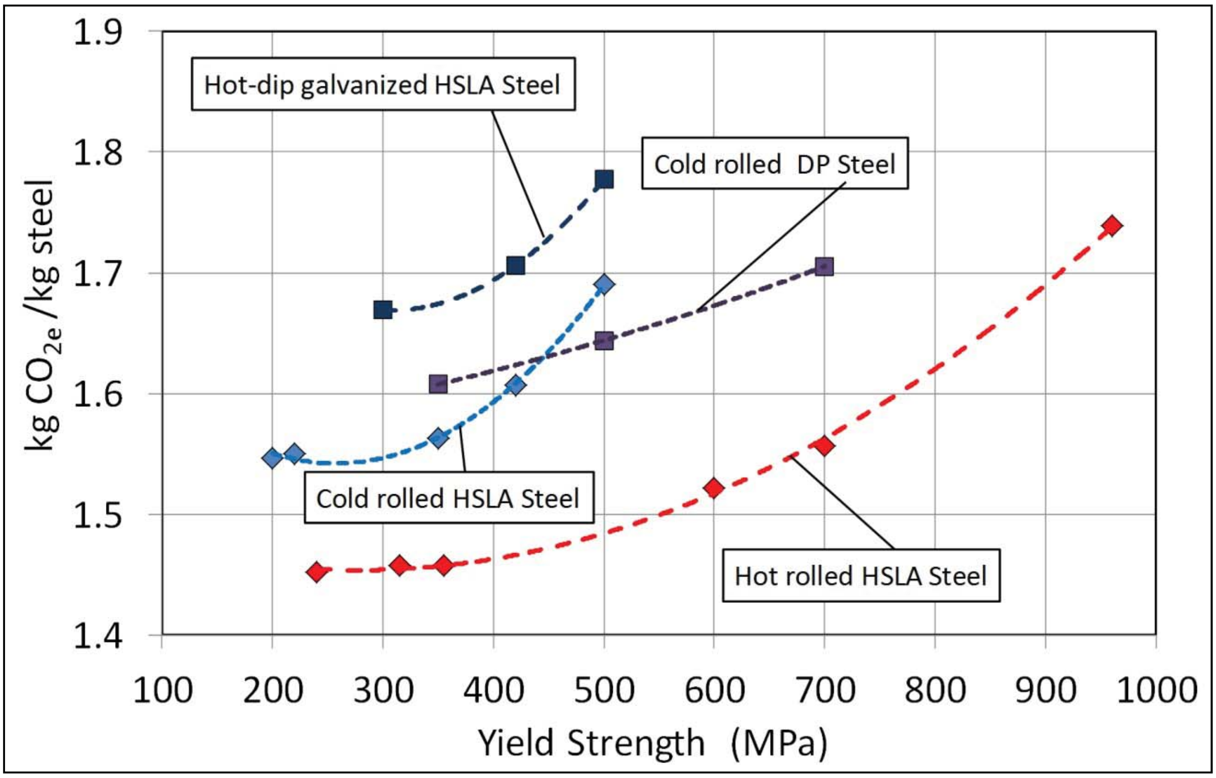

Figure 3.7 Environmental impact values (cradle to gate) for wide strip rolled steel plate in terms of carbon dioxide emissions (CO_{2e}).

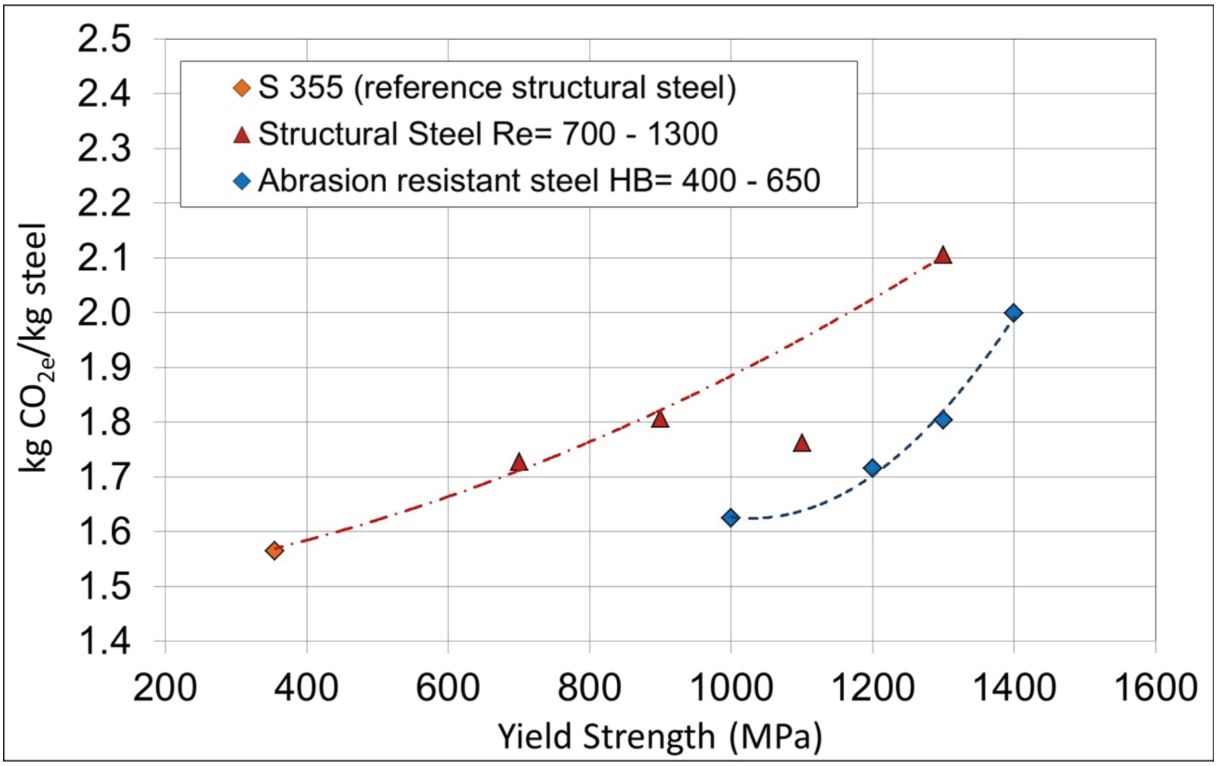

Figure 3.8 Environmental impact value (cradle to gate) for heavy gauge plate in terms of carbon dioxide emissions (CO_{2e}).

For stainless steel, a regression analysis between greenhouse gases (CO_{2e}) and percentage amounts of *virgin* Cr, Ni and Mo give the minimum standard deviation on the regression. The alloy amount that is added through scrap shall thus not be included in equation 3:2.

The regression formula is based on data from production of stainless steel and applies to normal analysis intervals. The regression is purely mathematical and is carried out with input data from eleven steel grades. It may seem strange that the constant for manganese is negative, but typically an increased manganese deposit gives a reduced addition of other alloying elements, in other words these parameters are linked to one another.

$$M_{Steel,\,x} = 1{,}379 + (0.236 * Cr) + (0.253 * Ni) + (0.093 * Mo) - (0.116 * Mn) \qquad [3:2]$$

$M_{Steel,\,x}$ =Environmental impact value (cradle to gate) for steel grade x [kg CO_{2e}/kg steel]

Besides the environmental impact value expressed as carbon dioxide (CO_{2e}), the total of used non-renewable energy resources (MJ) is also normally stated. This may, for example, comprise coal, oil, natural gas or uranium.

Evaluations within the *Steel Eco-Cycle* environmental research programme show that there is a strong link between the energy resources and the carbon dioxide emissions (CO_{2e}). The evaluation shows that the relationship between energy resources and emission of carbon dioxide (CO_{2e}) is relatively independent of steel grade for a particular production plant; they are 16 - 20 MJ/kg CO_{2e} for ore-based production of carbon steel and 12 - 14 MJ/kg CO_{2e} for scrap-based production of stainless steel.

3.3 Fabrication of steel structure

To estimate the environmental impact value of the steel in a particular structure, environmental data is normally required for several different steel grades. The purpose is normally to compare a steel structure manufactured of conventional steel with a steel structure that has the same function but is made of a more advanced steel material. Figure 3.9 gives an example of structures that are analysed in this way in a number of case studies within the *Steel Eco-Cycle* environmental research programme.

The case studies have focused on the special case where conventional steel is replaced by high strength steel. Other cases may be when conventional steel is replaced by more corrosion-resistant steel, for example when low alloy stainless steel is replaced by high alloy stainless steel or when low alloy stainless steel replaces surface treated carbon steel.

Figure 3.9 Examples of case study objects from the Steel Eco-Cycle where conventional steel is replaced by advanced high strength steel.

Generally speaking, steel's environmental impact (Cradle to Gate) increases somewhat with increasing yield strength when the environmental impact value per tonne of steel is considered. On the other hand, a lower amount of steel is required to fulfil a specific function. This means that the environmental impact for those structures manufactured of high strength steel is less than for structures manufactured of ordinary steel. Figure 3.10 demonstrates how the relative environmental impact is affected by increasing yield strength, partly *per tonne of steel*, partly for the functional unit i.e. *a structure*. When we study a structure, we thus change the functional unit from *per tonne of steel* to *per structure.*

In figure 3.10, it is assumed that the weight reduction for the structure in question follows the so-called root formula, which means that the carbon dioxide emission declines with increasing yield strength of the steel. See below where Re is the yield strength and HS and MS are high strength steel and conventional mild steel respectively.

$$\frac{Weight,HS}{Weight,MS} = \sqrt{\frac{Re,MS}{Re,HS}} \qquad [3:3]$$

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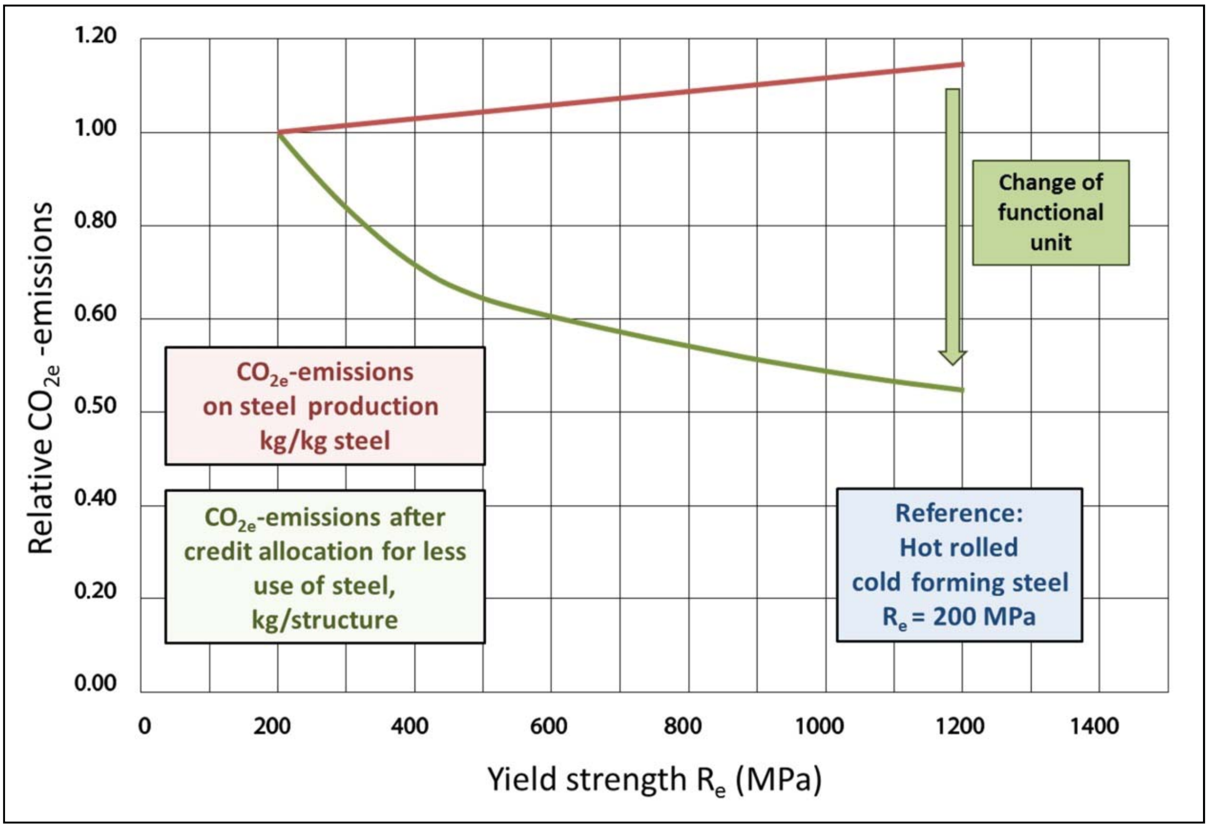

Figure 3.10 The environmental impact value [CO_{2e}] in relation to ordinary steel with R_e = 200 MPa as a function of the steel's yield strength, on the one hand per weight unit steel, on the other hand for the functional unit "a structure".

To obtain basic data for environmental evaluation of the structural elements upgraded from conventional to more advanced steel, for example high strength steel, it is necessary for these to be specified and the steel weight quantified before and after upgrading. It is appropriate to tabulate the number of kg steel of each steel grade used for a specific structure.

Steel grades that are not replaced, in other words are the same before and after the upgrading, do not need to be included here. However, they may be included where it is wished to determine the total environmental impact value, both before and after the upgrading.

3.3.1 Estimating the environmental impact value for production of the steel in a structure

Where the quantities of the steel grades included in a specific steel structure are known, the combined environmental impact value for the production of the different elements can be estimated. This takes place with the aid of the impact values for production of the individual steel grades (Cradle to Gate), as described in the previous section. The result is calculated through totalling up the environmental impact value, multiplied by the amount of steel for each steel grade, in accordance with equation 3:4.

$$M_{Steel} = \sum (M_{Steel,\,x} * Quantity_{Steel,\,x})_n \qquad [3:4]$$

M_{Steel} = *Environmental impact value for production of all input steel [per structure] [kg steel/structure]*
$M_{Steel,\,x}$ = *Environmental impact value (cradle to gate) for steel grade x [per kg steel]*
$Quantity_{Steel,\,x}$ = *Amount of steel of respective steel grade x used in the structure*
n = *Number of steel grades*

The calculation above is made for the two cases, before and after upgrading, and the savings (environmental relief) achieved on account of the upgrading, ΔM_{Steel}, can be worked out through calculating the difference before and after upgrading.

3.3.2 Estimating the environmental impact for transportation of the steel

In this case it is a question of identifying which transport mode is used for the respective steel grade, the transport distance of the steel, the load factor and fuel.

The calculation of the environmental impact value for the respective steel grade is obtained through totalling up the product of the transport mode's impact value, the quantity of steel and the transport distance for each mode of transport, according to equation 3:5.

$$M_{Trp\ steel,\,x} = \sum (M_n * Quantity_{Steel,\,x} * Distance_{Steel,\,x})_n \qquad [3:5]$$

$M_{Trp\ steel,\,x}$ = *Environmental impact value for transport of steel grade x [per structure]*
M_n = *Environmental impact value for mode of transport "n" [per tonne km]*
$Quantity_{Steel,\,x}$ = *Amount of steel of respective steel grade x used in the structure [tonne steel/structure]*
$Distance_{Steel,\,x}$ = *Transport distance for steel grade x [km]*
n = *Number of transport modes*

Environmental impact values for different forms of transport are exemplified in figure 3.11.

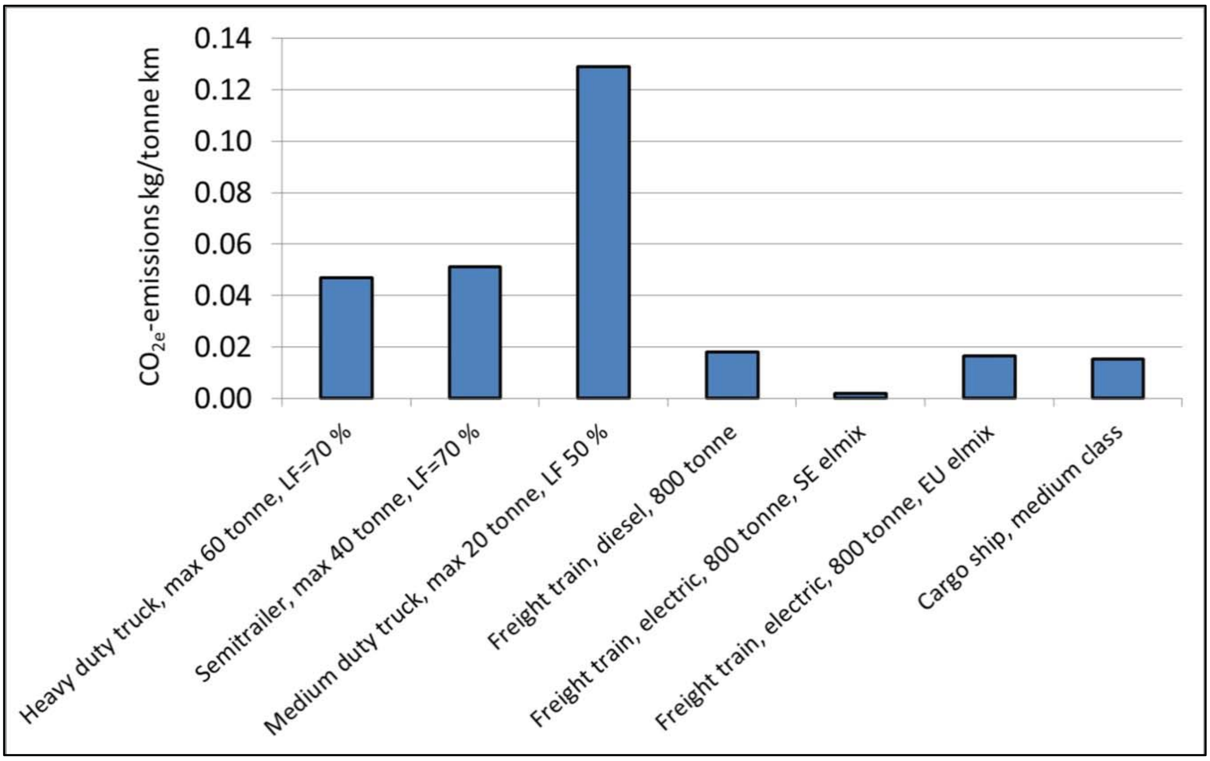

Figure 3.11 Example of environmental impact values for different forms of transport, kg carbon dioxide (CO_{2e}) per tonne km. The tonnage for trucks is the maximum permitted load.

The environmental impact value for transport of the steel grades included in the structure is obtained through totalling up the environmental impact value ($M_{Trp\ steel,\ x}$) for all steel grades above, according to equation 3:6.

$$M_{Trp\ steel} = \sum(M_{Trp\ steel,\ x})_n \qquad [3:6]$$

$M_{Trp\ steel}$ = Environmental impact value for transport of all steel [per structure]
$M_{Trp\ steel,\ x}$ = Environmental impact value for transport of steel grade x [per structure]
n = Number of steel grades

It is common for all steel used for production of a structure to come from the same location. In that case, the transportation becomes independent of the steel grade and the whole amount of steel can be considered, at one and the same time, according to equation 3:7.

$$M_{Trp,steel} = \sum(M_n * \text{Total quantity}_{Steel} * \text{Distance}_{Trp,\ x})_n \qquad [3:7]$$

$M_{Trp,steel}$ = Environmental impact value for transport of the steel [per structure]
M_n = Environmental impact value for transport mode "n" [per tonne km]
Total quantity_{Steel} = Amount of steel used in the structure [tonne steel/structure]
$\text{Distance}_{Trp,\ x}$ = Transport journey distance for transport mode x [km]
n = Number of forms of transport

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The calculation is made for the two cases, before and after upgrading, and the savings (environmental relief) achieved on account of the upgrading, $\Delta M_{Trp,steel}$, can be worked out through calculating the difference, before and after upgrading with the new steels.

For freight transport, it is important to find out if the transport journeys are weight-limited or volume-limited. Steel transport journeys are commonly weight-limited and, in that case, one can count on a high load factor, or 90 - 100 per cent. This means that transport data for truck transport journeys (where M_n in the formula above is a truck transport journey) should correspond to a load factor of 90 - 100 per cent.

Where the truck partly travels empty, then the load factor is reduced by the amount which corresponds to the empty journeys. For example, this means that if the truck always travels empty on the return journey then the load factor is 50 per cent.

There are a number of generic databases for transport produced, for example, by NTM or Gabi, see appendix 2 – Data sources for environmental evaluation.

Note that the environmental impact arising from the steel transport journeys, where analysis of active structures is concerned, frequently has little significance for the total environmental impact, see below. However, it may constitute a not negligible component in the analysis of passive structures. This appears from the examples in Chapter 4.

3.3.3 Data collection for fabrication of the structure

Identification of fabrication processes

To be able to correctly estimate the environmental impact value of new steel grades in a structure, it is sufficient to identify the different sub-processes. Consequently, one should determine the manufacturing approach, before and after upgrading.

It is common for the quantity of weld metal to be changed with reduced material thickness and, above all, the cost for the welding work. Furthermore, the quenching process may be left out where advanced high strength steel is utilised.

Consumption of energy and input goods

For fabrication of the structure, electric power is used for e.g. processing and welding, fuel for hardening and so on. It is mainly a question here of highlighting the differences that arise with the new steels in relation to those used previously.

The same approach should be adopted for consumption of the input goods. This may mean that differing amounts of welding wire are used or material required in one case and not in the other. Examples of input goods are welding wire and chemicals e.g. for surface treatment.

As basic data for the environmental impact value for the production of the structure for the two cases i.e. before and after upgrading, the different integral process stages are added up with reference to energy consumption [kWh] and input goods [kg].

Data collection relating to energy and input goods for production

When estimating a structure's environmental impact value, data for the consumption of energy and input goods such as LPG, oil, electricity and different chemicals e.g. for surface treatment are compiled. Data is also required for emissions from combustion of the fuels used. For input goods there is often combined data (cradle to gate) for its entire production. In this case, one normally makes use of data from existing databases, for example those that are found in different LCA software tools.

Estimation of the steel structure's environmental impact

When the amounts of energy and input goods are known and data for the production of these has been prepared, it is possible to estimate the environmental impact for fabrication of the structure. Then add up each type of energy and input goods multiplied by their environmental impact value. Then add up these totals in accordance with equation 3:8.

$$M_{Fabr} = (Electricity * M_{Elec}) + \sum(Fuel_x * M_{Fuel,\,x})_n + \sum(Input\ goods_y * M_{Input\ goods,\,y})_m \quad [3:8]$$

M_{Fabr} = Environmental impact value for the fabrication of the structure [per structure]
Electricity = Electricity consumption [kWh/structure]
M_{Elec} = Environmental impact value for production of the electricity [per kWh]
$Fuel_x$ = Quantity of fuel of type x [kWh]
$M_{Fuel,\,x}$ = Environmental impact value for production and combustion of the fuel x [per kWh]
n = Number of fuels
$Input\ goods_y$ = Quantity of input goods of type y [kg]
$M_{Input\ goods,\,y}$ = Environmental impact value for production of input goods y [per kg]
m = Number of input goods

The calculation above is made for two cases, before and after upgrading. The environmental savings (relief) for fabrication of the structure, $\Delta M_{Fabrication}$, is obtained by deducting from the environmental impact value before, the impact value after the upgrading with the new steel.

3.3.4 Estimating the environmental impact for transportation to customer

The choice of transport mode influences a structure's environmental impact value. For this reason, it is necessary to specify the freight carrier (truck, ship, freight train) and the vehicle type (total weight, max. load capacity as well as fuel). The distance the steel structure is transported to the end customer is also determined.

When this is carried out, the environmental impact value of the transport journeys can be estimated through the vehicle's environmental impact being multiplied by the structure's weight and the transport distance, in accordance with equation 3:9.

$$M_{Trp\ structure} = M_n * Weight_{structure} * Distance \quad [3:9]$$

$M_{Trp\ structure}$ = *Environmental impact for transport of the structure [per structure]*
M_n = *Environmental impact value for transport mode "n" [per tonne km]*
$Weight_{structure}$ = *Structure's weight [tonne/structure]*
Distance = *Transport distance for transport of the structure [km]*

The calculation above is made for the two cases, before and after upgrading, and the savings achieved owing to the upgrading ΔM_n can be calculated through working out the difference, before and after upgrading of the steel.

Transportation of a structure is commonly *volume-limited* and, in that case, one needs to calculate the transport vehicle's load factor through relating the quantity of freight (the steel structures) to the vehicle's maximum load capacity, in accordance with equation 3:10.

$$\mathbf{LF} = \frac{\text{Quantity of freight [tonne]}}{\text{Maximum load capacity [tonne]}} * 100 \quad [3:10]$$

Where M_n in the formula 3:9 above is truck transport, this means that data for the transport journeys should correspond to this estimated load factor which also takes into account the share of empty journeys.

Generic transport data is produced by e.g. NTM or is available in databases in the LCA software Gabi, see the section 2.3.3 -Data for transport journeys. See also figure 3.11 for approximate values for certain load factors.

In many cases, especially when the structure is active, it can transport itself. This is the case, for example, with a ship, bus or truck. Regardless of how the structure is transported during production and to the customer, it is important to point out that the transportation in this case is normally fairly insignificant when seen within an entire life cycle perspective especially for active structures.

3.4 Use of steel structure

Frequently, the upgrading of the steel in a structure takes place through using a stronger steel. This can make the structure lighter and/or more wear resistant, which affects the structure's environmental impact during use of the structure. Where the higher strength is combined with better corrosion resistance the structure's environmental impact value during use is further influenced in a positive direction.

3.4.1 Passive or active structure

How relevant or significant the structure's use is from an environmental viewpoint depends on whether the structure is passive or active.

PASSIVE STRUCTURES
Cisterns, tanks, process systems, shelves, furniture etc.

ACTIVE STRUCTURES
Private cars, trucks, trains, ships etc.

3.4.2 Passive structures

A passive steel structure often has insignificant environmental impact, or none at all, during the utilisation phase. Environmental benefits for passive structures are therefore mainly related to the consumption of lesser amounts of steel as well as a lesser amount of steel needing to be transported.

Where the use is significant, it is only interesting to include it in the analysis where it shows a variation before and after upgrading. One might envisage, for example, that the useful life of the structure, or parts of the structure, have different life spans, for example chutes in mines, figure 3.12. Account is then taken of the fact that repair, maintenance and replacement of different wearing parts in the structure may serve to differentiate before and after the change of steel, thereby affecting the useful life and environmental impact in a positive way.

The life span may also be extended through use of a more corrosion-resistant steel. If surface treatment can be avoided, either wholly or partly, then this may also extend the structure's useful life.

More heat-resistant steel may also increase the efficiency level in energy generation and overall offer significant environmental benefits during the structure's life cycle. Where the useful life of a passive structure varies before and after upgrading, then this may be taken into account by multiplying the environmental impact value for steel production after upgrading by the life span ratio L1/L2, where L1 is the life span before and L2 the life span after upgrading. Take this into consideration also when estimating the recovery of the steel when the structure, or parts of this, are scrapped.

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Figure 3.12 Example of a chute used in mines; its life span can change through the use of harder steel.

3.4.3 Active structures

For active steel structures such as vehicles, about 90 per cent of the avoided environmental impact is related to the use phase. For active structures it is relatively complex to estimate the absolute environmental burden before and after upgrading. In these cases one usually has to be satisfied with an estimate of the difference before and after upgrading, that is to say the environmental impact alleviation.

Weight- or volume-limited transport journeys

Where the transport journey is weight-limited, a reduction in weight can be replaced with a payload of equal weight. In that case, the fuel consumption and the environmental impact decrease for a given amount of freight. The environmental relief during the utilisation phase, in this case, is directly linked to the weight reduction on upgrading of the steel and the fuel or electricity consumption of a fully loaded vehicle.

Weight-limited transport journeys

For that part of the transport that is weight-limited (wc), the environmental relief can be calculated through multiplying the environmental impact value on production and consumption of fuel or production of electricity, by consumption of these energy sources, by total driving distance during the vehicle life and by the ratio between weight reduction and the vehicle's maximum load capacity, equation 3:11.

$$M_{savings,wc} = (M_{Fuel} * EC * L * WR/MPL) \qquad [3:11]$$

$M_{savings,wc}$ = Environmental savings owing to weight reduction, weight-limited transport
M_{fuel} = Environmental impact value on production and combustion of the fuel [per litre of fuel or kWh electricity, for current structure]
EC= Energy consumption litre/km or kWh/km on full load
L = Total driving distance during useful life [km]
WR = Weight reduction on upgrading [kg]
MPL = Vehicle's maximum load capacity [kg]

Volume-limited transport journeys

Where the transport journey is volume-limited (vc), then only a certain part of the weight reduction can be translated into lower energy consumption and a lesser environmental impact. This usually constitutes about 25 - 80 per cent, depending on style of driving, terrain, speed, acceleration, rolling resistance and the air resistance. In the case of operating conditions with many starts and stops, plenty of acceleration, undulating terrain and on low to moderate speeds, the energy savings are greatest for a given weight reduction.

There are two alternative ways of assessing the effectiveness of a weight reduction. One, that is normally used for simpler rough estimates, is to use an efficiency ratio (η) which is defined in equation 3:12 and is exemplified in figure 3.13. The effect of the weight reduction is calculated through multiplying the efficiency ratio η by the environmental impact value on production and combustion of the fuel or on production of electricity, by the consumption of these, by the weight reduction and the total driving distance during the vehicle's life span, see equation 3:12.

$$M_{savings,vc} = \eta * M_{fuel} * EC * WR * L \qquad [3:12]$$

$M_{savings,vc}$ = *Environmental savings owing to Weight reduction, Volume-limited transport*
η = *Energy savings [per cent]/weight reduction [percentage of current weight]*
M_{fuel} = *Environmental impact value on production and combustion of fuel [per litre fuel or kWh electricity, for relevant structure]*
EC = *Energy consumption litre/km or kWh/ km with current load*
WR = *Weight reduction on upgrading as percentage of current total weight*
L = *Total driving distance during useful life [km]*

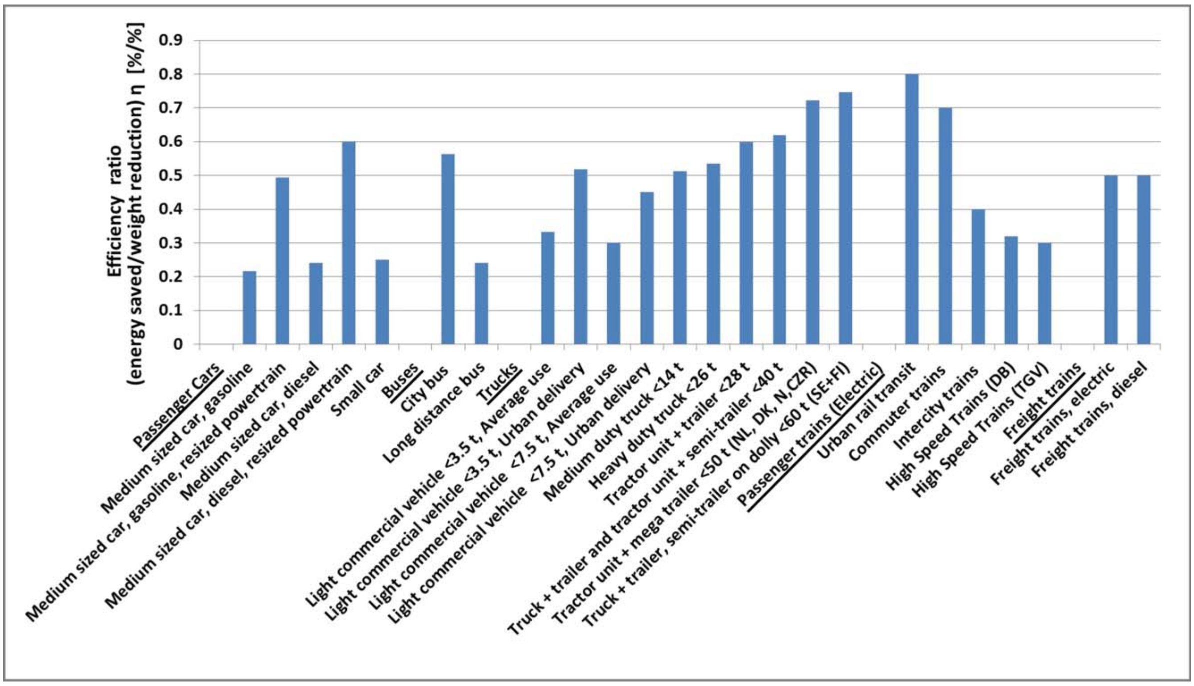

Figure 3.13 η-values for rough calculations for a number of different vehicle types and driving situations.

The other way to analyse fuel savings, resulting from a weight reduction for volume-limited and empty transport journeys, is to calculate the specific energy savings for a given weight reduction SFC [litre/km and kg weight reduction], or SEC [kWh/km and kg weight reduction] where electric vehicles are concerned. The reason that one can do this is that, under the same driving conditions, the link between energy consumption and the vehicle's weight is linear. In that case, information is needed on energy consumption for the vehicle in respect of two load factors (LF) e.g. empty and fully loaded, as well as the vehicle's maximum load capacity. SFC is then calculated as the fuel consumption for a fully loaded vehicle minus the fuel consumption for the vehicle without load divided by the maximum load capacity, according to equation 3:13.

$$SFC = (FC_{full} - FC_{empty})/MPL \qquad [3:13]$$

SFC= *Specific fuel savings [litre/km and kg weight reduction]*
FC_{full} = *Fuel consumption fully loaded [litre/km]*
FC_{tom}= *Fuel consumption without load [litre/km]*
MPL= *Maximum load capacity [kg]*

Where the fuel consumption for a fully loaded and an empty vehicle respectively is not known, an approximate value for SFC for the road vehicle can be determined from the diagram in figure 3.14. This applies to volume-limited and empty transport journeys. The average speed is then deemed to be an approximate measure that also takes account of different driving styles, for example.

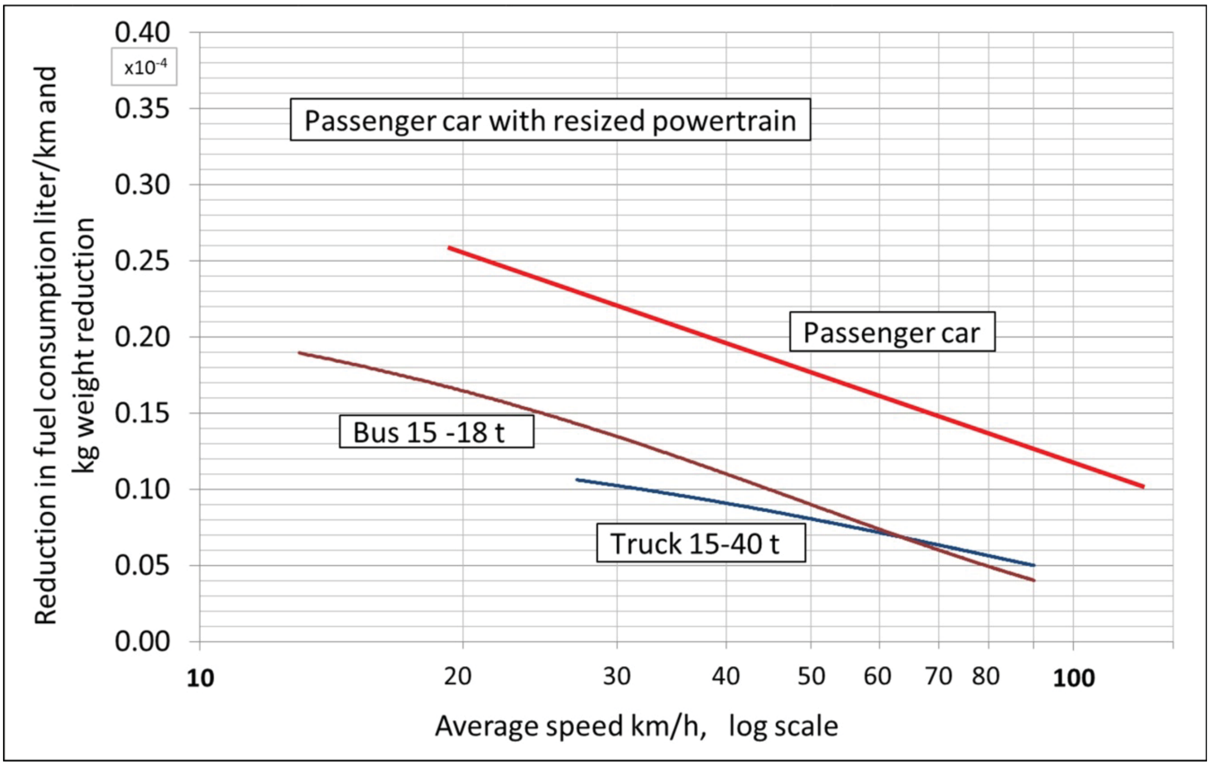

Figure 3.14 Fuel savings, SFC, litre/(km and kg weight reduction) as function of the vehicle's average speed.

For vehicles that consume energy in the form of electricity, the equation 3:14 is obtained, analogous to equation 3:13, where SEC is then calculated as the electricity consumption for a fully loaded vehicle minus electricity consumption for a vehicle without payload, divided by the maximum load capacity.

$$SEC= (EC_{full} - EC_{empty})/MPL \qquad [3:14]$$

SEC= *Specific energy consumption [kWh/km and kg weight reduction]*
EC_{full} = *Energy consumption fully loaded [kWh/km]*
EC_{empty} = *Fuel consumption without load [kWh/km]*
MPL= *Maximum load capacity [kg]*

Where a certain part of the transportation is weight-limited, a weighted average for SFC can be determined by combining the equations 3:11 and 3:13 or 3:14.

Estimate the environmental savings over the vehicle's life cycle through multiplying SFC or SEC by the weight reduction and the environmental impact value for the fuel in question and by the total driving distance during its life span, according to equation 3:15. Data sources for environmental impact values for different fuels and for electrical energy appear in appendix 2 – Data sources for environmental evaluation.

$$M_{savings,vc} = SFC * WR * M_{fuel} * L \qquad [3:15]$$
$$M_{savings,vc} = SEC * WR * M_{fuel} * L$$

$M_{savings}$ = *Environmental savings during life cycle owing to weight reduction for volume-limited transport*
SFC, SEC = *Specific fuel or energy savings [litre/km, kWh/km and kg weight reduction]*
WR = *Weight reduction on upgrading [kg]*
M_{fuel} = *Environmental impact value on production and combustion of fuel [per litre fuel or kWh electricity]*
L= *Total driving distance during useful life [km]*

3.5 Recycling of steel structure

3.5.1 Estimating the recovery rate

Here, it is necessary to assess how much of the steel in the structure can be recirculated as steel scrap when the structure has reached the end of its useful life (closed loop recycling).

Accordingly, calculate the quantity of recovered scrap metal for each steel grade x in the structure by multiplying the amount of steel grade x by the steel structure's recovery rate, in accordance with equation 3:16.

$$\text{Steel scrap}_{\text{out, x}} = \text{Weight}_{\text{Steel grade, x}} * \text{RE}_{\text{Rate}} \qquad [3:16]$$

Steel scrap$_{out,\,x}$ = *Quantity of recirculated (closed loop) scrap for steel grade x [kg]*
Weight$_{Steel\ grade,\,x}$ = *Quantity of steel of steel grade x in the structure [kg steel]*
RE$_{Rate}$ = *Steel structure's recovery rate [%/100]*

3.5.2 Environmental impact value of steel scrap

The amount of steel scrap recovered when a structure goes for scrap shall be assigned a credit for the scrap's inherent environmental impact value, i.e. the value of an equivalent amount of steel from iron ore (raw material) that does not need to be produced.

The World Steel Association has developed a calculation method for steel scrap's impact value covering low alloy steel/carbon steel. This has been adapted by Eurofer (*The European Steel Association*) for high alloy steel/stainless steel, see section 3.2.5. Both these trade organisations have published data for this environmental impact valuation.

The World Steel Association makes the assumption that all carbon steel has the same environmental impact value. This is inadequate, however, when one comes to assess the steel scrap's impact value for high strength steel.

Eurofer has published the environmental impact values for a number of stainless steel grades. But even this is insufficient, for which reason a special model for stainless steel's impact value has been developed in the environmental research programme *The Steel Eco-Cycle*.

A high alloy steel with high contents of Cr, Ni and Mo, for example, produces a high environmental impact value. The environmental impact value - in terms of greenhouse gases - for an ordinary low strength carbon steel, as defined by the World Steel Association (see above), is around 1 500 kg CO_{2e} per tonne of steel. The corresponding value for a high alloy stainless steel may be more than 5 000 kg.

3.5.3 Methodology for estimating the environmental impact value on recycling

We are able to obtain the effect of recycling on the total impact value by assigning a debit to the impact value for the amount of added steel scrap, and assigning a credit for the amount of recycled scrap. This is most clearly shown through dividing the calculations into a number of steps, since a steel structure may be composed of several steel grades x and - during production of the steel grades - both external and internal scrap have been added.

Carbon steel

The overall environmental impact value for the various grades of external steel scrap added during the production process is calculated through each scrap inflow being multiplied by its impact value.
After this, all the input scrap grades are totalled up in accordance with equation 3:17.

$$M^{x}_{\text{added scrap}} = \sum(M_{\text{Scrap, y}} * \text{Scrap}_{\text{in, y}})_n \qquad [3:17]$$

$M^{X}_{\text{added scrap}}$ = *Environmental impact value for all added scrap in steel grade x [per kg steel x]*
$M_{\text{scrap, y}}$ = *Environmental impact value of the scrap inflow y to steel grade x [per kg scrap y]*
$\text{Scrap}_{\text{in, y}}$ = *The amount of added scrap y for steel grade x [kg scrap y/kg steel x]*
n = *Number of scrap inflows y*

A series of different grades of steel scrap may be added to a steel grade on steel production and it may, therefore, be a question of totalling these up. Since internal scrap compensation has been applied already in the cradle to gate analysis (see section 3.2.5), it is only the amount of added *external* scrap that will be allocated an environmental burden here.

Stainless steel

The impact value for the different grades of steel scrap, added during production of a certain steel grade x, is obtained through multiplying each scrap inflow by its environmental impact value. Then total up all the added scrap grades according to equation 3:18. For stainless steel, no internal scrap compensation has been carried out in the foregoing calculations. For this reason a load also on the internal steel scrap shall be included.

$$M^{x}_{\text{Added scrap}} = \sum(M_{\text{Scrap, y}} * \text{Scrap}_{\text{in, y}})_n - (M_{\text{Scrap, z}} * \text{Scrap}_{\text{out, z}}) \qquad [3:18]$$

$M^{x}_{\text{Added scrap}}$ =*Environmental impact value for all added scrap in steel grade x [per kg steel x]. This includes both external and internal steel scrap as well as carbon steel and stainless steel scrap respectively.*
$M_{\text{Scrap, y}}$ = *Impact value of scrap inflow y to steel grade x [per kg scrap y]*
$\text{Scrap}_{\text{in, y}}$ = *Quantity of added scrap y for steel grade x [kg scrap y/kg steel x]*
n = *Number of scrap inflows y*
$M_{\text{Scrap, z}}$ = *Environmental impact value of internal scrap outflow z to steel grade x [per kg scrap z]*
$\text{Scrap}_{\text{out, z}}$ = *Quantity of internal steel scrap z for steel grade x [kg scrap z/kg steel x]. This is the internal steel scrap which falls away owing to yield losses in processes downstream of the steel plant.*

A series of different grades of steel scrap may be added to a steel grade during steel production; consequently, this may mean totalling up the different impact values. The credit allocation that is given ($M_{\text{Scrap, }\mathbf{z}} * \text{Scrap}_{\mathbf{out, z}}$) in equation 3:18 relates to the internal steel that falls away owing to yield losses in processes downstream from the steelworks.
For carbon steels, the calculation is carried out already in the Cradle to Gate analysis in connection with the internal scrap compensation. For stainless steel, which has a much more complex scrap balance, this is taken into account in the recycling calculation.

Environmental impact value of recycling

The environmental impact value on recycling of steel grade x is ascertained through deducting from the impact value of the added scrap the amount of recirculated (closed loop) scrap times its impact value, according to equation 3:19.

$$M^{RE}_{x} = M^{X}_{\text{Added scrap}} - (M_{\text{Scrap, x}} * \text{Scrap}_{\text{out, x}}) \qquad [3:19]$$

M^{RE}_{x} = *Environmental impact value on recycling of steel grade x [per kg steel X]*
$M^{X}_{Added\ scrap}$ = *Impact value for all added scrap in steel grade x [per kg steel X], [3:18] for carbon steel and [3.19] for stainless steel*
$M_{Scrap,\ x}$ = *Impact value of scrap for steel grade x [per kg scrap x]*
$Scrapo_{out,\ x}$ = *Quantity of recirculated (closed loop) scrap for steel grade x [kg scrap/steel structure], [3:16]*

The impact value for recirculated (closed loop) scrap of carbon steel of a certain steel grade, $M_{Scrap,\ x}$, is normally set at 75 % of the cradle to gate impact value on production of this steel grade, $M_{Steel,\ x}$ in equation 3:6.

The total environmental impact value for recycling of the structure is calculated accordingly; for each steel grade, multiplying the impact value for recycling by the amount of recycled steel of this steel grade and then totalling up all the input steel grades in the structure, according to equation 3:20.

$$M_{RE} = \sum(M^{RE}_{x} * \text{Quantity}_{\text{Steel, x}})_{n} \qquad [3:20]$$

M_{RE} = *Total impact value for recycling of the structure [per structure]*
M^{RE}_{x} = *Impact value on recycling of steel grade x according to equation [3:19]*
$Quantity_{Steel,\ x}$ = *Quantity of steel of respective steel grade used in the structure [kg steel/structure]*
n = *Number of steel grades*

3.6 EcoSteel – computational tool for environmental evaluation of steel structures

The software EcoSteel has been specially developed to facilitate the life cycle analysis of the environmental impact value of different steel structures. This has taken place within the environmental research programme *The Steel Eco-Cycle*. Figure 3.15 shows the introductory interface of the program with the relevant input modules.

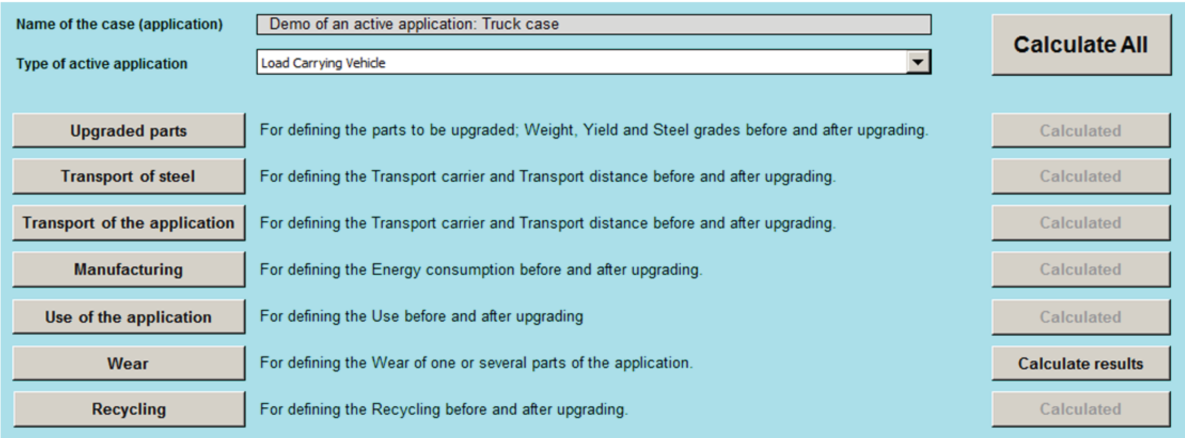

Figure 3.15 The main page of the EcoSteel data program with buttons for respective data input module, active structure.

In the EcoSteel tool one can choose to analyse active or passive structures. For active structures, the options truck, ship, train, car and bus are available. For passive structures, there is no direct application module, however if abrasive wear is relevant there is the possibility for taking this into account through estimating how the useful life, in the event of abrasive wear, is influenced by the choice of steel grade.

The EcoSteel computational tool is built up of a number of modules where data can be fed in for the selected structure, before and after the change of steel. For instance, in the data input module *Upgraded parts*, data is entered such as weight and steel grades for the different parts of the structure where the steel has been changed, normally to a more advanced steel. One always specifies data both for the reference structure and for the upgraded structure.

In figure 3.16 an example is given of how this input dialog appears.

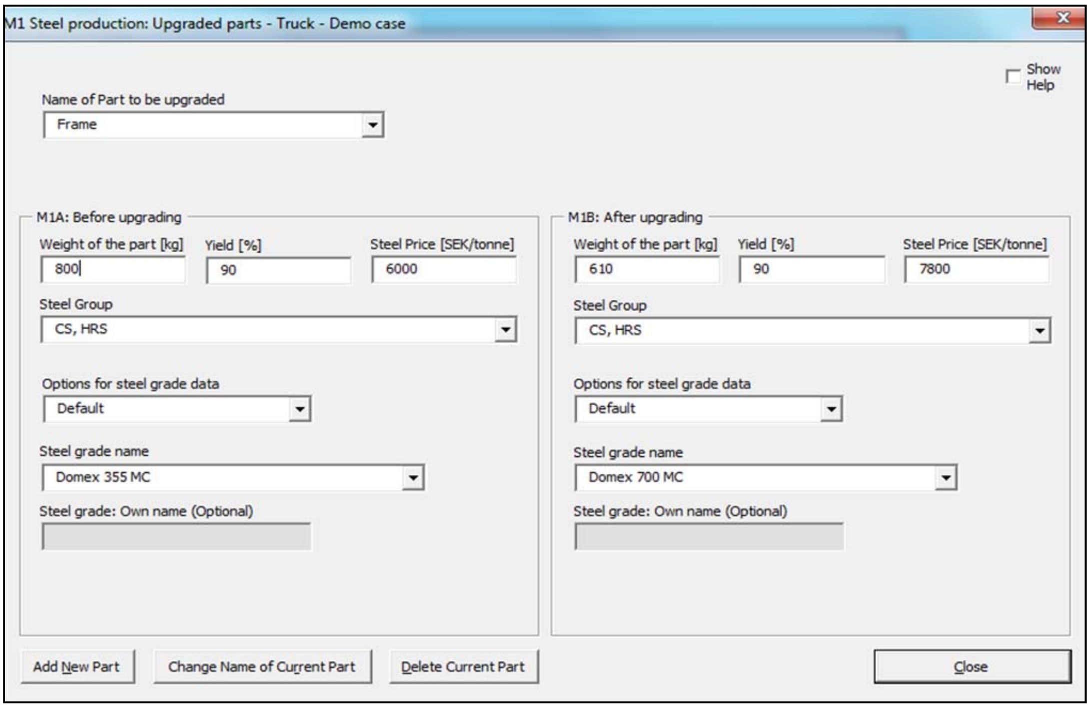

Figure 3.16 Example of module for data input “Upgraded parts”.

The EcoSteel software includes a pre-programmed graphics programme for presentation of the results. An example of this is shown in figure 3.17.

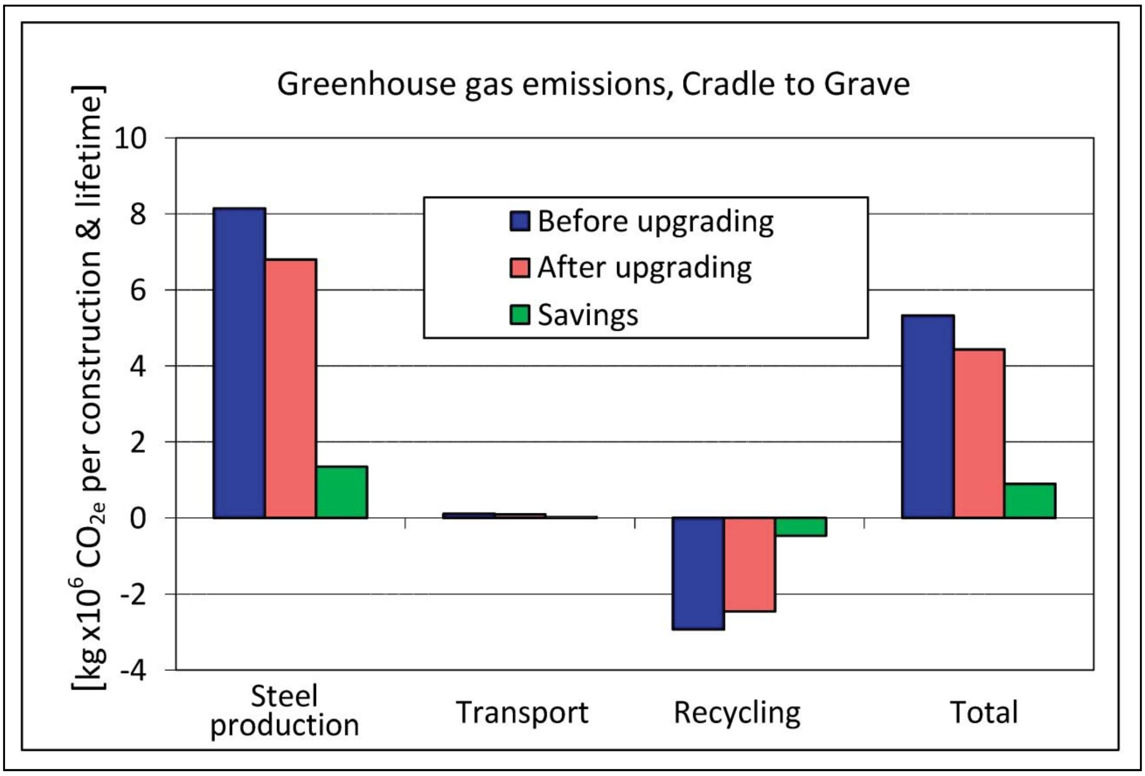

Figure 3.17 Example of results, print-out from EcoSteel, passive structure.

4 Examples of environmental evaluation of steel structures

4.1 Steel's environmental impact value – overview of results

Where analyses of environmental performance are concerned, it is necessary to know how the impact value is distributed over different stages of the process chain. Typical results are shown below for carbon steel and stainless steel, taken from the environmental research programme, *The Steel Eco-Cycle*. These results then constitute input data for the complete Life Cycle Assessment.

4.1.1 Carbon steel

For carbon steel, the plant-specific element (Gate - Gate) comprises 65-70 per cent and the production of upstream raw materials and energy 25-30 per cent of the so-called Cradle to Gate value. The alloying elements only account for about two per cent of the environmental impact. Figure 4.1 shows how the greenhouse effect, GWP expressed as carbon dioxide equivalents, CO_{2e}, is distributed for different stages of the process chain in respect of hot rolled, cold rolled and metal coated plate products respectively of carbon steel.

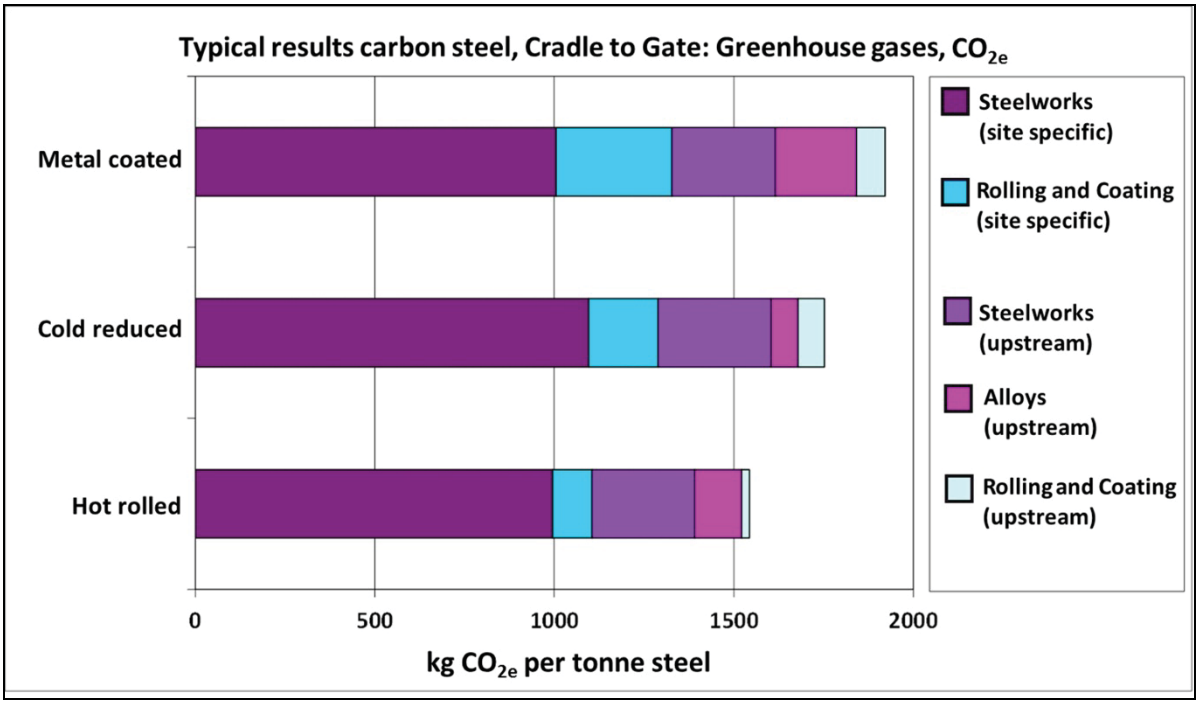

Figure 4.1 Typical results for hot rolled, cold rolled and metal-coated plate of carbon steel.

4.1.2 Stainless steel

For stainless steel, a dominant role is played by the production of alloys which may constitute 70 - 95 per cent of the steel's total environmental impact value. The plant-specific component normally constitutes only ten per cent or less. It is interesting to note that the production of electricity that is used in electric arc furnaces only comprises a few per cent of the environmental impact value. Figure 4.2 shows how the greenhouse effect, GWP expressed as CO_{2e}, is distributed across different stages in the process chain for cold rolled stainless steel.

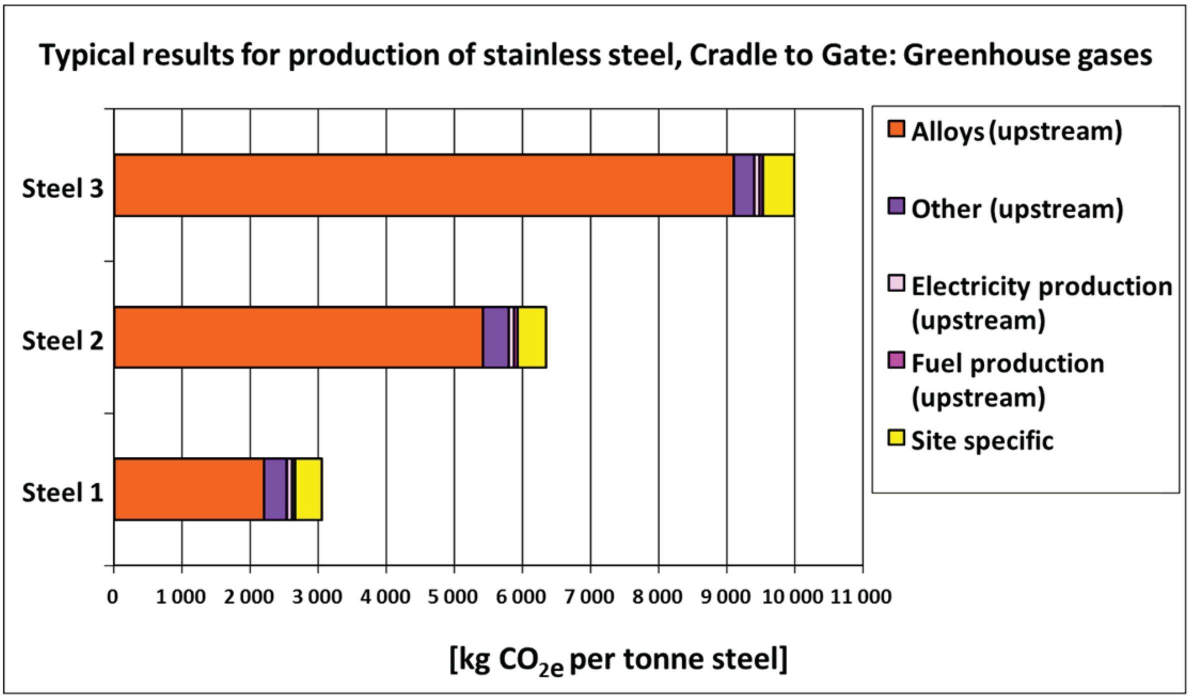

Figure 4.2 Distribution of the greenhouse effect (CO_{2e}) for different stages in the process chain for cold rolled stainless steel.

4.2 Example of a passive structure – Friends Arena

To illustrate a typical computation procedure for passive structures below, a rough calculation is shown of the environmental savings from using advanced high strength steel in the Friends Arena (Sweden's national arena), Figures 4.3 and 4.4.

Figure 4.3 Friends Arena, overhead view.

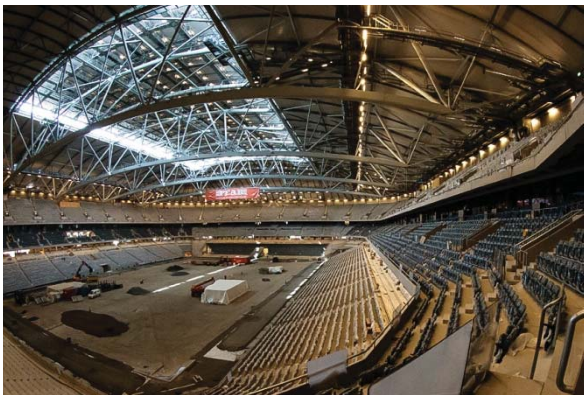

Figure 4.4 Friends Arena, roof trusses.

The arena has been built, to 32 per cent, with steel with a higher strength than the conventional S355 steel that has 355 MPa yield strength.

To estimate the environmental impact value of this upgrade, a recalculation has taken place to a hypothetical reference structure where all structural elements in the fixed roof are executed in the standard steel S355. So as to evaluate the additional possibilities that exist for weight savings through using more high strength steel, another calculation has also been carried out. This then enabled 54 per cent high strength steel to be used. This case is called alternative B whereas the arena, as it is constructed, is called alternative A.

Environmental savings with the upgraded roof can be calculated as the differences in weight and environmental impact value between the actual structure (alternative A), that with 54 per cent high-strength steel (alternative B) and the reference structure wholly manufactured in the conventional steel, S355.

The weights of those elements for the fixed roof that were modified on the steel upgrade are shown in table 4.1 divided into different steel grades. Here, too, is shown the environmental impact value for the respective steel grade according to figure 4.5.

Before upgrade				After upgrade						Environmental value GWP, tubes, sections and trusses [kg CO_{2e}/kg steel]	Environmental value GWP, plates [kg CO_{2e}/kg steel]
Reference						Alternative A		Alternative B			
Grade	Yield strength [MPa]	Weight alt. A [tonne]	Weight alt. B [tonne]	Grade	Yield strength [MPa]	Weight [tonne]	Weight reduction [tonne]	Weight [tonne]	Weight reduction [tonne]		
S355	355	1 506	564	S355	355	1 508	-2	561	4	2.340	2.044
S355	355	1 149	2 091	S460	460	920	230	1 719	372	2.385	2.089
S355	355	600	600	S690	690	307	293	307	293	2.489	2.188
S355	355	107	107	S900	900	43	64	43	64	2.581	2.278
Total		3 362	3 362	Total		2 778	584	2 630	732		

Table 4.1 Steel grades and weights, before and after the upgrade, as well as environmental impact values for steel tubes, sections, trusses and plate (provided by supplier Ruukki).

Data in figure 4.5 has been evaluated from data published by the steel company Ruukki, which supplied the steel for the fixed roof. The base level for the environmental impact value is converted to Cradle to Gate data in accordance with worldsteel methodology, whereas the effect of the yield strength is based on data from SSAB EMEA Oxelösund, see figure 3.8 section 3.2.6.

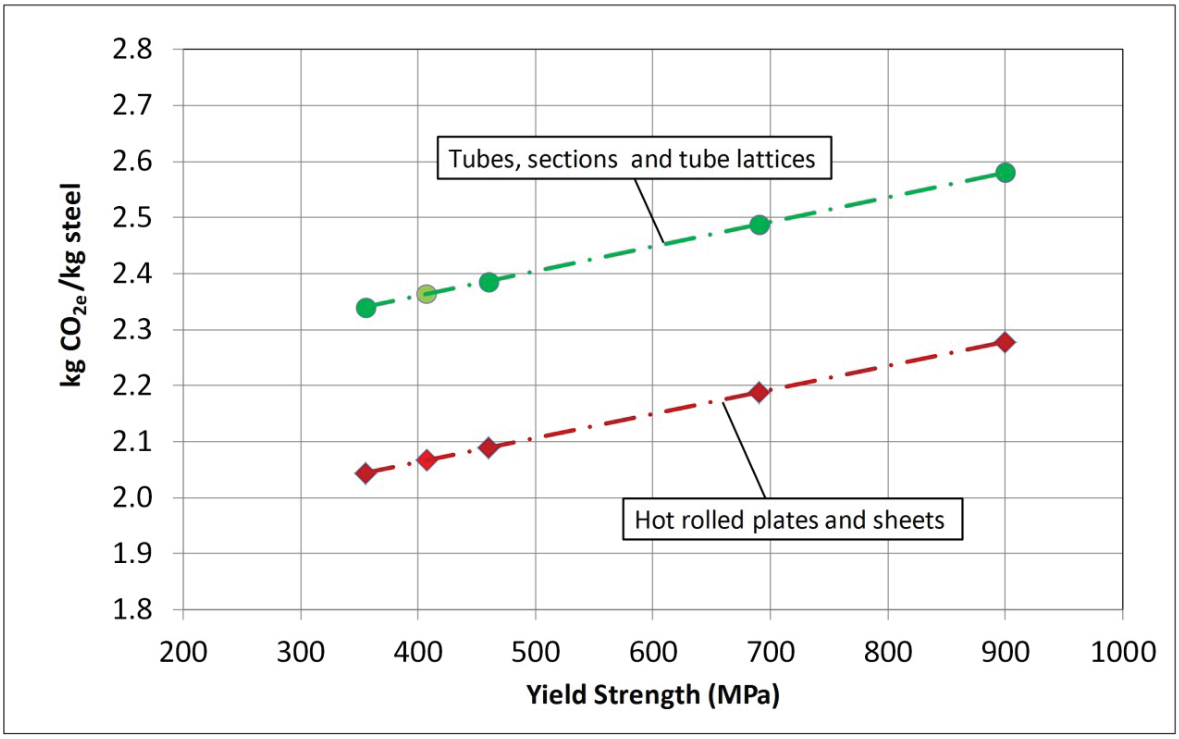

Figure 4.5 Greenhouse effect [kg CO_{2e}/kg steel] as function of yield strength for steel from Ruukki, adjusted for effect of yield strength with data from SSAB EMEA Oxelösund.

Certain elements that remain in the steel S355, even after the upgrade, have also been changed. This means that even if the total quantity of these elements is largely unchanged, the composition of the elements has been redistributed which has resulted in an upgraded, optimised design.

The total weight of the fixed roof is calculated at 4 584 tonnes before and 4 000 tonnes after the upgrade carried out on the roof of the actual arena. This is equivalent to a total weight reduction of 13 per cent overall, and 21 per cent for those elements that are included in the upgrade. For the roof, where more than half of the steel had higher strength than 355 MPa (alternative B), the weight was calculated at 3 852 tonnes. This gives a total weight reduction of 16 per cent, and of 28 per cent for the elements that are included in the upgrade.

4.2.1 Estimating the reduced environmental impact on production of the steel

The basis of calculation is the weights, distributed by steel grade, before and after the upgrade as well as the environmental impact value for the respective steel, as per table 4.1. The environmental impact value relates to the Cradle to Gate value.

The yield from steel product for the finished structural elements has been assumed to be 95 per cent, that is to say the amounts of steel required to produce the different structural elements are (100/0.95 – 100) = 5.263 per cent greater than those forming part of the finished structure as a whole.

The calculation of the total environmental savings during production of the steel is carried out through applying the equation 3:4 which is also shown below:

$$M_{Steel} = \sum(M_{Steel,\,x} * Quantity_{Steel,\,x})_n$$

M_{Steel} = *Environmental impact value for production all input steel [per structure]*
$M_{Steel,\,x}$ = *Environmental impact value (cradle to gate) for steel grade x [per kg steel]*
$Quantity_{Steel,\,x}$ = Amount of steel of respective steel grade x used in the structure [kg steel/structure]
n = *Number of steel grades*

Applying the above equation, *the savings* of greenhouse gases owing to the upgrade is as follows: $\Delta\ M_{steel,alt\ A}$ = 1.05263 * [(2.303 * 3 362) - [2.34 * 1508 + 2.385 * 920 + 2.188 * 307 + 2.278 * 43] = *1 316 tonne CO_{2e}*.

Analogous to the above, the savings for alternative B: $\Delta\ M_{steel,alt\ B}$ = *1 643 tonne CO_{2e}*.

4.2.2 Estimating the reduced environmental impact on transportation

Profiles, tubes and struts for the roof structure are manufactured at a production plant in proximity to a harbour, 85 km from the steel mill. This transport is weight limited and takes place by truck with a maximum gross weight of 40 tonnes.

After production, the finished structural elements are transported by ship for a distance of 275 km and subsequently a further 616 km by truck. The environmental impact value M_n is obtained as per figure 3.11; it works out at about 0.047 and 0.015 kg CO_{2e}/tonnekm for truck and ship respectively.

The calculation of the environmental savings during transportation of the steel is carried out through applying equation 3:4 which is also shown below:

$\Delta\ M_{Trp\ steel,\ alt\ A}$ =1.05263 * [(0.047 * 85 * (3 362 - 2 778)) + (0.015 * 275 * (3 362 - 2 778)) + [0.047 * 616 * (3 362 - 2 778)] = 23 tonnes CO_{2e}.

Analogous to this, for alternative B: $\Delta\ M_{Trp\ steel,\ alt\ B}$ = 29 tonne CO_{2e}.

The total environmental benefit, due to a lesser amount of steel needing to be produced and transported, for alternative A will thus be: 1 316 + 23 = 1 339 tonne CO_{2e}
and for alternative B: 1 643 + 29 = 1 671 tonne CO_{2e}.

4.2.3 Estimating the reduced environmental impact on production of the structure

Even though, from an environmental viewpoint, there should be a number of positive factors during production and installation of the upgraded structure it has been difficult for the manufacturer to quantify these. Positive factors include handling of lighter structural parts, less welding work on account of reduced material thickness, lighter framework during erection of the structure and so on.

This analysis does not take into account these differences since they are adjudged to be relatively minor within the overall context.

4.2.4 Estimating the environmental impact and environmental credits on recycling

When determining the total environmental load during a structure's useful life, there may also take place a credit allocation for the scrap that can be recycled. When this takes place, the scrap that is added during production of the steel must also be allocated a burden, since in a Cradle to Gate analysis the added scrap is not considered to give any environmental burden.

To calculate the environmental value for recycled scrap is relatively complex in this context. In the software developed within the framework of the Steel Eco-Cycle research programme for the purpose of a complete LCA (Cradle to Grave), this is included nevertheless.
To exemplify the effect of taking into account the recycling of scrap from passive structures, such an overall analysis has been carried out in this case. Results appear in section 4.2.5.
To make the results more generally applicable, the recycling rate has been assumed to be 60 per cent, a figure that is often cited for buildings with steel frames.

4.2.5 Overall results for environmental impact value on upgrading of Friends Arena

The overall result for the greenhouse effect, produced with the software tool EcoSteel, appears from figure 4.6 for alternative A and B. The total savings diminish slightly when account is taken of the recycling. This is due to the fact that a larger amount of the conventional steel is recycled since the structure is heavier before the upgrade.

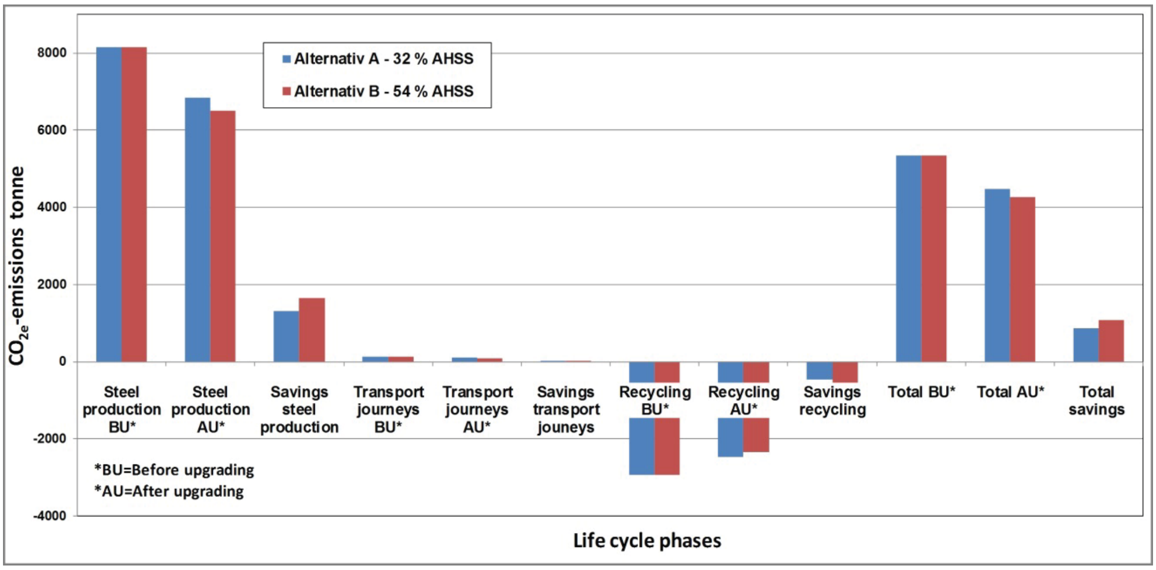

Figure 4.6 Environmental impact value for greenhouse effect (CO_{2e}), for example with lighter weight roof structure for Friends Arena.

To increase the share of high strength steel from 32 % to 54 % steel, in this case, yields a moderate increase in environmental savings, but even if the share of high strength steel increases quite a lot, the weighted average for the yield strength does not increase by more than about 80 MPa. The weight reductions obtained on account of this strength increase are greater than what one could expect considering the rule of thumb, the root formula, figure 4.7. The root formula indicates that the relative weight, after the upgrade, is inversely proportional to the square root of the yield strength quotient, before and after the upgrade, see chapter 3.3 equation 3:3.

In addition to the environmental savings, a financial saving is also achieved of about SEK 20 million owing to lower production costs for the structural elements. These relate to a lower number of beads during welding and lower preheat temperatures owing to thinner steel plate being used. The combination of these also leads to a reduction in the labour costs.

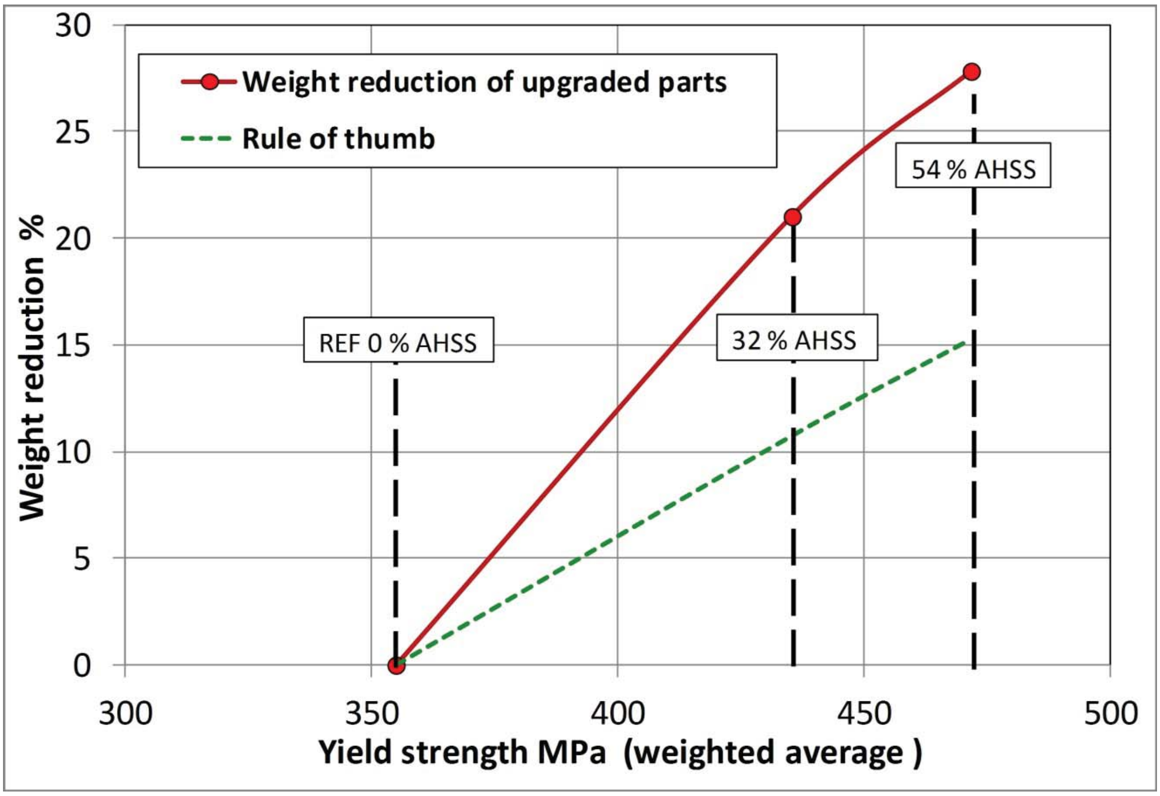

Figure 4.7 Weight reduction for alternatives A and B as function of the weighted average for the yield strength.

4.3 Example of an active structure – semitrailer for timber transport

To enable the realisation of a complete LCA relating to the environmental savings to be achieved on the upgrade of an active structure, a case study has been carried out on a semitrailer for timber transportation, figure 4.8. This trailer is manufactured by Mjölby Släp & Trailer AB in Sweden. The company reduced the weight of the semitrailer through using advanced high strength steel in the vehicle frame structure.

Figure 4.8 Environmentally evaluated semitrailer after upgrade.

The trailer is a so-called active structure which implies that the major part of the environmental impact takes place during use of the vehicle.

4.3.1 Structural parts and operating mode

The longitudinal beams on this semitrailer have been upgraded from conventional rolled IPE profiles in S310 steel to welded beams of the steel grade Domex 700.
Strengths and weights, before and after the upgrade, are shown in table 4.2.

Trailer chassis	Before upgrade				After upgrade			
	Steel grade	**Yield strength [MPa]**	**Thick-ness [mm]**	**Weight of part [kg]**	**Steel grade**	**Yield strength [MPa]**	**Thick-ness [mm]**	**Weight of part [kg]**
Flanges	HS310	310	12.7	943	Dx 700	700	8	593
Web	HS310	310	8		Dx 700	700	4	
Cross beams	HS350	350		257	HS350	350		257
Total main parts				1 200				850
Total tare weight				6 330				5 270

Table 4.2 Steel grades and weights in the upgraded trailer chassis.

For the upgraded parts, the weight decreased by no less than 350 kg, which is equivalent to a weight reduction of 37 per cent for these parts.

The total weight reduction following the upgrade of the steel in the longitudinal beams (350 kg) means that the unladen weight of the trailer decreased from 5 770 kg to 5 420 kg or by 6.1 per cent. In addition to this, the weight was further reduced by 150 kg thanks to changes in design and weight savings in other parts of the chassis. This means that the semitrailer's load capacity increased by 500 kg from 30 230 kg to 30 730 kg with a maximum gross weight for the trailer of 36 tonnes. The semitrailer is coupled to a tractor unit that also carries a payload of timber. The total payload capacity for the entire vehicle is about 40 tonnes and the total gross weight 60 tonnes.

The trailer's useful life is about seven years, with an average driving distance of 175 000 km/year. On average, it is assumed that 50 per cent of the journeys take place empty and, for purposes of calculation, are regarded as volume limited transport journeys (section 3.4.3). The remaining 50 per cent are weight limited transport journeys with full load.

4.3.2 Estimating the reduced environmental impact on production of the steel

This module covers the environmental impact of production of the steels used for manufacture of the upgraded parts, before and after the upgrade. The yield of steel in production of the trailer is assessed to be 90 per cent, both before and after the upgrade. This means that eleven per cent more steel must be produced in both cases.

The environmental savings (CO_{2e}), owing to the need for production of a lower quantity of steel after upgrading, are calculated in the same way as for the passive structure above. Data relating to the environmental performance of the different steels is now obtained from figure 3.7 in section 3.2.6.

$\Delta M_{steel} = 1/0.9 * [(1.45 * 943) - (1.55 * 593)] = 498$ kg CO_{2e}/vehicle

4.3.3 Estimating the reduced environmental burden during transport journeys

The steel in the form of IPE beams that was used before the upgrade was supplied from Luxemburg. The freight transport distance to Mjölby was 1 300 km. The steel used after the upgrade undergoes laser cutting in Borlänge, is transported to Kilafors for welding and subsequently goes to Mjölby. This gives a total transport distance, after the upgrade, of 610 km. All transport journeys are weight limited and are carried out by truck.

The calculation of the environmental savings (CO_{2e}), owing to the need for less transportation following the upgrade as well as the fact that the transport distance decreases after the upgrade, is analogous to the example for the passive structure above.

$\Delta M_{Trp\ steel} = 1/0.9 * [(0.047 * 1300 * 943) - (0.047 * 610 * 593)]/1000 = 45$ kg CO_{2e}/vehicle

4.3.4 Estimating the reduced environmental impact on manufacture

There is no information on differences in energy consumption on manufacture before and after the upgrade respectively. If there are any differences, they are probably small and the product manufacturing phase has therefore been excluded from this analysis. It is of little significance anyway, especially in comparison with the environmental savings during the utilisation phase.

4.3.5 Estimating the reduced environmental impact during use

To analyse the fuel savings on weight reduction for the *volume limited and empty transport journeys*, the specific fuel savings for a certain weight reduction (litre/km and kg weight reduction) can first be calculated through applying the equation 3:13 which is shown below:

$SFC = (FC_{full} - FC_{empty})/MPL$

SFC= Specific fuel savings [litre/km and kg weight reduction]
FC_{full} = Fuel consumption fully loaded [litre/km]
FC_{empty} =Fuel consumption unladen [litre/km]
MPL= Maximum load capacity [kg]

The fuel consumption for the timber transport unit is 0.71 l/km fully loaded and 0.36 l/km empty; the maximum load capacity is 40 000 kg. This gives a specific fuel saving SFC:

$SFC = (0.71 - 0.35)/40\,000 = 9 \cdot 10^{-6}$ litre/(km and kg weight reduction)

The environmental savings for the *volume limited (vc)* part of the transport journeys are obtained, in accordance with equation 3.15, which is shown below:

$M_{saving,vc} = SFC * WR * M_{fuel} * L$

$M_{saving,vc}$ = Environmental savings owing to weight reduction for volume limited transport [kg CO_{2e}]
SFC = Specific fuel saving [litre/km and kg weight reduction]
WR = Weight reduction on upgrade [kg]
M_{fuel} = Environmental impact value on production and combustion of fuel
[kg CO_{2e} per litre diesel fuel = 3 kg CO_{2e}/litre incl. production of the fuel]
L = Total driving distance during useful life [km]

This gives the following, for this part of the transportation, which is 50 per cent:

$M_{saving,vc} = 9 \cdot 10^{-6} * 500 * 3 * 7 * 175\,000 * 0.5 = 8\,268$ kg CO_{2e}/vehicle

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The environmental savings for the *weight limited* part of the transport journeys are estimated in accordance with equation 3:11, also shown below:

$$M_{savings,wc} = (M_{Fuel} * FC_{full} * L * WR/MPL)$$

$M_{savings,wc}$ = *Environmental savings due to weight reduction, weight-limited transport [kg CO_{2e}]*

M_{fuel} = *Environmental impact value on production and combustion of fuel [kg CO_{2e} per litre diesel fuel = 3 kg CO_{2e}/litre incl. production of the fuel]*

FC_{full}= *Energy consumption litre/km or kWh/km with full load*

L = *Total driving distance during useful life [km]*

WR = *Weight reduction on upgrading [kg]*

MPL = *Vehicle's maximum load capacity [kg]*

$M_{saving,wc}$ = 3 * 0.71 * 7 * 175 000 * 0.5 * 500/40 000= 16 308 kg CO_{2e}/vehicle

The utilizationphase thus contributes with a lifetime saving of 8 268 +16 308 kg = 24 576 kg CO_{2e} for each trailer. Moreover, a lifetime saving in cost of fuel of SEK 122 900 (SEK 15/litre per vehicle) is achieved.

4.3.6 Determining allocation of environmental credits and burden on recycling

In determining the total environmental impact during a structure's useful life, there may also, in certain cases, take place a credit allocation for the steel scrap that can be recycled. When this takes place, the scrap that is added on production of the steel must also be assigned a burden since, in a Cradle to Gate analysis, the added scrap is not assigned any environmental burden.

To estimate the environmental performance for recycled steel scrap is relatively complex. Nevertheless, in the software program, EcoSteel, developed within the framework of the Steel Eco-Cycle programme for purposes of complete "cradle to grave" analysis, this function is included. To exemplify the effect of taking into consideration the recycling of scrap for active structures, a complete analysis has been made in this case. The results appear in section 4.3.7, where the all-inclusive results are shown. The recycling rate has been assumed to be 90 per cent.

4.3.7 Overall result for environmental impact value on upgrade

The overall result for global warming potential, (GWP), expressed as carbon dioxide equivalents (CO_{2e}) and estimated with the data program EcoSteel, appear in figure 4.9. This shows that the savings in carbon dioxide emissions on combustion of the fuel during use of the structure contribute decisively to the total savings. It also means that environmental savings during manufacture of the steel as well as the consequent structures, transport journeys and the influence of credit allocations on recycling all comprise a lesser share for active than for passive structures.

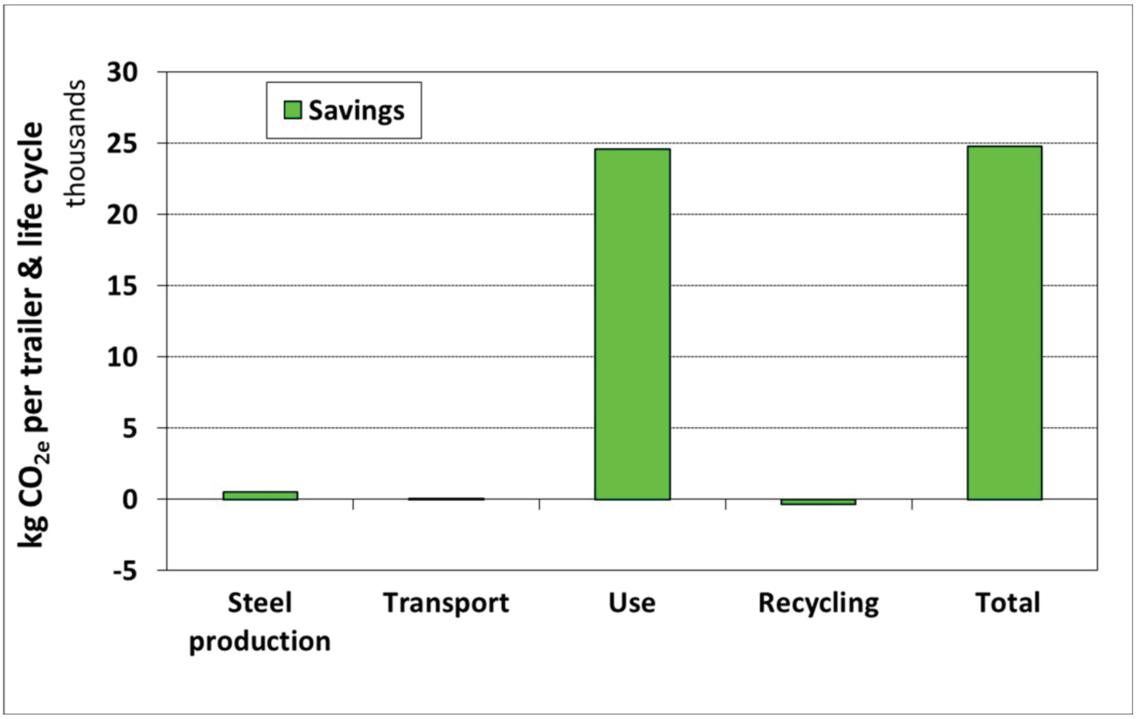

Figure 4.9 Environmental impact value of greenhouse gases (CO_{2e}) per timber trailer, estimated using the data program EcoSteel.

4.4 Example of a passive structure in stainless steel – Storage tank

4.4.1 Description of storage tank

A storage tank has been upgraded through replacing conventional stainless steel with high strength, duplex stainless steel, Figure 4.10.

The tank is mainly used to store marble sludge and similar liquids. Data for the tank before and after upgrade is shown in Table 4.3.

The plate segments for the tank are manufactured in a workshop and installed on the site where it is intended that the tank shall operate.

Figure 4.10 Storage tank in stainless steel.

Table 4.3 Data for the tank.

	Steel grade	**Total weight [tonne]**	**Height [m]**	**Diam. [m]**	**Volume [m^3]**	**Plate width [m]**	**Calculating stress [MPa]**
Before upgrade	EN 1.4301	57.4	14	17	3 178	2.0	140
After upgrade	EN 1.4162	38.3	14	17	3 178	2.0	260

The plate thickness, before and after the upgrade, appears in figure 4.11.

After the upgrade, the first plate is 9 mm thick, the second is 7 mm and the remaining 5 plates are 6 mm thick. The latter is the minimum permitted thickness as standard in this case.

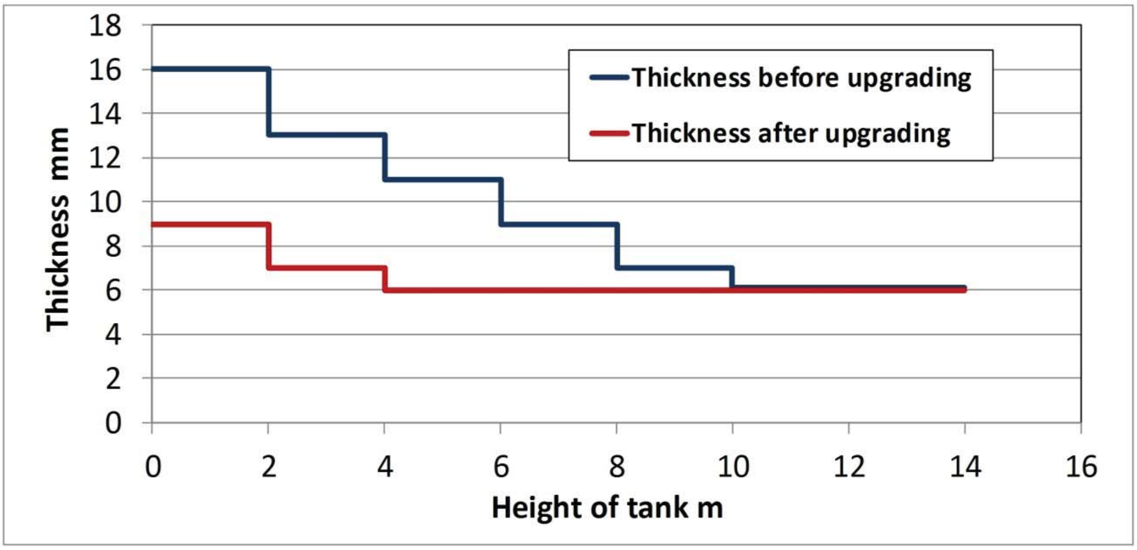

Figure 4.11 Plate thickness as function of tank height before and after upgrade.

The total weight reduction was 19.1 tonnes or 33 %.

Data for the tank was provided by Outokumpu Stainless, Avesta. Information about the costs has been provided by Stålmonteringar AB in Trollhättan, Sweden, a manufacturer of this type of tank.

4.4.2 Life Cycle Assessment

Since the Life Cycle Assessment, in computational terms, is shown in detail in the preceding two examples, an analysis is made here directly with the software tool EcoSteel.
The preconditions for the life cycle assessment are given below for the different phases.

4.4.3 Steel production

This module covers production of raw materials and steel for the tank. Since the steel plates were delivered to the site in the "correct size", the yield losses are small and assumed to be the same before and after the upgrade. These losses have therefore not been included in the analysis. The steel quantities that are analysed are assumed to be equal to the weight of the containers shown in table 4.3.

4.4.4 Transportation of steel

Since this is a general example, the transport distance to the place of erection is assumed to be the same before and after the upgrade and, in this case, is assumed to be 1 000 km. The mode of transport chosen was truck.

4.4.5 Fabrication

As mentioned above, the tank is fabricated on the same site where it will be in operation. It is welded of 2 m wide steel plates, and so 7 plates are required for the height of 14 metres.

The horizontal weld length is 320 m while the vertical weld length is 35 metres. The consumption of welding wire is 825 kg before and 419 kg after the upgrade with the high strength duplex steel.

The production of the welding wire has been environmentally approximated with the production of the corresponding steel grade. The energy consumption for welding is 8 250 kWh before and 4 190 kWh after the upgrade.

4.4.6 Use of the tank

The environmental aspects related to the use of the tanks may comprehend differences in maintenance, corrosion resistance and useful life. In this case, however, a useful life of at least 30 years has been assumed, both before and after the upgrade.

4.4.7 Recycling

The added scrap on production of the steel is not assigned any environmental burden in a Cradle to Gate analysis. A stainless steel grade where a large share of steel scrap is added during the production process will thus have a relatively low environmental burden in a Cradle to Gate analysis, even if it has a high content of alloys.

Comparable results for a structure manufactured with different steel grades can only be obtained, therefore, when the environmental burden for the added scrap and the allocation of credits for the environmental impact value of the recycled scrap obtained when a steel product is recycled, is considered. See also section 3.5.3. In this example a recovery rate of 90 % is assumed.

4.4.8 Results of the analysis

The total carbon dioxide emissions divided into different life cycle phases are shown in figure 4.12. *Global warming* has been selected to illustrate the results since the other effects for the different categories show the same pattern as for global warming.

For global warning, (CO_{2e}), the storage tank with the high strength steel EN 1.4162 has 43 per cent lower environmental impact than the reference case using conventional stainless steel, namely EN 1.4301.

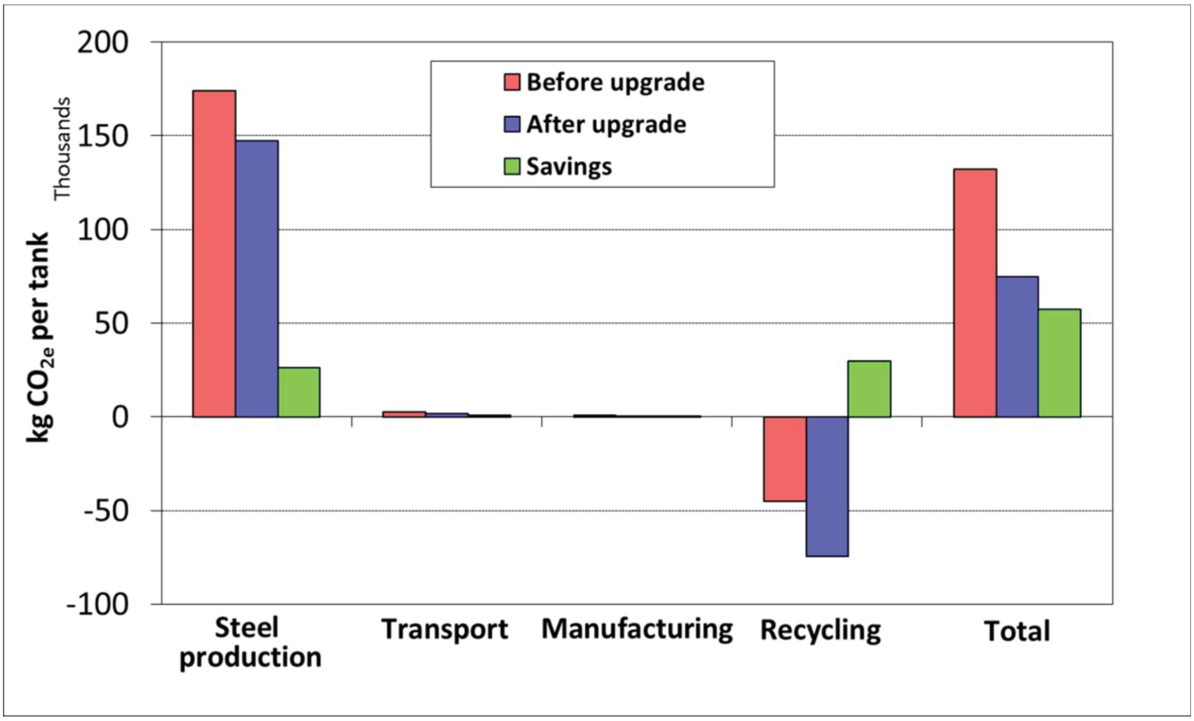

Figure 4.12 Environmental impact value in respect of global warming for the upgraded storage tank, estimated using the EcoSteel tool.

4.4.9 Environmental changes in different phases of the life cycle chain

Since the tank in question is a passive structure the environmental impact during the utilisation phase is only small. The environmental influenced by the upgrade, in this case, is related to steel production and recycling. The effects in connection with transportation of the steel and fabrication of the structure only amount to a few per cent. The fact that the recycling of the lighter, upgraded structure yields a larger environmental credit than the conventional steel is due to the latter being manufactured with a larger portion of scrap; in the Cradle to Gate analysis this scrap was considered to be free from environmental burden.

4.4.10 Life Cycle Costing

The steel prices are assumed to be SEK 26 700/tonne and SEK 28 800/tonne for the stainless steels, EN 1.4301 and EN 1.4162 respectively. The scrap price, on the other hand, is assumed to be SEK 16 400/tonne and SEK 16 300/tonne respectively.

The manufacturing cost of the tank is influenced, above all, by the fact that less welding material and less welding work is required owing to reduced material thicknesses. The total manufacturing cost per tank, before and after the upgrade, was SEK 1 210 000 and SEK 720 000 respectively. How this cost is distributed appears in Table 4.4.

Table 4.4 Distribution of manufacturing costs before and after the upgrade

Item	Before upgrade	After upgrade
Welding consumables etc, %	11.0	15.8
Cost for welding equipment, gas etc, %	25.6	26.2
Labour cost for welding, %	31.3	29.0
Labour cost for assembly, %	31.3	29.0
Total manufacturing cost, SEK	1 210 000	720 000

Through upgrading the material in the tank to duplex high strength steel, with double the strength of a tank manufactured in conventional steel, the life cycle cost including recycling of the steel can be cut by 34 %. Two thirds of this reduction is due to the cost of fabrication of the structure being lower. Figure 4.13 shows a summary of the life cycle costs.

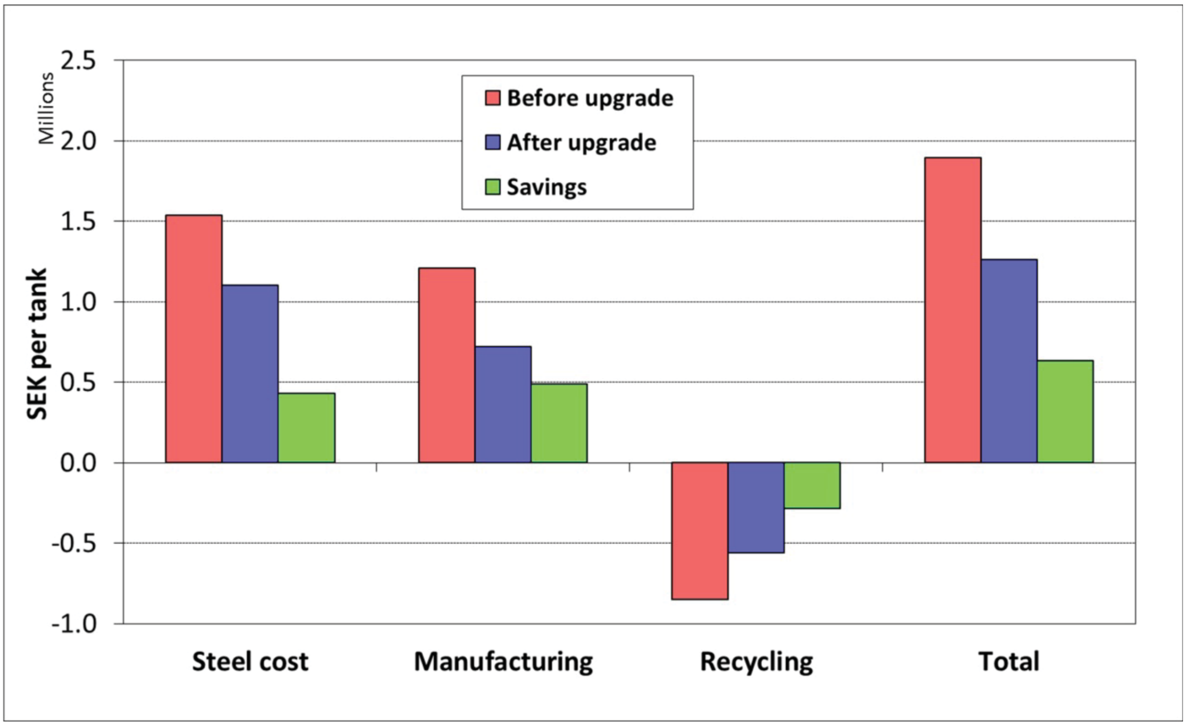

Figure 4.13 Life cycle cost for the upgraded storage tank divided into different phases, estimated with the EcoSteel tool.

Contents

5 Environmental evaluation of process changes

5.1 General working methodology for environmental analysis of process changes

5.1.1 General

This chapter describes how one analyses the environmental impact value of process changes during steel production.

An environmental analysis of this type compares two scenarios, the present one and the modified procedure. The difference between the environmental impact value of the newly modified process and the existing one is then calculated using a differential calculus.

The analysis is facilitated by the fact that the technical change is described in a flow chart; also that the data for the mass and energy flows, before and after the change, are noted so that the difference between the two alternatives is clearly shown. In practice, this involves quantifying the inflows and outflows of the process, for example:

- Consumption of raw materials such as iron ore, coal, coke, alloys and chemicals.
- Use of energy (electricity and fuels), e.g. coal, oil, natural gas, LPG and bio fuels.
- Emissions to air and water. It is preferable to select data that has already been prepared in other contexts.
- Residual products and residual energies and their utilisation with the existing and the new process.
- In the case where the process constitutes one part of a production chain, e.g. an LD converter (oxygen converter), the product's mass and energy flows from the preceding and subsequent process stages are recorded in such a way that the difference is clearly evident.

Data is related to the amount of product produced, for example one tonne. Such a process description is illustrated schematically in figure 5.1.

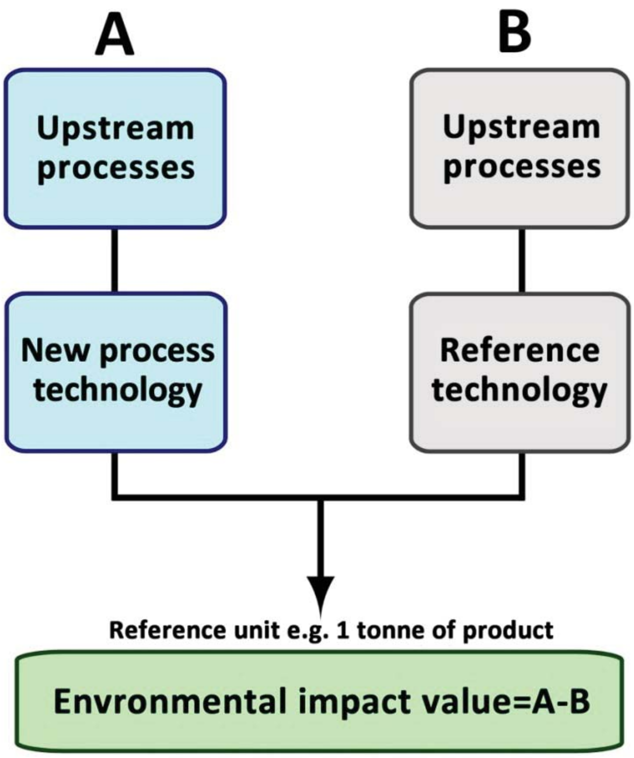

Figure 5.1 Calculation of environmental impact value of a process change.

One way of visualising the mass and energy flows of the processes is to arrange the values in the block diagram as per figure 5.2. If the new process has a limited effect on the preceding and subsequent process stage, the environmental impact value can be directly identified in such a block diagram.

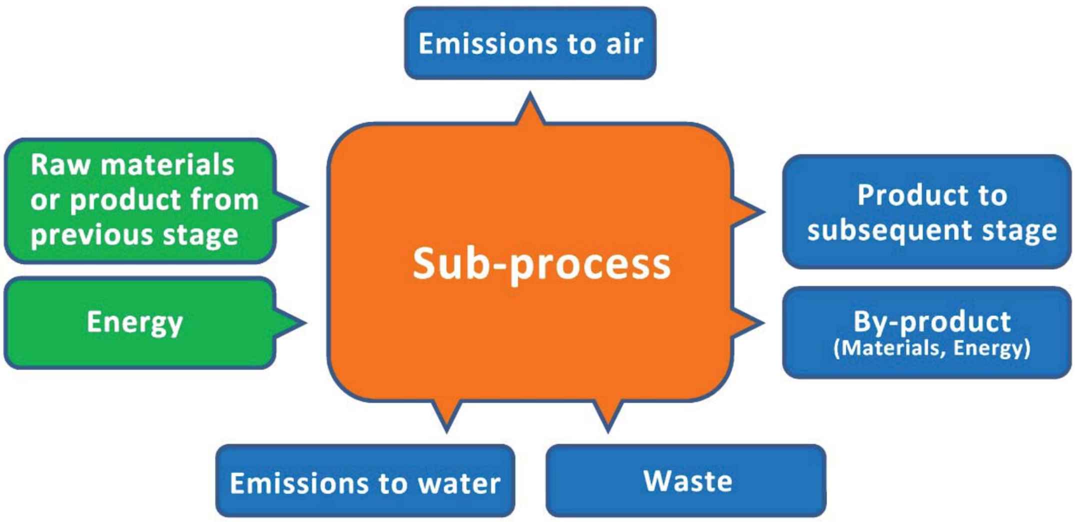

Figure 5.2 Description of a process step in a production chain.

The goal and scope of the analysis determine how detailed the data collection shall be; that is which inflows and outflows are relevant.

One example of a goal for the analysis may be: "*To investigate if it is possible to save fossil resources and reduce carbon dioxide emissions with the new process technology.*" In such a case, it is most often unnecessary to collect information on discharges to water or airborne emissions other than carbon dioxide, nor even data that concerns the amount of residual products.

With major process changes, it may be necessary to environmentally evaluate several parameters in order to obtain a relative picture of the environmental impact value. In Chapter 2.2.2 several different categories of environmental impact are indicated.

On definition of the function, the selected system limit and marginal effects for the environmental analysis, it is necessary that:

- Both scenarios shall generate the same functions; this may involve one or indeed several, for example steel with the same properties and a slag of quality for recycling
- Differences in process data outside the system limit shall be marginal
- Process steps that are the same in both the scenarios can be left out, since the environmental impact value is calculated as a difference for the process steps that are changed

Where the resultant environmental impact value is positive, this means that the process change results in an environmental improvement. Where it is negative, then the new technology is inferior in environmental terms to that of the reference case.

5.1.2 Expanded analysis of process change

It can be of interest to compute those environmental impact values that individual process changes can produce, where the effect is analysed for the steel eco-cycle in e.g. Sweden. Such a calculation gives an idea of the maximum amelioration potential for the environmental impact where the process improvement is concerned; it also indicates the technical change's wider public benefit.

When seen in terms of the entire steel and scrap flow, however, there may be both positive and negative synergies from process changes since the Swedish steel eco-cycle is not a closed system. Much of the Swedish steel production is exported and a large share of the steel that is used within the country is imported. The same applies to steel scrap.

A more detailed model of the steel eco-cycle in Sweden, as illustrated in figure 5.3, can form the basis for a more precise estimate.

By way of example, we can consider the effect of increased utilisation of steel scrap in the production of steel from pig iron in an LD converter through introducing a new process step, “Thermal surface cleaning of scrap” before the steel production process. In figure 5.3 it is termed “Surface cleaning of scrap”.

One effect, among others, is that the use of crude steel made from iron ore can be reduced, which in overall terms delivers an environmental amelioration. However, it is necessary to check that sufficient scrap is available so that a shortage of scrap does not arise. The steel must then perhaps, in a longer perspective, be produced from crude steel (ingots and semi-finished products) made from iron ore. The environmental gain in the individual process cannot thus be geared to an environmental benefit for the entire national steel eco-cycle.

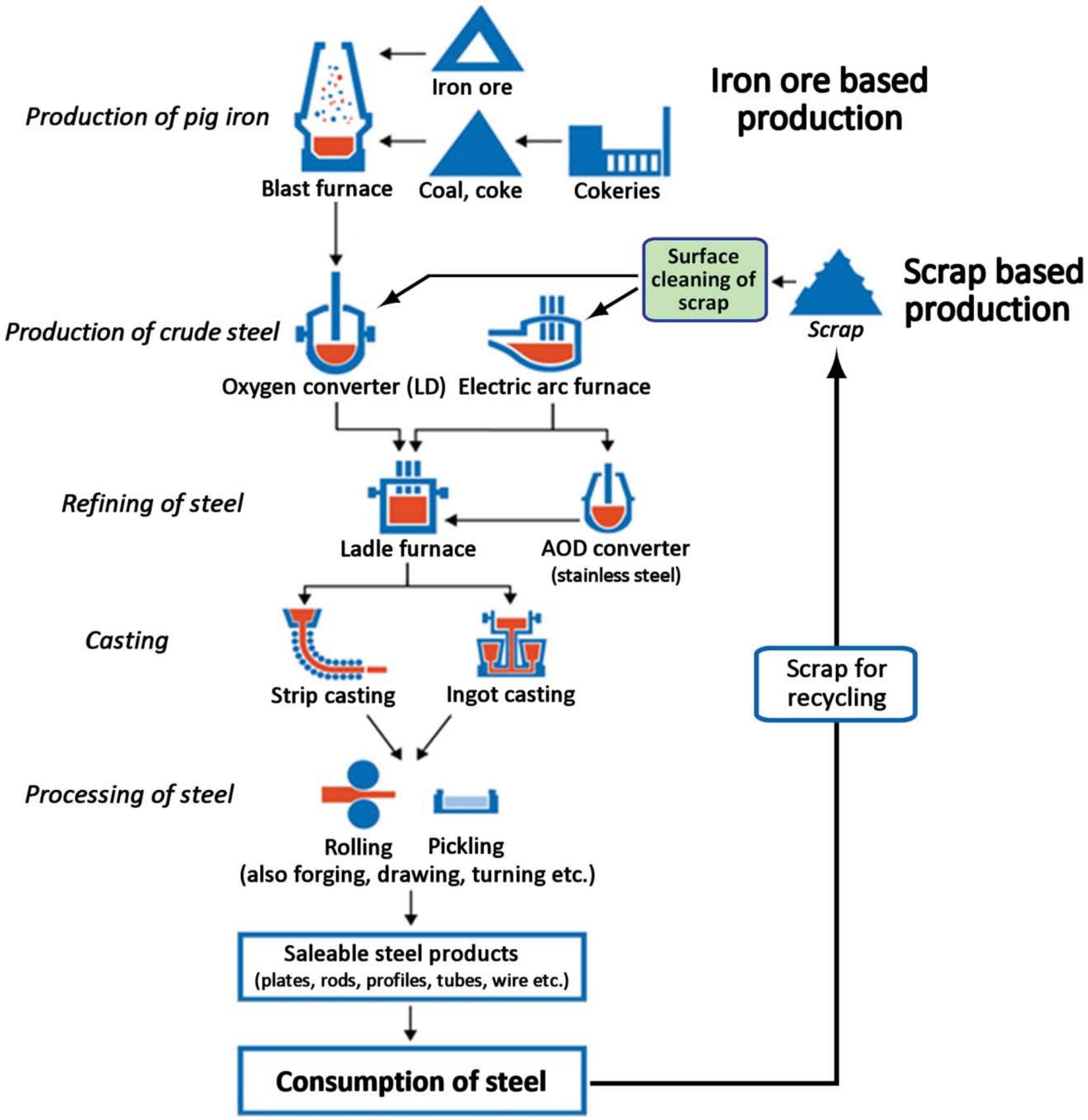

Figure 5.3 Model of the steel’s production with surface cleaning of scrap marked.

Another conceivable scenario, however, is that improved scrap analysis, with more effective scrap collection and enhanced shredding/sorting overall, increases the supply of scrap, so that it covers parts of the increased demand. Each additional tonne of carbon steel scrap that can be recycled in this way - and used instead of crude steel made from iron ore during steel production - delivers an environmental benefit of about 1.5 tonne CO_{2e}. This signifies a decrease in the environmental burden of around 75 %. The result here can then be geared up into an environmental benefit for the steel's entire eco-cycle, corresponding to the reduction in crude steel from iron ore.

Where a comprehensive analysis is concerned, any differences in material yield with the processes compared shall be determined; also, how the supply of raw materials such as iron ore and alloy metals is affected. Related processes for the supply of production resources (steam, hot water, gases in air etc.) and how residual energies and products are handled also need to be examined. Possible differences in transportation in both these scenarios shall also be taken into account.

Once the concept is analysed and formulated, the next step is to collect data i.e. to compile quantitative information on mass and energy flows so that the differences can be computed. When this is complete, a check is made that the data is reasonable (credible). Material balances must tally with one another; emissions of carbon dioxide shall be credible taking into account the use of the carbon content of fossil fuels. There must be no obvious technical incongruities or deficiencies.

The diagram with data is converted into an LCA model and the environmental assessment itself is carried out in the manner described in Section 2.4 "Modelling of the LCA system."

A detailed analysis and environmental impact value estimate is shown in Appendix 3 for a process that is developed within the context of the environmental research programme, *The Steel Eco-Cycle*. The process involves the thermal surface cleaning of scrap before it is utilised in the steel mill.

Appendix 1

Abbreviations

SETAC

Society for Environmental Toxicology and Chemistry. An international, impartial scientific association that has played a major role in the development of the LCA as a scientific activity since the early 1990's.

ISO

International Organization for Standardization. A non-governmental standardisation body that develops standards on a voluntary basis and a global level, frequently with considerable participation from industry. It is responsible for environmental management standards within the ISO 14000 series. It has played a large role in the development of the LCA through its LCA standards: SS-EN ISO 14040:2006 and SS-EN ISO 14044:2006.

The EPD system

The first programme for certified, LCA-based environmental declarations of goods and services in accordance with ISO 14025. It was launched in Sweden in 1998 based on a technical report from the ISO, which was later developed into SS-EN ISO 14025:2006. The EPD system was transformed in 2008 into a global system, with about 10 nations participating (2012).

ISO 14025

SS-EN ISO 14025:2006. An ISO standard for certified, LCA based environmental product declarations of goods and services (ISO type III environmental declarations) which are also a Swedish (SS) and European (EN) standard. The ISO standard mainly sets requirements in respect of the formulation of programmes and regulations for type III declarations. They cannot be employed directly to prepare an environmental product declaration.

JRC

Joint Research Centre. The JRC is the European Union's scientific and research organisation with laboratories at several sites across Europe. JRC at Ispra in Italy works on LCA issues, among others. JRC Ispra is responsible for the so-called ILCD handbook, for example.

ILCD handbook

The International Reference Life Cycle Data System, ILCD, is developed by JRC at Ispra (Italy) and consists of a handbook, *ILCD handbook*, which offers detailed guidance for implementation of the LCA in different applications as well as the *ILCD data network*, which is an international network for LCA data, under construction (2012). The ILCD handbook comprises several parts that were published during the period 2009 to 2012.

The ILCD handbook sets more detailed standards than the ISO 14040 series but is flexible enough to cover all applications of the LCA.

EPD

Environmental Product Declaration. EPD designates the LCA-based environmental product declarations.

CEN

The European Committee for Standardization. This is a European standardisation body with 33 national members which develops European standards (EN) and technical specifications. These standards then become national standards. CEN has a more formal role than the ISO since EN standards may form part of the European legislation.

PEF guide

Product Environmental Footprint Guide has been developed by JRC in Ispra and is based on the ILCD handbook. However, it is not as flexible but is more prescriptive and very much resembles the EPD system. The goal is to develop a joint European LCA methodology that facilitates comparisons of the environmental performance of products. The document was published in July 2012.

ELCD database

The European Reference Life Cycle Database has been developed by JRC in Ispra and contains LCA data that has been developed mainly by European trade organisations. ELCD is a forerunner of the future ILCD data network.

GaBi

GaBi, like Simapro and others, is a commercial software tool for LCA calculations. It includes tools for modelling and environmental data, for example the ELCD database. The software has come to be something of an industry standard within the European engineering industry.

Appendix 2

Data sources for environmental evaluation

This appendix lists different sources concerning data for environmental evaluations. The tables contain information on search paths, grouped for raw materials, energy, transportation etc.

Generic LCA databases

Database	Description	Contact details
GaBi	For the LCA software GaBi there are a number of databases to acquire separately and a database (GaBi Professional) which is included. The latter includes most that one needs concerning production and combustion of fuels, transport data and a number of materials and chemicals. Licence required.	PE International, Germany (www.gabi-software.com)
EcoInvent	Operated by several parties within a competence centre in Switzerland. Data is supplied in Excel, but can also be bought in GaBi format. Licence required.	www.ecoinvent.org
ELCD	EU's open LCA database.	http://lct.jrc.ec.europa.eu/assessment/data
NTM	Data for transportation by different transport modes.	The Network for Transport and Environment (NTM) www.ntmcalc.se

Iron and steel

Process	Potential data sources	Comments	Contact details
Carbon steel	worldsteel	Global and European averages for a number of categories of carbon steel. Data is based on Cradle to Gate analyses made at steel companies.	www.worldsteel.org
Stainless steel	Eurofer	Average for a number of categories of stainless steel. Data is based on Cradle to Gate analyses made at steel companies.	www.eurofer.org
Steel production	Jernkontoret	Swedish and Scandinavian data for the steel industry.	www.jernkontoret.se
Steel plants and recycling industries	Yearly public environmental reports.	Raw materials, energy and emissions per operating area and year.	Companies' homepages or direct contact.

Raw materials

Process	Potential data sources	Comments	Contact details
Alloying elements etc.	GaBi	FeCr, FeMn, FeSi, FeV, Cu & Zn	www.gabi-software.com
Molybdenum	IMOA	FeMo, Mo briquettes & Mo oxide	www.imoa.info
Nickel	*Nickel institute*	FeNi, Ni & Ni oxide	www.nickelinstitute.org
Aluminium	EAA *(European Aluminium Association)*	*Environmental Profile Report for the European Aluminium Industry, European Aluminium Association, Brussels,* September 2005.	www.alueurope.eu
Gases	Suppliers of gases e.g. AGA and Air Liquide	Data for oxygen, nitrogen, argon etc.	Companies' homepages or direct contact.
Gases	Ecoinvent	Average data for Europe	www.ecoinvent.org

Fuels

Process	Potential data sources	Comments	Contact details
Refineries	Yearly public environmental reports.	Raw materials, energy and emissions per operating area and year.	Companies' homepages.
Extraction and refining	GaBi and Ecoinvent respectively	Fuels classified by countries and regions.	www.gabi-software.com and www.ecoinvent.org
Combustion	GaBi and Ecoinvent respectively	Combustion of different fuels for different countries and regions.	www.gabi-software.com and www.ecoinvent.org

Electricity

Process	Potential data sources	Comments	Contact details
Electric power	GaBi and Ecoinvent respectively	Data for individual types of power.	www.gabi-software.com respektive www.ecoinvent.org
Electricity statistics	International Energy Agency (IEA)	Statistics for electricity generation mixes for countries and regions. Import & export of statistics that facilitate the calculation of consumption mixes.	www.iea.org
Electricity statistics	European Network of Transmission System Operators for Electricity	Electricity statistics	www.entsoe.eu
Electricity statistics	Svenska Kraftnät (Swedish national grid)	Electricity statistics for Sweden	www.svk.se
Electric power	Environmental product declarations e.g. from Vattenfall, Eon etc.	Data for separate types of power.	Companies' homepages.

Transportation

Process	Potential data sources	Comments	Contact details
Transport journeys	The Network for Transport and Environment (NTM)	Data for transport journeys with different modes of transport.	www.ntmcalc.se
Transport journeys	Ecoinvent	European average data for transport journeys with different vehicles of different weights and environmental classes.	www.ecoinvent.org
Transport journeys	GaBi	Models for several types of vehicle with possibility of varying payload capacity, type of road (motorway, main road, built-up area), share of biofuel and sulphur content in the fuel etc.	www.gabi-software.com
Transport distance	Mappy	Calculation of road distance	http://en.mappy.com
Transport distance	ViaMichelin	Calculation of road distance	www.viamichelin.com
Transport distance	World Shipping Register	Calculation of nautical distances	http://e-ships.net/dist.htm
Transport distance	Sea-Rates.com Port to port distances	Calculation of nautical distances	www.searates.com/ reference/portdistance
Transport distance	PortWorld	Calculation of nautical distances	www.portworld.com/map
Transport distance	Surface Distances Between Two Points	Calculation of distance between two points on the earth and of great-circle distances between cities.	www.chemical-ecology.net/java/ lat-long.htm

Other

Process	Potential data sources	Comments	Contact details
Energy	Jernkontoret's energy handbook	A web-based energy fact book	www.energihandbok.se
Environmental evaluation of steel	Environmental Potential Report, IVL	Environmental evaluation of steel processes and steel structures.	www.stalkretsloppet.se, www.jernkontoret.se
Life Cycle Assessment	Wikipedia	General description and overview	www.en.wikipedia.org/wiki /Life-cycle_assessment

Appendix 3

Examples of environmental evaluation on process change

Surface cleaning of steel scrap

This section describes, step by step, how an environmental analysis of a process change can be carried out. This is done with the help of an example whereby a new process is used to preheat and to remove organic substances and metallic coatings from the surface of the steel scrap before the scrap is melted. The surface cleaned steel scrap is used subsequently as raw material in an electric arc furnace or as cooling scrap in an LD converter. For preheating of steel scrap, thermal energy is used from process gases or the energy in waste products.

Environmental benefits arise through preheated steel scrap reducing the electrical energy demand in an electric arc furnace. Alternatively, the heat is utilised in the steel scrap to charge more cooling scrap into an LD converter; this means that the need for crude steel from iron ore production can be reduced. With an effective cleaning of the flue gases using the new surface cleaning process, a diffuse discharge is avoided with low content of metals and organic substances from the steel production.

The analysis here was made before the process was fully developed but it does not change the manner of carrying out an environmental evaluation using the LCA methodology.

Starting point – system description

The new process implies, for steel production based on scrap metal, that metal scrap is surface cleaned through preheating before it is charged in an electric arc furnace. Flue dust from the melting process contains zinc from metal-coated steel scrap. The zinc is separated from the flue dust for reuse.

In the integrated steel process (blast furnace and LD converter), coated steel scrap is not normally charged into the converter since it prevents the reuse of the dust.

In a new development of the surface cleaning process, plastic waste from motor vehicles is used as fuel, so-called auto fluff which is a fraction of ASR (*automotive shredder residue*). This residue contains PVC. In the course of combustion, hydrogen chloride is formed that reacts with zinc to form zinc chloride. This is then emitted with the flue gases and can be taken care of appropriately. Organic substances such as paints, for example, can also be burned off. The preheated scrap that is surface cleaned of zinc can then be used in the integrated steel production process. The process and its connection to an LD converter within an integrated steel process are shown in figure 1.

Contents

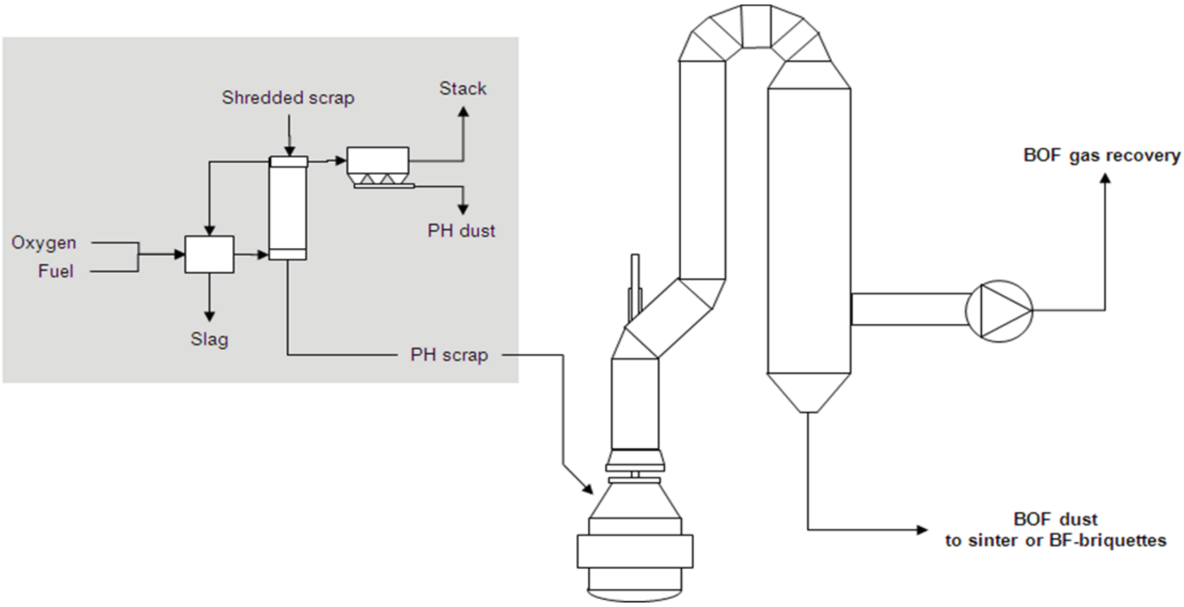

Figure 1 Schematic diagram for connection of the surface cleaning process to an LD converter (BOF, basic oxygen furnace). The preheating oven with flue gas cleaning and dust collection (PH dust) is shown on the left. "PH scrap" is the flow of preheated scrap. "PH dust" contains zinc for recovery.

The function-descriptive model

To define the data requirement for the environmental analysis a simplified schematic diagram is drawn in modular form, using the system description as the starting point. What is of interest for the environmental analysis are the in- and outflows from each process step, according to figure 5.1. For the scrap preheating process, the function-descriptive model may appear as in figure 2.

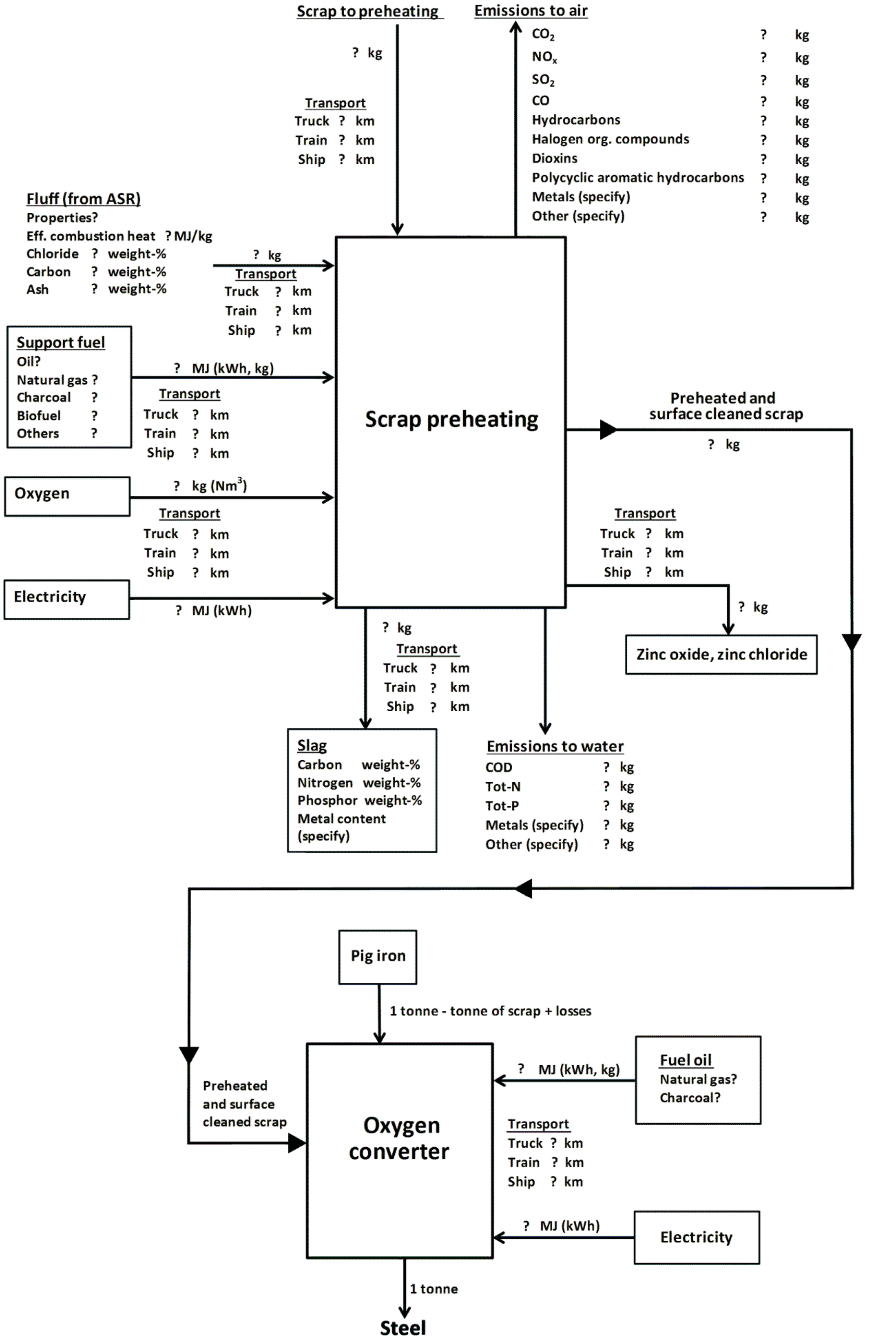

Figure 2 Draft of function-descriptive model for environmental analysis of surface cleaning of steel scrap in an integrated steel plant.

The primary function is to obtain steel and 1 tonne of crude steel is chosen as the functional unit. If one considers the system model it appears probable that the greatest environmental effects are caused by the operation of the preheating. Furthermore, the transportation of scrap and shredder residue can have an influence here. How much this affects the environmental impact value depends on how far, and by which transport mode, these products are transported and how much fluff is required. It is important to find out how much preheated scrap can be charged per tonne of steel that is produced. To then be able to calculate the scrap preheating step requires data on how much steel scrap, in practice, can be charged and how much fuel (fluff) this requires.

The shredder residue or auto fluff is regarded as a waste product and the only environmental impact comes from its transportation to the steelworks. The fluff's composition and its carbon content are needed in order to calculate the amount of carbon dioxide that arises on combustion. The amount of carbon dioxide is calculated on the basis of the carbon content in carbon dioxide, based on 1 kg of carbon emitting 3.67 kg carbon dioxide on combustion.

Preheated steel scrap increases the LD converter's requirement for scrap to cool the pig iron when oxygen is supplied. This has a significant impact on the environmental effects of the steel production as a consequence of a reduction in the amount of pig iron from iron ore that needs to be produced.

Where metallised steel scrap is preheated, the dust from the plant will contain zinc as an oxide or chloride. Whatever the case may be, one should take account of the amount of zinc and determine an environmental credit for this. This credit may be significant, especially if it is easier to recycle in this case than from steel plants without a surface cleaning facility.

Any environmental impact caused by the need for fuel, oxygen and electricity is likely to be less significant. However, one should find out the estimated consumption of these utilities as well as how, and from where, they are obtained. This is necessary, for example, to calculate the environmental effects of the transportation and the electrical energy required. In figure 2, the process or substance designations within the frames specify that data must be collected for this process. Data relating to production and combustion of the fuel, production of oxygen as well as for transportation and landfill are to be found in different databases or literature sources, see appendix 2.

Formulation of the reference scenario (current technology)

The system, illustrated in figure 2, performs three functions:

1. Delivers 1 tonne of crude steel from an integrated steelworks
2. Treatment of a certain quantity of waste plastics
3. Treatment of a certain quantity of steel scrap

The reference scenario, which shall model the present situation, must deliver the same three services as the system that uses scrap preheating. One system, without scrap preheating, which meets this precondition, may look like figure 3 below.

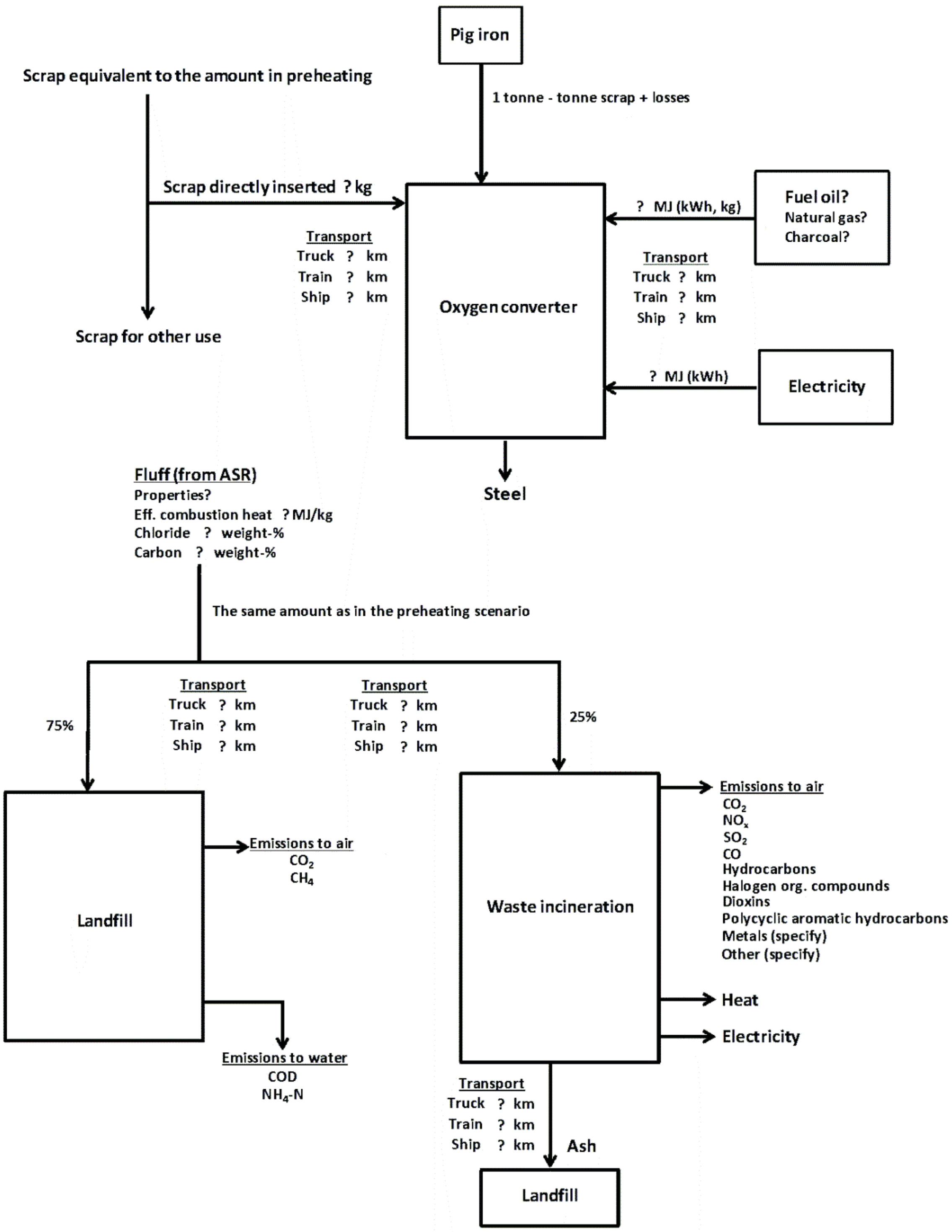

Figure 3 Model for the reference scenario for scrap preheating at an integrated steel plant.

In the reference scenario the steelworks will use more pig iron and less scrap than in the preheating scenario. Compared with this, one thus obtains a certain amount of surplus scrap which may be used for some other purpose.

It may be necessary to describe in more detail both the use of landfill and the combustion of the shredder residues. Auto fluff is an organic material and landfill gives rise to the formation of biogas which is a mixture of carbon dioxide and methane.

The biogas can be taken in hand for energy extraction, however if this is not the case it becomes the greenhouse gas emission that delivers the climate change effect. Methane is a potent greenhouse gas. 1 kg methane, over a hundred year period, has the same effect as 25 kg carbon dioxide. Furthermore, the decomposition of the organic material gives rise to other breakdown products, including ammonium salts of fatty acids, which leach out and produce eutrophication effects in surrounding watercourses. Landfill also utilises land resources and demands excavation with diesel-powered machinery. The burning of waste, in principle, gives the same emissions as during combustion in the scrap preheating oven. The incineration of waste, however, enables the extraction of district heating and electric power. The ash from the incineration process must, like the slag in the scenario with scrap preheating, be sent to landfill.

Both the scenarios fulfil now the three functions as specified. Despite this, they are not really comparable. They can generate additional assets of utility. The scenario with scrap preheating can yield zinc whereas the reference scenario can produce power and district heating. To take account of this it is possible to “credit” the environmental effects of these utilities by carrying out a so-called system expansion.

One estimates the environmental impact of zinc production according to a relevant procedure and then subtracts this from the environmental impact arising from the scrap preheating scenario (reduced environmental impact). In the same way, one can estimate the environmental impact from the generation of electric power and district heating in a way that is relevant for the locality where the shredder residue shall be taken care of as plastic waste; this impact can then be subtracted from the environmental impact for the reference scenario.

Definition of goal and scope of the analysis

It is only now, when the technical systems are set up and the data requirement for effectively describing them is identified, that the goal and scope of the study shall be formulated in a concrete and detailed manner.

Goal

The goal must be formulated so concretely that is “operative”. In the case in the example, an objective may be defined as follows:

To investigate if one can save resources and reduce emissions during steel production from pig iron, through introducing scrap preheating and surface cleaning in an integrated steelworks.

Scope – delimitations in respect of the biosphere

Here, the framework of the system is specified so that material and energy flows can be traced backwards and forwards. The main principle is that material and energy raw materials shall be followed backwards to their origin in natural resources. Products shall be followed forwards to their final disposal/treatment, which is that point where they are transformed into anther product's life cycle or are emitted to the biosphere. Deviations/exceptions can be made, for example, for process lines that are identical in two compared cases, or where one wishes to know a product's environmental impact up to the time when it is delivered from the production plant (factory gate).

For the example case, the following may apply:

The system limit upstream is extraction of ore for production of pig iron and extraction of raw materials for other added materials and used energy resources such as electricity, oil etc. Auto fluff is classed as a residual product and is only burdened with an environmental impact from the transport journey to the steelworks.

The production of the plastic material is allocated to the particular product where the plastic was incorporated. After all, the plastic cannot be recycled into a new product of the same type. The metal scrap's environmental impact value is limited to transportation to the steelworks. At the other end of the process, we do not allocate any credit for the environmental value of the recycled steel from crude steel or excess scrap in the reference scenario. Downstream, we are able to set the system limit for the steel to the extraction from the LD converter. The subsequent processing is not affected, whether or not scrap preheating takes place. In other respects, the system limits downstream are the final treatment of waste products. This means that the environmental impact from landfill of slag and ash shall, in principle, be included as well as landfill and combustion of shredder residue.

The system expansion in order to take account of the extraction of zinc, district heating and electric power is scenario dependent and may produce varying results.

Scope – delimitations of environmental impact analysis

Which environmental impact categories shall be included in the analysis are determined, in the first place, by the question asked/formulated. The more categories that are taken into account, the greater the assurance one has that essential aspects are not overlooked. For a heavy process industry, where energy utilisation is an important factor, a rough analysis can often be limited to the following categories:

- Use of primary energy resources, divided into non-renewable and renewable resources.
- Use of non-renewable material resources.
- The climate change effect, i.e. the emission of greenhouse gases.

This delimitation means, in the case in question that we can in practice overlook the landfill of inorganic materials, such as ash and slag. The climate change effect to which these give rise comes from the use of diesel in excavation machinery and should be negligible in a preliminary estimate. The essential environmental impact from the landfill of inorganic material is the ecotoxic effects from metals and the effects of eutrophication from the nutrient salts of nitrogen and phosphorus in the leachate from landfills. These aspects are disregarded through the demarcation of the system boundaries. On the other hand, we cannot disregard the landfill of plastic waste in the reference scenario. Here there may be a greenhouse effect from the organic material.

Scope – delimitations in time

An environmental impact analysis of a process naturally loses its relevance subsequently, since both the studied process and the technologies that provide the process with energy and input goods undergo development over time. One should, therefore, attempt to indicate during which period of time the data used is collected, and if the data relates to the best available technology or just average technology.

For the case in the example, it is like this:

The data that, at the time of writing, is available for the scrap preheating procedure will come from the pilot study carried out during 2009. There is no data from an actual plant. The development of the process is underway.

Data for production of pig iron is representative for the company SSAB in 2005. Data for other materials and energy products which we can obtain from different sources (databases) is of varying relevance. In general, it reflects the average technology available during the period 1995 – 2005.

Scope – geographical delimitations

The geographical location of the process is of significance in several respects. Logistics, that is to say transport routes and transport modes, for raw material supply and product deliveries are naturally affected. Furthermore, the localisation is significant for the environmental impact from the electricity supply.

For the case in point, we assume that the scrap preheating process is introduced at an integrated steelworks in Sweden and we have chosen to work on the basis of Swedish average data for the electricity production.

The functional unit

Since the goal of the study in the example case is the environmental impact from steel production, it is the production of steel which is the utility in focus. It is natural to choose 1 tonne of steel as the functional unit.

Contents

The inventory

After the system and the goal are stipulated, the next step is to make an inventory of and compile the data required in order to be able to produce a differential calculus for the existing and the new process.

The core processes

The core processes are those processes that are modified in the process development. For these, the inventory consists of filling in data on those items where a need for data is identified in the model produced.

For the example case, raw data may appear as in figure 4 and figure 5.

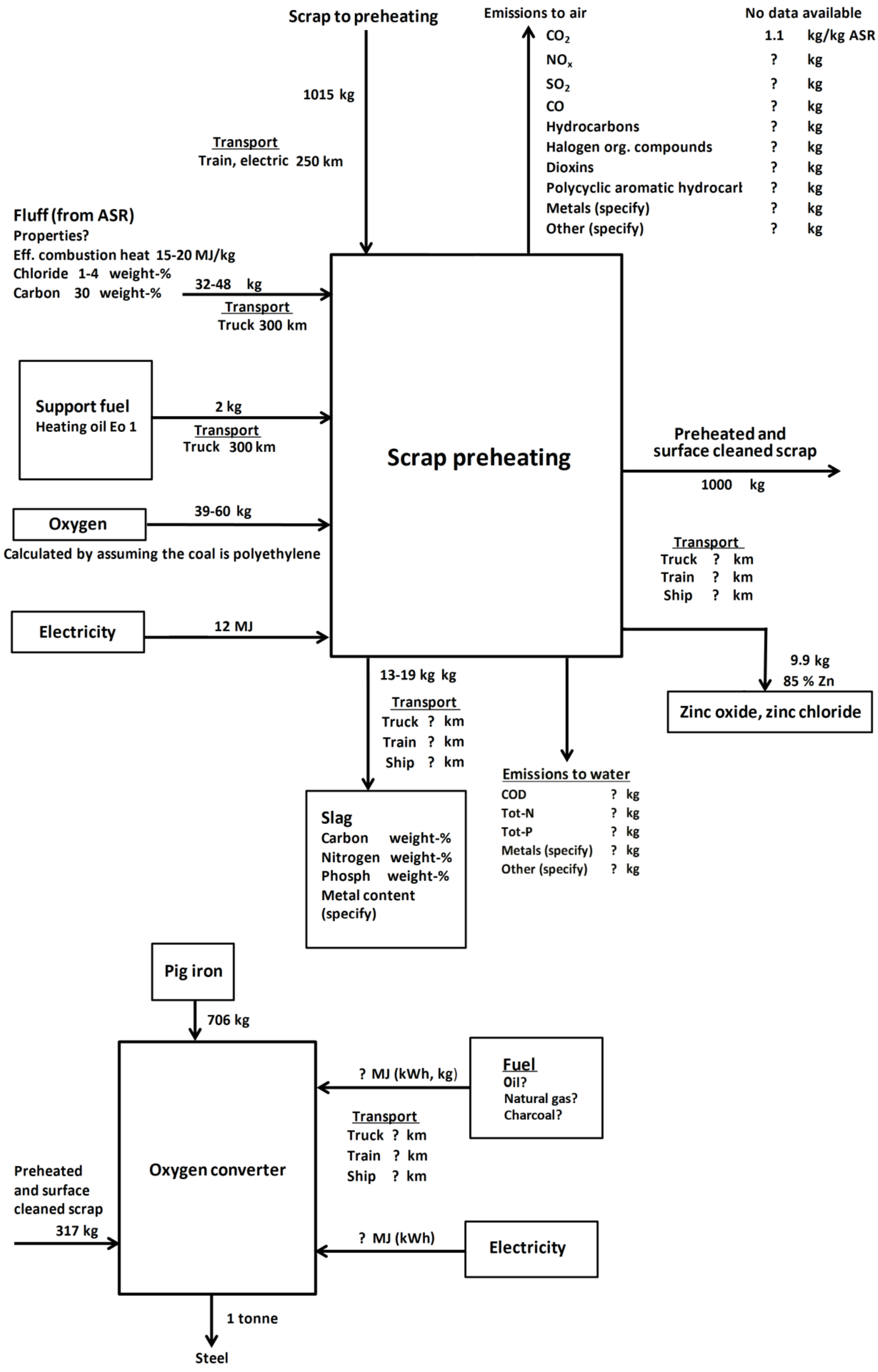

Figure 4 Inventory data for the core processes on scrap preheating.

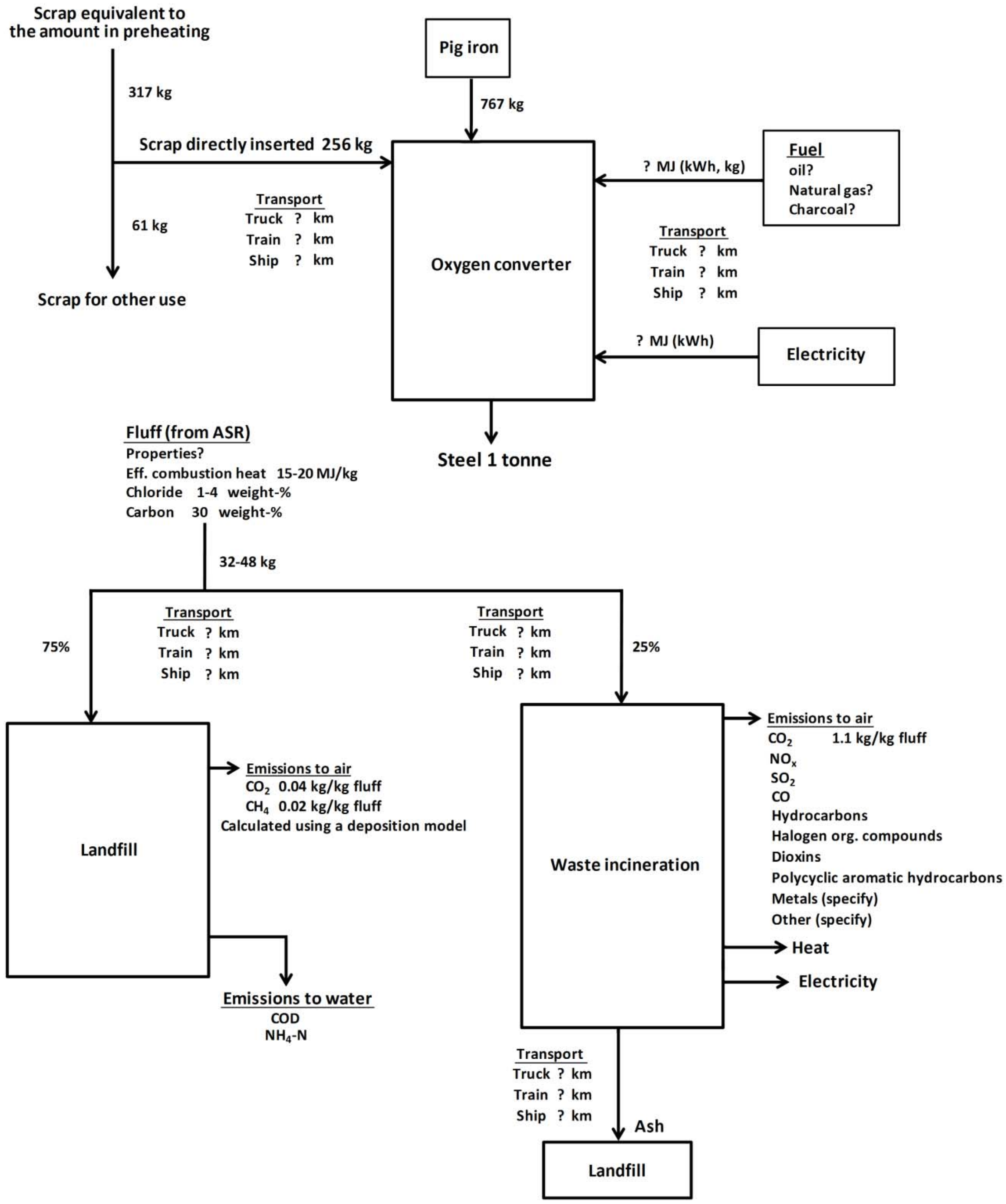

Figure 5 Inventory data for the core processes in the reference scenario.

For the scrap preheating itself, there is an incomplete material balance based on 1 tonne treated scrap.

The first task is to fill in substantial data gaps. One large gap is the lack of emission data from the pilot plant. Since our analysis shall only cover resources and the climate change effect, which mainly comes from combustion, it is sufficient to calculate the carbon dioxide emissions from the scrap preheating oven. This is carried out with the aid of the carbon content in auto fluff and the carbon content in carbon dioxide (1 kg carbon => 3.67 kg carbon dioxide). With a carbon content of 30 %, this gives 0.3 x 3.67 ≈ 1.1 kg CO_2/kg fluff.

After the above calculation it is now possible, with the help of the given inventory information, to calculate data for the most essential environmental aspects, that is to say the operation of the preheating oven and the production of pig iron. Scrap preheating means that for one tonne of crude steel a total of 317 kg of scrap must be preheated. Of this quantity, 256 kg is needed even if there is no scrap preheating. With scrap preheating, an additional 61 kg scrap must be transported to the steelworks. Consumption of 15 kg auto fluff occurs for the preheating of 317 kg (0.317 x 48 kg), if we calculate the maximum specified amount of auto fluff. Quantities of other consumables that are needed are calculated in the same way, through downscaling of the quantities per 1 000 kg scrap. On incineration of fluff there is a release of 15 x 1.1 = 16.5 kg carbon dioxide of fossil origin to the atmosphere. However, thanks to the extra addition of scrap we are able to save 61 kg of pig iron.

The environmental burden avoided from the production of this amount is surely the most significant environmental aspect, when compared to the reference scenario. This environmental burden must be calculated with the aid of a model for iron production from iron ore. The model shall include the process steps shown in figure 6.

Data for the production of pig iron from iron ore via the blast furnace is best obtained for Swedish conditions, e.g. from SSAB. This company has complete inventories and calculation models for steel production, divided into the different process steps, from ore extraction to final processing.

Furthermore, we avoid the need to take care of 15 kg plastic waste in the form of auto fluff from ASR. In this way, we avoid emissions of carbon dioxide and methane from waste handling (combustion and landfill). These emissions are probably the second most significant environmental factor which can be avoided, compared to the reference scenario.

The major part of the auto fluff goes to landfill in the reference scenario, whereby subsequently a part of the organic content is broken down anaerobically during formation of methane and carbon dioxide.

To be able to estimate the climate effect from this scenario we must, therefore, estimate the amount of these emissions. The environmental impact in the case of landfill occurs over a long time. As a convention, one normally chooses a period of time of 100 years, which is regarded as the foreseeable future. Data for calculation of emissions from landfills can be obtained from databases and literature sources, see appendix 2. The data we placed in figure 5 is an estimate for polyethylene and PVC plastic. (As you can see, only a fraction of the carbon in the plastic is converted into emissions for the foreseeable future. From a climate change viewpoint, a landfill functions as a carbon sink). A smaller portion of the plastic undergoes incineration in a waste incineration facility. There are models for calculation of emissions from waste incineration. Since we limit our analysis to the climate change effect, we need only calculate the carbon dioxide emission.

The LD converter in itself is a significant environmental factor. However, there is no information on how the LD converter is affected by an increased scrap input. We assume, therefore, that this utilises the same amount of fuel and electricity in both the scenarios.

Consequently, we can in the analysis disregard the converter's energy use and the emissions from this.

A data gap of less significance is the lack of information concerning how much oxygen is required for the preheating oven. One can obtain a rough estimate of the oxygen requirement for combustion through assuming that the plastic in the auto fluff is polyethylene and calculating the theoretical oxygen requirement with the aid of the specified carbon content and the following reaction formula:

$-CH_2- + 1.5O_2 \rightarrow CO_2 + H_2O$; 1 kg C in polyethylene => $1.5 * 32 / 12 = 4$ kg O_2

The transportation of auto fluff and extra scrap is probably of lesser environmental significance, given the transport distances and amounts reported.

Zinc extraction from the fluff can in itself deliver a significant environmental benefit, if the extracted zinc can replace zinc from zinc ore. Since this is unclear at the time of the analysis, the cautious assumption is made that no zinc extraction takes place in relation to the reference scenario. For the same reason, we disregard the possibility of generating district heating and electric power from the combustion of auto fluff in the waste incinerator.

Ash and slag landfill can be ignored, bearing in mind the delimitations that have been made. The only climate change gases that these processes give rise to derive from the use of diesel oil in machines. These emissions ought to be negligible in the overall context.

The inventory of the core processes in both cases may, in this case, be summarised in a model as illustrated in figure 6.

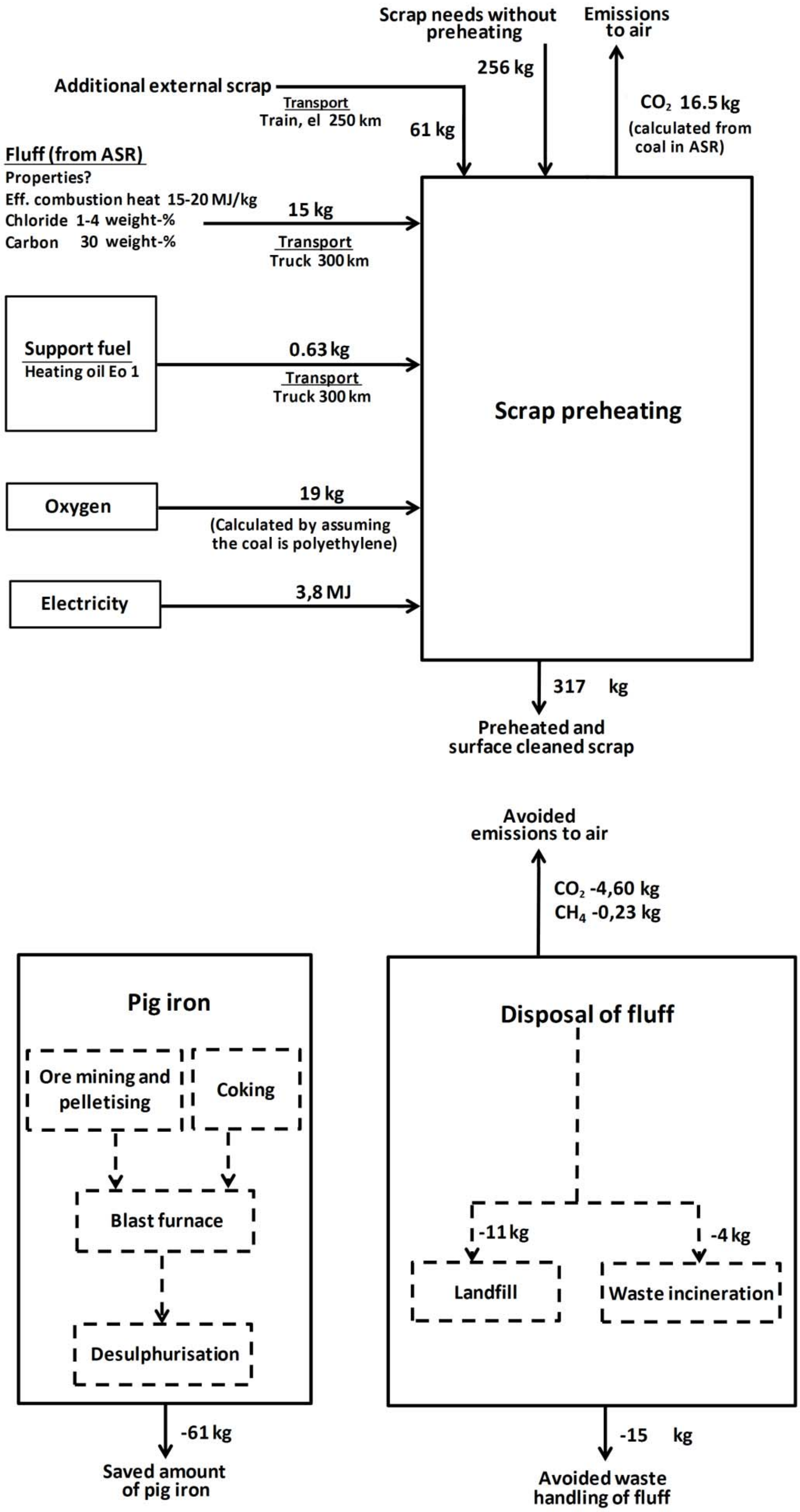

Figure 6 Final model for analysis of scrap preheating. All data here relates to 1 tonne of crude steel from the LD converter.

Contents

Peripheral processes – upstream and downstream processes

Data for the production of raw materials, chemical inputs, energy and transport journeys can be obtained from different databases and literature sources, see appendix 2.

Calculation of results

If one has available one of the specialised LCA software tools that are available on the market then this simplifies the calculation work. For simpler systems one can, nevertheless, also use Excel. Each process module may then be represented by a worksheet. The worksheets are then linked to one another.

In the example case, the models and calculations were made using GaBi which is an advanced software tool. The graphic interfaces for the models are shown in the figures 7 and 8.

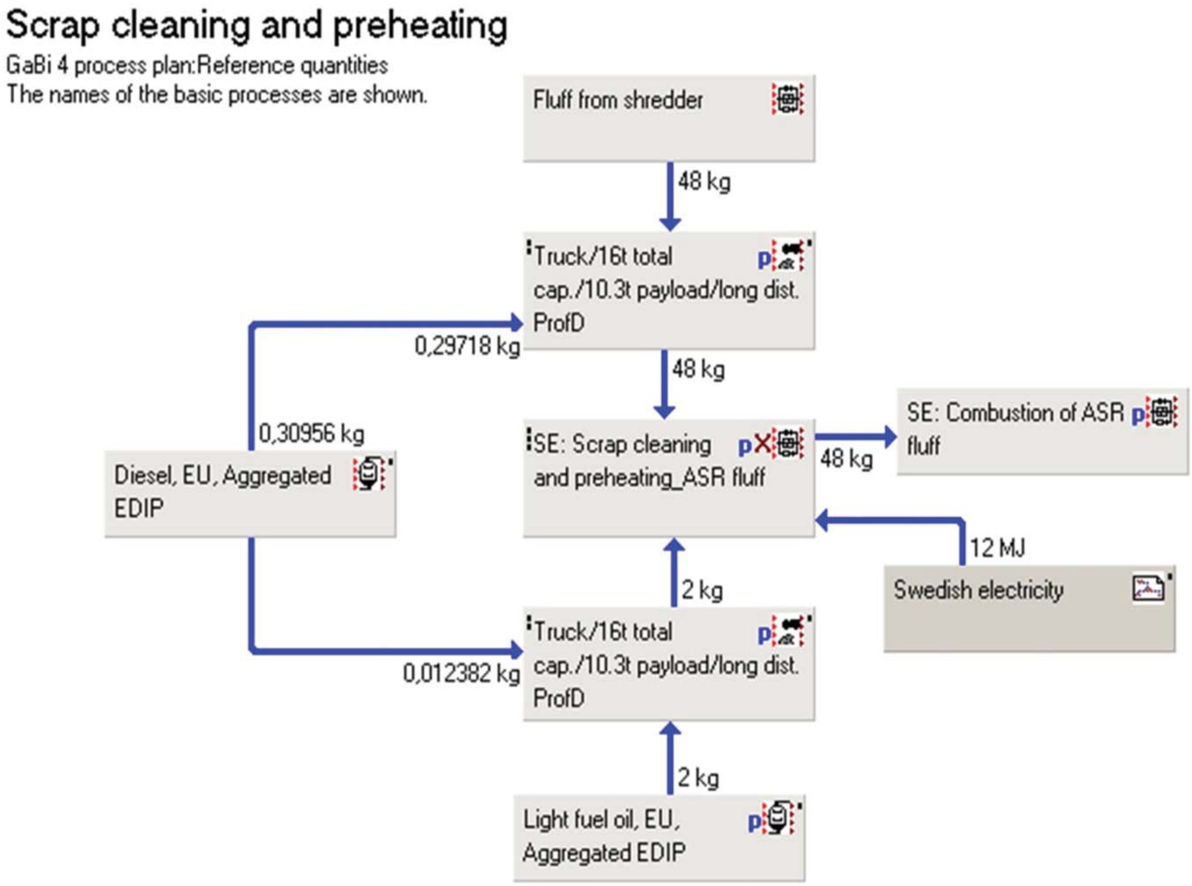

Figure 7 Flow chart for scrap preheating oven in GaBi 4. The diagram is based on 1 000 kg preheated scrap.

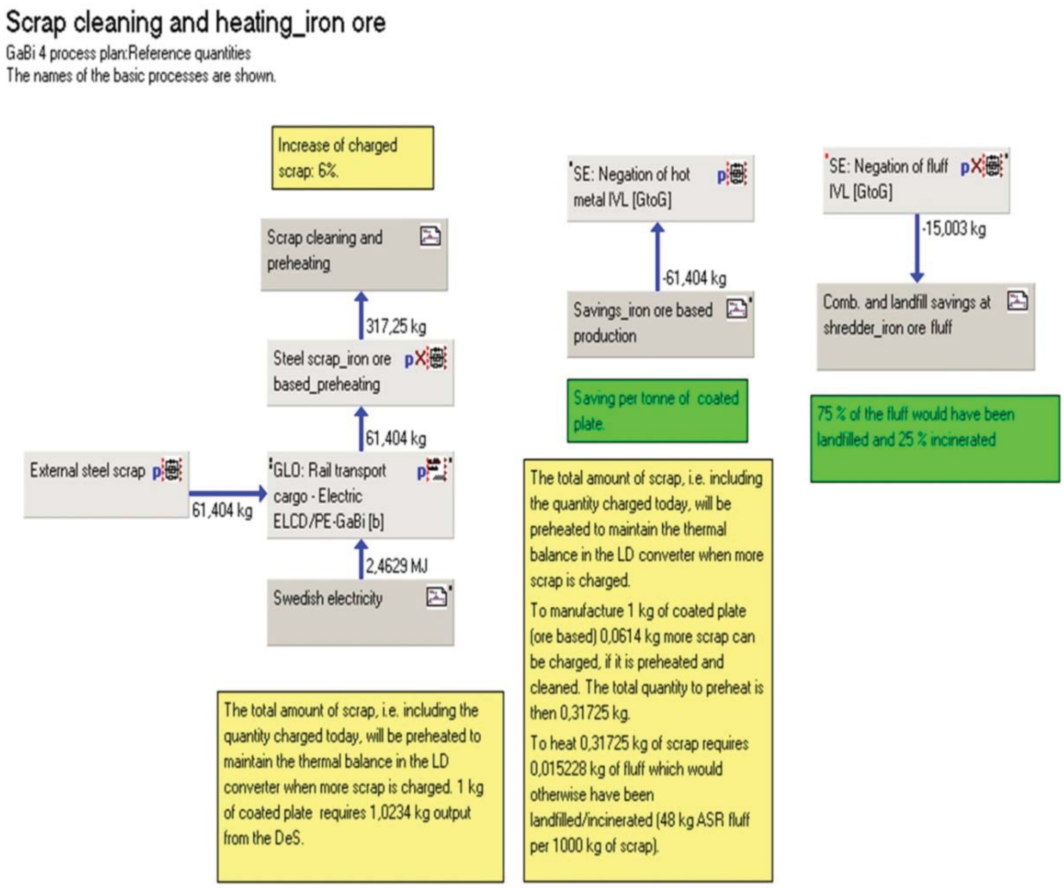

Figure 8 Flow chart for the compendium model in GaBi 4. Scrap preheating has been aggregated here into a single module. The modules for production of pig iron and waste handling of fluff are likewise aggregated, underlying the flow chart. The same applies to the electric power module for Swedish electricity.

In the GaBi models, the data for the peripheral processes has been entered directly in the form of complete process modules (*diesel, light fuel oil, truck, rail transport*). These can be obtained from databases linked to GaBi. Other models, that one has built up oneself in previous steps and which are used as a foundation, may also be added as a single module (*Scrap cleaning, Savings iron ore based production, Combustion and landfill at shredder, Swedish electricity*).

To show how one can add in Excel, it is possible to take figure 5 as starting point and calculate the end result for the climate change effect. Data from databases can, as a rule, be obtained in the form of Excel tables instead of modules from databases in LCA software. In figure 9 data is reproduced for scrap preheating, including the extra transportation, in the form of an Excel table.

The original table contains a large number of parameters. What is retained is the input (data entry) of scrap and energy resources, the yield of cleaned and preheated scrap as well as the most important emissions that contribute to climate change (the greenhouse effect). Data in the table is per 1 000 kg of charged scrap.

In the same way, data is compiled for pig iron per 1 000 kg iron that enters the converter. For the sake of simplicity, only climate change emissions have been included. Furthermore, data for waste management per 1 kg auto fluff, after shredding, has been collected. Of this 1 kg of auto shredder residue (ASR), 0.75 kg is sent to landfill and 0.25 kg to waste incineration.

Scrap preheating, including transport of extra scrap, per 1 000 kg scrap for preheating

Inputs

Flow	Quantity	Amount	Unit
Fluff from shredder_MEFOS [Waste for recovery]	Mass	47.293	kg
Steel scrap (total, external) [Waste for recovery]	Mass	558.098	kg
Steel scrap, internal [Waste for recovery]	Mass	441.962	kg
Steel scrap, (additional external) [Waste for recovery]	Mass	193.56	kg
Coal [Hard coal (resource)]	Mass	0.016	kg
Coal (22 MJ/kg) [Hard coal (resource)]	Mass	0.096	kg
Crude oil [Crude oil (resource)]	Mass	2.503	kg
Energy unspecified (APME) [Energy resources]	Energy (net calorific value)	-0.0212	MJ
Energy unspecified (APME) (Copy) [Energy resources]	Energy (net calorific value)	-0.00328	MJ
Hard coal [Hard coal (resource)]	Mass	0.0466	kg
Lignite [Lignite (resource)]	Mass	0.00445	kg
Lignite, fuel [Lignite (resource)]	Mass	0.0317	kg
Natural gas [Natural gas (resource)]	Mass	0.0121	kg
Natural gas, fuel [Natural gas (resource)]	Mass	0.136	kg
Natural gas, raw material [Natural gas (resource)]	Mass	1.46E-05	kg
Primary energy from hydro power [Renewable energy resources]	Energy ren. (net calorific value)	9.398	MJ
Primary energy from wind power [Renewable energy resources]	Energy ren. (net calorific value)	0	MJ
Soft wood, dry matter, fuel [Renewable energy resources]	Mass	4.62E-08	kg
Uranium in ore [Uranium (resource)]	Mass	7.40E-05	kg
Uranium natural [Uranium (resource)]	Mass	2.93E-06	kg
Wood [Renewable energy resources]	Mass	0.089	kg

Outputs

Flow	Quantity	Amount	Unit
Cleaned and preheated scrap [Waste for recovery]	Mass	985.281	kg
Carbon dioxide [Inorganic emissions to air]	Mass	54.371	kg
Methane [Organic emissions to air (group VOC)]	Mass	0.0106	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	3.73E-05	kg

1 000 kg pig iron saved

Outputs

Flow	Quantity	Amount	Unit
Hot metal [Metals)	Mass	1000	kg
Carbon dioxide [Inorganic emissions to air]	Mass	1420	kg
Methane [Organic emissions to air (group VOC)]	Mass	1.18	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	6.02E-02	kg

1 kg fluff (from ASR) from shredding to waste management

Outputs

Flow	Quantity	Amount	Unit
Carbon dioxide [Inorganic emissions to air]	Mass	0.305	kg
Methane [Organic emissions to air (group VOC)]	Mass	0.0153	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	8.18E-09	kg

Figure 9 The three scrap preheating modules, including transportation of extra scrap, production of pig iron and waste management of fluff in Excel format. The tables are extracts from the complete tables.

In the next step, the three tables in figure 9 are rescaled to the functional unit, 1 tonne of crude steel. This has been carried out for the climate change emissions in figure 10. For each module the data table is multiplied by a scale factor. This is also what happens in LCA software.

Scrap preheating including transport of extra scrap, per 1000 kg scrap from oxygen converter				
Outputs	**Scale factor**	**0.322**		**Climate impact**
Flow	**Quantity**	**Amount**	**Unit**	**kg CO_{2e}**
Cleaned and preheated scrap [Waste for recovery]	Mass	317	kg	
Carbon dioxide [Inorganic emissions to air]	Mass	17.49	kg	17.49
Methane [Organic emissions to air (group VOC)]	Mass	0.0034	kg	0.085
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	1.199E-05	kg	0.0036
				17.58
Pig iron saved	**Scale factor**	**0.0614**		
Outputs				
Flow	**Quantity**	**Amount**	**Unit**	
Hot metal [Metals)	Mass	61.4	kg	
Carbon dioxide [Inorganic emissions to air]	Mass	87.19	kg	-87.19
Methane [Organic emissions to air (group VOC)]	Mass	0.072	kg	-1.81
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	0.0037	kg	-1.10
				-90.10
Saving in waste management of fluff (from ASR)	**Scale factor**	**15**		
Outputs				
Flow	**Quantity**	**Amount**	**Unit**	
Carbon dioxide [Inorganic emissions to air]	Mass	4.58	kg	-4.58
Methane [Organic emissions to air (group VOC)]	Mass	0.23	kg	-5.74
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	1.227E-07	kg	-0.000037
				-10.31
Characterisation factors for climate change effect				-82.83
kg CO_{2e}/kg substance				
Carbon dioxide [Inorganic emissions to air]	1			
Methane [Organic emissions to air (group VOC)]	25			
Nitrous oxide (laughing gas) [Inorganic emissions to air]	298			

Figure 10 Calculation of reduced climate change effect per tonne crude steel on scrap preheating at an integrated steelworks.

In the lowest section above, there appears a so-called characterisation table for the greenhouse effect. This converts emissions of greenhouse gases to the joint scale of carbon dioxide equivalents. The factors here come from IPCC (*Intergovernmental Panel on Climate Change, 4th Assessment Report 2007*).

The characterisation tables are multiplied by the tables with the greenhouse gas emissions. The result is the table ‘Climate change effect’, where the contributions from all emissions can be totalled. The negative values denote emissions avoided.

In figure 11 the complete results, including resource savings, are shown.

	Unit	Savings (saving is indicated with minus sign)
Climate change effect	kg CO_{2e}	-82
Non-renewable energy resources	kWh	-490
Crude oil	kWh	-5.3
Hard coal + lignite	kWh	-480
Natural gas	kWh	-1.9
Uranium in ore	kWh	-1.9
Renewable energy resources	kWh	-0.72
Non-renewable material resources	kg	-180

Figure 11 Reduced energy use and avoided greenhouse effect with scrap preheating at an integrated steelworks. Data per tonne of crude steel after LD converter.

Shredder residue combustion for scrap preheating yields an inherently higher climate change effect than alternative waste handling; this is easily outweighed, however, by the savings one can achieve by using lower quantities of pig iron in the steel production. Even if one had taken into account the possibility of generating power and heat from waste incineration, the result would still have been that the climate change effect is diminished with scrap preheating.

The EU's long-term environmental policy assumes that the environmental performance of existing products will steadily improve, with the accent on the efficient use of natural resources. It is assumed also that companies will develop new products incorporating the same approach.

For steel, which is easily the world's most utilised metallic structural material, this means that it is especially important that the steel can be given a quantifiable environmental value from a life cycle perspective.

One may think that steel is fully developed but such is not the case; specialist steel grades are being developed on an ongoing basis and at an ever fast rate. From a sustainability perspective, the steel grades of today and tomorrow give ample scope for making energy and material utilisation even more efficient, and for delivering increased effectiveness and useful life to products that form the backbone of our society.

This book, that has arisen as a result of the environmental research programme called *The Steel Eco-Cycle,* shows examples of how products in steel, and how improvements in the steel production process, can be given an environmental impact value from a life cycle perspective. The examples chosen illustrate how one can produce quantitative data to facilitate decision-making. It is also intended to offer inspiration; to stimulate new thinking where sustainable development and the use of steel in society are concerned.

Through carrying out a Life Cycle Assessment (LCA), where account is taken of raw material extraction, production, use and handling of residual products as well as end-of-life recycling, one acquires an idea of both the larger picture and the smaller details.
It then becomes possible to implement measures where they deliver the greatest environmental benefit.

To carry out environmental evaluations from a life cycle perspective is a challenge, as much for environmental experts as for other researchers and engineers. At the same time, those who accept the challenge, learn the methodology and use it in their work stand to gain significant environmental and commercial advantages.

Price SEK 350

Students SEK 150

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