JERNKONTORETS FORSKNING

PROCEDURE FOR ENVIRONMENTAL RANKING OF MATERIALS FOR SELECTION PURPOSES

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SAMMANFATTNING

Målsättningen för detta arbete var att utveckla en bättre förståelse hur man kan ta hänsyn till miljön, mha ekoindikatorer, vid systematiskt materialval. En ekoindikator valdes till detta ändamål, Eco-Indicator 99: en metod för att bestämma den totala miljöpåverkan av en produkt. Eco-Indicator 99 data samlades från IdeMat och SimaPro, som innehåller stora materialdatabaser.

En analys utfördes av Eco-Indicator 99 värden för att bestämma enskilda legeringsämnenas miljöpåverkan. Med dessa data skapas ekvationer för att beräkna miljöpåverkan av metalliska material, där också användandet av recirkulerat material (skrot) beaktades.

Det var också av intresse att analysera de individuella bidragen till legeringsämnenas miljöpåverkan, vilket hjälper till att förklara miljöbelastningen. En tabell för varje enskilt legeringsämne skapades, där de största bidragande orsakerna listas.

Abstract

The objective of this work was to develop a better understanding of how to include the environmental aspect, with the use of ecoindicators, when systematically selecting material. One ecoindicator was chosen for this purpose, the Eco-Indicator 99 method: a damage oriented method for Life Cycle Impact Assessment. Eco-Indicator 99 data were collected from IdeMat and SimaPro, which hold large material databases.

An analysis was made of Eco-Indicator 99 values to calculate the environmental impact of single elements. Equations were established calculating the environmental impact of metallic materials. The use of recycled material was accounted for in the equation.

Individual contributions to the elements impacts were studied, which helps to explain the environmental load. For each element, a table was built that lists the main contributions to the environmental impact.

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1 Introduction

This Master Thesis, at the Royal Institute of Technology, examines the possibilities of using ecoindicators to take into account the environmental aspect for material selection purposes. The main aim is to set up models for the role of single elements on the total environmental load of a material, and develop equations to calculate the environmental impact of any given material using the amounts and impact-values of the included elements. This makes it possible to compare a number of materials when making a selection, considering the environmental impact. When making a materials selection it is often the case of minimizing the expense, while satisfying the property requirements on the material. Ecoindicator allows calculating with the environmental impact as a property, when minimizing expenses. Therefore it is possible to calculate the cost of reducing the environmental impact with one unit (in this case Point/kg), making the material more environmentally friendly.

2 Objectives

The objectives of the thesis are to:
- Analyse ecoindicator data for a range of metals and set up models for single elements significance
- Create methods for calculating the ecoindicator value of any metal
- Create methods for including the environmental impact when selecting material

When these objectives are satisfied the hope is that the employment of ecoindicators can be increased.

3 Approach

The first step was to create a material database with property data and ecoindicator data, and to analyse the ecoindicator data to calculate the single elements significance and impact on the environment. With this information it is possible to build models to calculate the environmental impact of metallic materials, and to establish methods for including the environmental aspects when selecting material.

IdeMat and SimaPro were used, where ecoindicator data are available.

4 Delimitation

This work does not evaluate the ecoindicator method.

Only data from one ecoindicator, Eco-Indicator 99, is examined in this work. This is partly because of lack of published data and documentation on other ecoindicators. Other ecoindicators are presented shortly in the text.

5 Material selection and optimisation

Materials selection and optimisation aim to make the best out of a chosen material by adjusting the design. Factors that control the choice of material are decided by the application. It can be divided into different steps.

The first step is to formulate a function specification for the application, similar to any function specification in design but with emphasis on the material. The specification should contain items such as:
- Description of the products or components function and purpose
- Planned life and performance
- Limitations in geometry
- Conditions of thermal and chemical surroundings
- Mechanical load
- Demands on environmental impact and adaptation of cycle

From the function specification the design criteria are derived, where more precise conditions on the properties are specified, such as stiffness, strength, geometry etc.
The design criteria form the basis of estimating what types of materials are possible for the application. A number of proposed material types, manufacturing processes and design configurations are listed and the second step: pre-selection is made.

Since property data of materials may be limited, it is wise to set up the function properties criteria in terms of common properties found in material databases, such as elasticity, tensile strength, maximum/minimum employment-temperature etc. It is also important to take advantage of experiences of use of materials for similar components and applications.

If the chosen material is to function as a part of a component or a complete product, it is important to consider how it may influence the material choice of another component or part. Or the other way around: the choice of material in one part may be influenced by the material in another part to make recycling possible. For example by choosing the same material for several parts of a component it may be possible to recycle, which may compensate that the material may not be the most optimal choice looking at the production cost. Material selection demands a systematic approach and the choices for individual parts must not be looked at in isolation but as a series of choices.

The third step is to form a complete profile of the requirements for the material and to identify the most suitable material grades and designs of the component. Knowledge about the materials is very important in this step. It is preferred to begin with knowledge of the material types, before more precise requirements to the material are formed, to recognize how different types of materials behave in certain environments and with different treatments. The environmental load of the material is also of importance here, and it is like other properties dependent of the material type.

The demand profile of the material concerns the following areas:
- Production – where properties such as possibility of processing and working the material etc, are related.
- Function – depending of the employment purpose different properties can be of interest, such as tensile strength, colour and electrical properties.
- Reliability and lifetime – depending on the components environment, properties like chemical and physical resistance.
- Environmental load – concerning properties like toxicity and what substances are emitted affecting the soil and atmosphere etc.
- Adaptation to cycle – possibilities of recycling and related properties like waste treatment are included.
- Availability –material and processes.

The result is preferably a list of interval values of different material properties that form the demand profile. To be able to use material databases and documentation it is of importance both that the requirements are expressed in properties found in databases and documentation, and that the data is quantitative.

All requirements in the profile must be met for a material to qualify as suitable for the component. Earlier knowledge and experiences of materials in similar components are of value to verify that the result is reasonable, and that the requirements set seem correct. For example, a material used for such components earlier should fit the requirements.

The de-selection step in materials selection involves eliminating unsuitable material. Material databases are well suited for this, since all material data are collected in one place, and it is possible to list and sort a large number of materials by set properties. A common weakness with material databases is that they are sometimes incomplete and some data of a certain property could be missing. Therefore other sources of documentation could be necessary as a complement, such as information from a manufacturer.

There is now a list of materials matching the requirement profile from step three, and the last step is to find the most optimal choice of material. A quantity to be optimised is chosen, with a so-called target function or objective function. For example the weight could be minimised or a specific property maximised. It is very common to minimise the cost. Constraints are set on specific properties or costs etc. Manufacturing often plays a large role, and constraints could be set on an expensive process. This is very useful also in an environmental point of view, where constraints could be set on a property that have a substantial load on the environment. With the trade-off method, a term is added to the target function, which increases or decreases with a specific property. When the target function is optimised, the influence of the

property is taken into account. It could, for example be about a manufacturing process that emits toxic substances that is carcinogenic or weight-savings to reduce transportation that pollutes the environment. This trade-off method could be used for other purposes as well that includes savings or reductions etc [1].

6 Environmental impact in materials selection

There is a wide spread consciousness today about the environmental issue when choosing material. The traditional way of addressing this is to make a full Life Cycle Assessment (LCA). Such LCA is made for one product or material and is typically a very extensive analysis. It includes every aspect from raw material and production, to use and recycling or deposition. Therefore it is not very well suited for the purpose of materials selection and optimisation, which could deal with hundreds of materials to make an accurate choice. It would demand too much resources and material developers could instead end up choosing a material that may not be the optimal, but that has been used before, and therefore have extensive knowledge and data of.

Ecoindicators are methods that are used as the basis for calculating the probable environmental impact, in the form of ecoindicator points, for materials and processes. They are built on LCA data, where the entire processing chain of materials, processes, transports, recycling etc. is taken into account. There are several different ecoindicators today.

Ecoindicators could serve as an appropriate method of ranking the environment for materials selection purposes. Since data for different materials are very easy and quickly calculated, it is possible to make comparison between a large number of materials, which is needed in materials selection. Also the data for different materials are calculated in the same way, using the same method, which makes a comparison of data for different materials more accurate. And the number of assessments is minimized, and the method is built so that the most critical assessments are made in the end. This makes it easier to understand and possible to adjust the assessments to fit a certain area. Since any changes alter the result, it is important that they are made systematically.

Choosing material in a systematic way requires access to extensive data of a number of materials. This also applies to the data of the environmental load.

IdeMat and SimaPro provide data for the analysis. They are software tools and databases, with data built on the Eco-Indicator 99 method.

The Eco-Indicator 99 is a "damage oriented" impact assessment method. It is the basis for the calculation of ecoindicator points for materials and processes. These can be used as a design for environment tools for designers and product managers. A large team of experts from 1997 to 1999 has developed the Eco-Indicator 99. The Dutch Ministry of Urban Planning, Housing and the Environment (VROM) as part of the Product Oriented Environmental Management policy commissioned the project. Further detailed description of Eco-Indicator 99 is found in chapter 8.

7 Databases

The data on materials and Eco-Indicator 99 used in this work are collected from the databases in IdeMat and SimaPro.

7.1 IdeMat

IdeMat is a product by Delft University of Technology, Netherlands. It is designed for materials selection purposes, in the early stage of the design process. A database with information on more than 400 materials, processes and components makes it possible to perform a proper selection, which requires data on a large number of materials to be accurate.

The materials are categorised into different types, such as ceramics, ferro metals, non-ferro metals, etc, which are also categorised into subcategories. For example for ferro metals there are subcategories cast iron, stainless steel, high grade steel, etc. Processes and components are categorised as well.

When chosen a category, a subcategory and a material, all information about it is presented in the same window:
- *Category*, what is significant with the category it belongs
- *Subcategory*, what is characteristic with this type of materials
- *Properties*, price, Young's modulus, tensile strength, density etc.
- *Application*, what types of application it is suited for
- *Composition*, amounts of different elements
- *Environmental data*, with Eco-Indicator 99 among other data represented
- *Process description*, illustration of the production chain
- *Input-output*, for 1kg material, what goes in and what comes out (amounts of emissions, minerals and other substances)

It is also possible to add or change data to the database. For example, add a new material, processes and components, new properties, technologies and applications etc.

IdeMat provides a filtering function that lets the user search for materials that match a given criteria. Criteria can be an upper and/or lower bound for materials properties, materials for an application, materials process technologies, and specific categories and subcategories.

It is also possible to compare materials, processes and components. Either compare one property (or environmental indicator or principal number) in a "High-low graph", or a combination of two properties in a "Scatter gram", or one or more properties in a "Table" [2] [3].

7.2 SimaPro

PRé, Product Ecology Consultants in the Netherlands designed SimaPro. It is a Life-Cycle Assessment (LCA) tool, where it is possible to collect, analyse, model and monitor environmental information for materials, products and services. SimaPro follows the ISO 14040 series standards.

SimaPro includes several inventory databases. There are, in the version used, 9 databases available, providing inventory data and/or scripts in different areas:

- ETH-ESU 96, transport, processing and waste treatment
- BUWAL 250, packaging materials, energy, transport and waste treatment
- Industry data, inventory data
- IDEMAT 2001, engineering materials, energy and transport
- Franklin US LCI database, North American inventory data
- Data archive, materials, energy, transport, processing and waste treatment
- Dutch Concrete database, concrete production and use in the Netherlands
- IVAM, materials, transport, energy and waste treatment
- FEFCO, corrugated board production

Data on materials, energy, transport, processing, use, waste scenario and waste treatment are found categorised and subcategorised, similar to IdeMat. Choosing to view information about a material opens a new window, with documentation, system description and input-output data on the material. From here it is possible to get a graphic tree on the different process steps of the material, or compare specific data on the material with others. It is also possible to further analyse the material. With a so-called "LCIA[1] Profile", environmental data on characterization, damage assessment, normalization, weighting are presented in either a chart or table. The "LCI[2] Results" and "Process contributions" lists the substances and the process steps contributing to the environmental load from the production of the material. Figures of how much impact they have on the ecoindicator value are listed, and for the substances, also amounts.

SimaPro contains extensive environmental data from the Eco-Indicator 99 method. Other methods also provided by the tool are: Eco-Indicator 95, CML 92, CML 2 (2001), EDIP/UMIP, EPS 2000 and Ecopoints 97 [4] [5].

8 Eco-Indicator 99

The Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) commissioned the ECO-INDICATOR 99 project. Eco-Indicator 99 was developed through evaluation groups of experts as an update of the Eco-Indicator 95 method. But although its similar names and the fact that they are built on similar methods, it is an entirely new ecoindicator. The two are not compatible, which means that it is not possible to compare old data with new, nor is it possible to give a conversion factor.

This chapter will go into the methodology of calculating the Eco-indicator score, and the different categories it is divided into. Other ecoindicator methods will also be described shortly.

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[1] Life-Cycle Impact Assessment
[2] Life-Cycle Inventory

8.1 Eco-Indicator 99 methodology

There are three basic steps to calculate the Eco-indicator score:

- *Inventory step*. What emissions etc from the process of making the product may cause an impact on the environment?
- *Damage step*. What damage does these emissions have on the human health, ecosystem quality and resources?
- *Weighting step*. What category is considered the most important of the three?

8.1.1 Inventory

An inventory is standard procedure when producing a LCA for a product, and it is the first step here as well. It is made to get to know the life cycle of the product. Three things are looked on in the different processes of making the product (in this case a material): emissions, resource extractions and land-use.

8.1.2 Damage

When the inventory is made there is the question of the damage of each emission, the resource extraction and land-use. There are models to calculate each one of these damages.

The damage model for emissions consists of fate analysis, to calculate the concentrations and the transfer of substances in the different compartments: air, water and soil. Then it is calculated how much of the substances are taken in by people and other living species, and what effects the exposures have in terms of different types of diseases and other effects. The effects are finally translated into the specific damage unit, depending on what category it belongs to: how many years of life lost or lived disabled, or what percentage of plants and species likely to disappear or exposed to toxic stress.

In the case of resource extraction it is assumed that mankind always extracts the best (richest) resources first. This leaves the lower quality resources for future extraction, which will demand a greater effort to extract the same amount of resource. The damage model is a matter of calculating the extra effort it takes to extract the resource. Fossil fuels are also included in this model. The damage unit used is "surplus energy".

Mankind occupies a large area of land, both for urban, agricultural and industrial use. This is a big environmental threat, most of all to the species diversity, since natural land is converted. Field observation studies have been made showing that the species diversity also depends on the size of a land-area. This means that the land-use does not only have a direct effect on the local area occupied, but it also has an indirect regional effect on the surrounding area, which becomes smaller. Therefore the species diversity decreases both locally and regionally. This is taken into account in the damage model for land-use, also measured in units of fraction of disappeared species.

8.1.3 Weighting

A panel of 365 people from a Swiss LCA interest group was asked to weight the seriousness of three damage categories: human health, ecosystem quality and resources. This way of weighting differs a bit from the traditional way, used when making an LCA, where the panel is asked to weight all the impact categories instead.

This is much harder for the panel since there are 10, or more impact categories, and it is hard to really understand and see the seriousness of each category.

The result from the weighting shows that the panel found damage to human health and ecosystem quality equally serious, while damage to resources was only half as serious.

8.2 Human health

Environmental factors in this category represent damages connected to the human health. They are measured in DALY (Disability Adjusted Life Years). The DALY system is a disability scale rated from 0 – 1, where 1 equals death. For example, a 10 years premature death for a person results in the value of 10 DALYs. The same scenario with two persons gives 20 DALYs.

The environmental loading categories connected to the Human Health category are carcinogenity and respiratory effects, effects of climate change, ionising radiation and ozone layer depletion.

8.2.1 Carcinogenity

IARC (The International Agency for Research on Cancer) has a classification system to group substances carcinogenity. All substances classified in groups 1, 2a, 2b and 3 are included when calculating the estimate of cancer incidence.

The cancer incidence is estimated using the Unit-Risk concept:
The unit risk factor for inhalation is an estimate of the probability that an average individual will develop cancer when exposed to pollution at an ambient concentration of one microgram per cubic meter for the individual's life (70 years).

8.2.2 Respiratory effect (organics)

The respiratory effects are divided into organic and inorganic substances, since the inorganics almost entirely represent the respiratory effects.

The substances found (through epidemical studies) to cause respiratory effects to humans are:
- Particulate matter
- Nitrate and sulphite primarily from emissions of NH_3
- SO_3 primarily from emissions of SO_x
- O_3 primarily from emissions of VOCs
- CO
- NO_x

Seriousness and duration of the diseases caused by respiratory effects are estimated to get the result in DALYs.

8.2.3 Respiratory effect (inorganics)

See 8.2.2 Respiratory effect (organics) for a description.

8.2.4 Climate change

Climate change is no real direct damage to human health, but predictions are that the greenhouse effect will cause considerable damage in the coming decades. To estimate the damages, models and possible scenarios are set up:

- Exposure to thermal extremes – may cause altered rates of heart- and cold-related illnesses and death.
- Effects on range and activity of vectors and infective parasites – may cause changes in geographic ranges and incidence of vector-borne diseases[3].
- Sea-level rise, with population displacement and damage to infrastructure – may cause increased risk of infectious disease and psychological disorders.

8.2.5 Ionizing radiation

Ionizing radiation refers to the damages related to releases of radioactive material to the environment. The carcinogenic and hereditary effects are most significant. There are three steps to estimate the damage of radiation:

- Calculate what dose a human actually absorb when exposed to given radiation levels.
- Establish the number of cases that occur as a result of the exposure.
- Calculate the number of DALYs per case.

8.2.6 Ozone layer depletion

Any emission of substance that depletes the ozone layer will contribute to damages to human health. It is the increase of UV radiation levels that may cause cataract and skin cancer.

The excess incidence or mortality of skin cancer and cataract as a result of 1% ozone depletion during one year is calculated. Start age of disease, average duration of the disease and disability weighting; help to form the translation to DALYs.

8.3 Ecosystem quality

Environmental factors in this second category represent damages to the ecosystem quality. They are expressed in PAF (Potentially Affected Fraction of species) and PDF (Potentially Disappeared Fraction of species). The damage is measured for the affected area in m^2 and for the number of years it takes for the ecosystem to restore back to 'normal', i.e. the original level.

The environmental factors connected to the Ecosystem Quality are effects from ecotoxicity, acidification and eutrophication, and land-use.

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[3] A disease that is transmitted to humans by an insect such as a mosquito or a tick is called a *vector-borne disease*. For example malaria and Lyme disease.

8.3.1 Ecotoxicity

To measure the damage from ecotoxicity to the ecosystem, there is a method of determine the Potentially Affected Fraction (PAF) of species to a specific concentration of toxic substances:

- Determine the temporary increase of the concentration in a specific environmental compartment for each specific substance.
- Determine the increase of toxicity from the concentration increase.
- Choose a reference value as the present level of toxic stress.
- Determine the temporary damage from the increase of toxicity.

This is made for each specific emission, for all environmental compartments, e.g. water, agricultural soil, industrial soil, natural soil.

8.3.2 Acidification/Eutrophication

Acidification and eutrophication are caused by depositions of inorganic substances into the water and through the air affecting the soil. Different sulphates, nitrates and phosphates in particular are the cause of the damage.

8.3.3 Land-use

The impact of land-use on the ecosystem is significant not only to the area used (local area), but also to the surrounding area (regional area), since the number of species increases with the area size. The land-use is measured in PDF (Potentially Disappeared Fraction) multiplied with the area and time span:

$$EQ = PDF * area * time = \frac{S_{ref} - S_{use}}{S_{ref}} * A * t$$

where: S_{ref} is the species diversity on the reference area type

S_{use} is the species diversity on the converted or occupied area

A is the area in m^2

t is the time in years

When an area is occupied or converted there is a restoration time also taken into account. This is the time for the land to restore back to its natural condition, or equal to.

8.4 Resources

The environmental factors in the third and last category represent damages to the quality of remaining mineral and fossil resources. They are measured in surplus energy (MJ) required for extracting the next one kg. Since extraction will decrease the quality of remaining resources it results in higher energy requirements.

8.4.1 Minerals

The most important quality parameter for mineral resources is the concentration. Parameters such as location are not taken into account in the model and effects from transporting minerals are not calculated.

8.4.2 Fossil fuels

The concentration parameter used for minerals is not useful for fossil fuels. Here is the "effort" to extract the resource used. The resource quality does not decrease as continuous as for minerals. It decreases more in a stepwise way. For example, when an oil finding runs dry there is additional drilling and pumping to be done to find a new resource. The average effort is taken over a period/amount, to get the surplus energy.

Use of fossil fuels also affects Climate change, and Respiratory effects and Acidification/Eutrophication, since use of fossil fuels result in pollutions of CO_2 (Climate change), and NO_x, SOx (Respiratory effects, Acidification/Eutrophication) [6] [7].

9 Other ecoindicators

9.1 EPS

EPS (Environmental Priority Strategies) is developed by IVL (Institute for Water and Air Conservation) together with the Federation of Swedish Industries, including Volvo who requested the development of an ecoindicator like EPS in 1989. EPS follows the requirements of ISO standard 14042. The system is aimed to be a tool for internal product development process in a company. Indices are not transparent and country specific. The system at present pertains mainly to Sweden. The latest version is called EPS 2000.

The EPS method is based on valuations. For each material an Environmental Load Index (ELI) is evaluated. This index assigns values to emissions and resource extraction based on five criteria:
- Biodiversity
- Human health
- Ecological health
- Resources
- Aesthetics.

These are named safeguard subjects. The indices are then multiplied by the materials loadings; emissions and resource extraction that are valued to one common unit together forming the materials loadings. The result is so called Environmental Load Unit (ELU), dimensionless units representing the materials environmental impact [8] [9].

The method has limitations being the safeguard subjects may vary a lot, because of valuation. For example, ozone layer depletion is very highly rated. Not all emissions are classified, which may result in falsely low values [10].

9.2 Ecopoint

Ecopoints is developed by BRE (Building Research Establishment) mainly for Envest: a tool designed to simplify the process of making environmentally friendly buildings.

This method comes from the critical volumes approach. Each environmental issue (13 in total) has their own unit. This makes it hard to make a comparison between them. Therefore each impact is weighted in relation to environmental quality targets, politically stated goals for the environment, working as a norm for each environmental issue. This norm derives from the total impact of one person (UK citizen). Results are calculated in dimensionless ecopoints, which are summed to give a single number, so called Ecoscore. The 13 different environmental impact categories are [11] [12]:

- Climate change
- Fossil fuel depletion
- Ozone depletion
- Freight transport
- Human toxicity to air
- Human toxicity to water
- Waste disposal
- Water extraction
- Acid deposition
- Ecotoxicity
- Eutrophication
- Summer smog
- Minerals extraction

One limitation is the fact that the method is based on politically stated goals for the environment in one specific country. The ecopoints are defined for one country's situation and political choices [10].

10 Data used

Two analyses were performed. The first one aims to calculate the impact of the elements in the materials (Analysis A), and the second one to calculate the cause of the impact of each element (Analysis B).

10.1 Analysis A: Element coefficients

A method is used based upon the assumption that the ecoindicator value is a direct result of its elements impacts. It could be expressed as a linear equation of the sum of the elements impacts, where each impact would be the product of the amount of element and a specific coefficient.

To calculate the specific coefficients for the different elements, ecoindicator data of approximately 150 materials, listed in Tables 1a-i, was collected from SimaPro to an Excel sheet.

Table 1a. Cast irons analysed.

AISI	DIN	Main composition (typical)
	GG-15	Fe, C 3.7, Si 2.4, Mn 0.5
	GG-35	Fe, C 3.1, Si 2.0, Mn 0.5
	GGG 40	Fe, C 3.7, Si 2.5, Mn 0.4
	GGG 60	Fe, C 3.6, Si 2.32, Mn 0.45, Cr 0.25, Mo ,1.0
	GGG 70	Fe, C 3.0, Si 2.4, Mn 0.5, Cr 0.5
	GGG-NiCr20 2	Fe, C 1.5, Ni 20.0, Cr 1.75, Si 1.85, Mn 1.1
	GGG-NiSiCr 20 4 2	Fe, C 1.5, Ni 20.0, Si 4.5, Cr 1.75, Mn 1.25
	GGL-NiCuCr15 6 2	Fe, C 1.5, Ni 15.5, Cu 6.5, Cr 1.75, Si 1.9, Mn 1.25
	GTS-35-10	Fe, C 2.3, Si 1.2, Mn 0.45
	GTS-65-02	Fe, C 2.3, Si 1.2, Mn 0.45
	GTS-70-02	Fe, C 2.3, Si 1.2, Mn 0.45

Table 1b. Stainless steels analysed.

AISI	DIN	Main composition (typical)
CA-15	GX12Cr14 (mart.)	Fe, Cr 13, Ni 1.0, Si / Mn 0.5, Mo 0.5,
CF-8	GX5CrNi 19 10 (aust.)	Fe, Cr 19, Ni 10.0, Si / Mn 1.0
304	M-X5CrNi 18 10 (aust.)	Fe, Cr 19, Ni 9.25, Si 0.5, Mn 1.0
410	X10Cr13 (mart.)	Fe, Cr 12.5, Si 0.5, Mn 0.5
	X10CrNiMoNb 18 12	Fe, Cr 17.5, Ni 13.25, Mo 2.75, Nb 1.65, Si 0.5, Mn 1.0
303	X10CrNiS 18 9 (aust.)	Fe, Cr 18, Ni 9.0, S 0.25, Si 0.5, Mn 1.0
416	X12Cr13 (mart.)	Fe, Cr 13, Si 0.5, Mn 0.875
301	X12CrNi 17 7 (aust.)	Fe, Cr 17, Ni 7.0, Mn 1.0
420	X20Cr13 (mart.)	Fe, Cr 13, Si 0.5, Mn 0.5, Mo 0.70, V 0.20
431	X22CrNi17 (mart.)	Fe, Cr 16, Ni 1.875, Si 0.5, Mn 0.5
316L	X2CrNiMo18 10 2 (aust.)	Fe, Cr 17, Ni 12.0, Mo 2.5, Si 0.30, Mn 1.0
	X30Cr13	Fe, Cr 13, Si 0.5, Mn 0.5
	X35CrMo17	Fe, Cr 16.5, Mo 1.05, Ni 0.5, Si 0.5, Mn 0.5
304	X5CrNi 18 10 (aust.)	Fe, Cr 19, Ni 9.25, Si 0.5, Mn 1.0
316	X5CrNiMo 18 10 2 (aust.)	Fe, Cr 17, Ni 12.0, Mo 2.5, Si 0.30, Mn 1.0
430	X6Cr17 (ferr.)	Fe, Cr 16, Mo 0.25, Mn 1.40, Si 0.40
	X6CrNi18 10	Fe, Cr 18, Ni 10.0, Si 0.5, Mn 1.0
405	X7CrAl13 (ferr.)	Fe, Cr 13, Al 0.20, Si/Mn 1.0

Table 1c. Other steels analysed.

AISI	DIN	Main composition (typical)
	10SPb20	Fe, S 0.2, Pb 0.225, Mn 0.7, Si 0.25
	35S20	Fe, S 0.2, Mn 0.7, Si 0.25
	9S20	Fe, S 0.195, Si 0.025, Mn 0.9
	9SMnPb 28	Fe, S 0.28, Mn 1.1, Pb 0.225, Si 0.025
	GS-10Ni6	Fe, Ni 1.55
	GS-22Mo4	Fe, Mo 0.4, Si 0.3, Mn 0.65, Cr 0.15
	GS-25CrMo4	Fe, Cr 0.4, Mo 0.2, Ni 0.6, Si 0.4, Mn 0.65
	GS-38.3	Fe, Si 0.30, Mn 0.85, S 0.02
	GS-45.3	Fe, Si 0.3, Mn 0.85, P 0.02, S 0.02

Table 1c. Continuation: Other steels analysed.

AISI	DIN	Main composition (typical)
	GS-52.3	Fe, Si 0.3, Mn 0.85, P 0.02, S 0.02
	GS-70	Fe, Si 0.375, Mn 0.6, P 0.02, S 0.02
	G-X40CrNiSi 25 12	Fe, Cr 26, Ni 12.5, Mn 1.0, Mo 0.25
	HA	Fe, Cr 9, Mo 1.05, Mn 0.5
	HT	Fe, Ni 35, Cr 15, Mn 1.0, Mo 0.25
	St 13	Fe, N 0.035
	14NiCr14	Fe, Ni 3.5, Cr 1.5, Si 0.27, Mn 0.45, S 0.02, P 0.02
	15Cr3	Fe, Cr 0.65, Si 0.27, Mn 0.5, S 0.02, P 0.02
	18CrNi8	Fe, Cr 1.95, Ni 1.95, Si 0.27, Mn 0.65, S 0.02, P 0.02
	25CrMo4	Fe, Cr 1.05, Mo 0.25, Si 0.2, Mn 0.4, S 0.02, P 0.02
	30CrNiMo8	Fe, Cr 2.0, Ni 2.0, Mo 0.4, Si 0.2, Mn 0.3, S 0.02, P 0.02
	34Cr4	Fe, Cr 1.05, Si 0.45, Mn 0.2, S 0.02, P 0.02
	34CrAl6	Fe, Cr 1.5, Al 0.9, Si 0.27, Mn 0.47, S 0.02, P 0.02
	35NiCr18	Fe, Ni 4.5, Cr 1.3, Si 0.17, Mn 0.4, S 0.02, P 0.02
	36NiCr6	Fe, Ni 1.5, Cr 0.5, Si 0.17, Mn 0.4, S 0.02, P 0.02
	37MnSi5	Fe, Si 1.25, Mn 1.25, S 0.02, P 0.02
	42CrMo4	Fe, Cr 1.05, Mo 0.2, Si 0.27, Mn 0.65, S 0.02, P 0.02
	42MnV7	Fe, Mn 1.75, V 0.095, Si 0.27, S 0.02, P 0.02
	50CrV4	Fe, Cr 1.0, V 0.135, Si 0.27, Mn 0.65, S 0.02, P 0.02
	C15	Fe, Si 0.27, Mn 0.5, S 0.02, P 0.02
	C35	Fe, Si 0.17, Mn 0.3, Cr 0.2, Ni 0.2, Mo 0.05, S 0.02, P 0.02
	C45	Fe, Si 0.27, Mn 0.65, Cr 0.2, Ni 0.2, Mo 0.05, S 0.02, P 0.02
	C55	Fe, Si 0.27, Mn 0.65, S 0.02, P 0.02
	C60	Fe, Si 0.27, Mn 0. 65, S 0.02, P 0.02
	A517(A)	Fe, Si 0.6, Mn 0.95, Cr 0.6, Mo 0.28, Zr 0.05
	A517(B)	Fe, Si 0.27, Mn 0.85, Cr 0.52, Mo 0.2, V 0.03, Ti 0.01, B 0.005
	S355J2G1W	Fe, Mn 0.5, Cu 0.4, Cr 4
	13CrMo 4 5	Fe, Cr 0.95, Mo 0.55, Si 0.30, Mn 0.55
	21MoV53	Fe, Mo 0.5, V 0.35, Cr 0.3, Si 0.25, Mn 0.8
	22Mo4	Fe, Mo 0.35, Si 0.3, Mn 0.35
	28NiCrMo4	Fe, Ni 1.15, Cr 1.15, Mo 0.25, Si 0.25, Mn 0.4
	15NiMn6	Fe, Mn 1.15, Si 0.35, Ni 1.5
	A514(A)	Fe, Si 0.6, Mn 0.95, Cr 0.65, Mo 0.23, Zr 0.2
	ASt 35	Fe, Si 0.17, Mn 0.2, Al
	X12CrNi 18 9	Fe, Cr 18, Ni 9.0, Si 1.0, Mn 1.0
	X8Ni9	Fe, Ni 9, Si 0.25, Mn 0.55
	38Si6	Fe, Si 1.5, Mn 0.65
	50CrV4	Fe, Cr 1.05, V 0.15, Si0.2, Mn 0.55
	55Si7	Fe, Si 1.65, Mn 0.9
	67SiCr5	Fe, Si 1.3, Cr 0.5

Table 1d. Titanium alloys analysed.

AISI	DIN	Main composition (typical)
	Ti 99.5	Ti 99.5
	TiAl5Sn2	Ti, Al 5.0, Sn 2.5
	TiAl6V4	Ti, Al 6.0, V 4.0
	TiV15Sn3Cr3Al3	Ti, V 15.0, Sn 3.0, Cr 3.0, Al 3.0

Table 1e. Zinc alloys analysed.

AISI	DIN	Main composition (typical)
	G(K)ZnAl4Cu3	Zn, Al 4.0, Cu 2.9, Mg 0.045
	Superplastic Zn	Zn, Al 22
	Zamak 3	Zn, Al 4.0, Mg 0.04
	Zamak 5	Zn, Al 4.0, Cu 1.0, Mg 0.04
	Zn	Zn

Table 1f. Aluminium alloys analysed.

AISI	DIN	Main composition (typical)
204	G-AlCu4TiMg	Al, Cu 4.5, Ti 0.22, Mg 0.2, Si 0.2, Fe 0.2, Zn 0.1, Mn 0.05
242	G-AlMg3	Al, Mg 3.0, Si 0.5, Fe 0.5, Mn 0.2, Zn 0.1, Cu 0.05
314	G-AlMg5	Al, Mg 5.0, Si 0.5, Fe 0.5, Mn 0.2, Zn 0.1, Cu 0.05
230	G-AlSi12	Al, Si 12, Fe 0.5, Mn 0.2, Zn 0.1, Mg 0.05, Cu 0.05
231	G-AlSi12Cu	Al, Si 12, Cu 1.0, Fe 0.8, Mg 0.3, Mn 0.3
	G-AlSi7Mg (Thixo)	Al, Si 7, Mg 0.3, Fe 0.2, Mn 0.1, Zn 0.1, Cu 0.05
380.0	G-AlSi8Cu3	Al, Si 8.0, Cu 3.0, Zn 1.2, Fe 0.8, Mn 0.4, Mg 0.2
1100	Al99,0	Al 99.0
1050	Al99,5	Al 99.5
1090	Al99,9	Al 99.9
2036	AlCu2,6Si0,5Mg0,3	Al, Cu 2.6, Si 0.5, Mg 0.3
2017	AlCuMg1	Al, Cu 4.0, Mg 0.7, Mn 0.65, Si 0.5
2024	AlCuMg2	Al, Cu 4.4, Mg 1.5, Mn 0.6
~2011	AlCuMgPb	Al, Cu 4.2, Mg 1.1, Pb 0.4, Mn 0.7, Bi 0.4
5005	AlMg1	Al, Mg 1.0
~5754A	AlMg3	Al, Mg 3.1, Mn 0.25, Cr 0.15
5182	AlMg4,5Mn0,4	Al, Mg 4.5, Mn 0.4
6060	ALMgSi0,5	Al, Mg 0.5, Si 0.5, Fe
6005	AlMgSi0,7	Al, Mg 0.6, Si 0.7, Cr, Mn
3003	AlMn1	Al, Mn 1.0
3004	AlMn1,2Mg1	Al, Mn 1.2, Mg 1.0
6009	AlSi1,1Mg0,6Mn0,4	Al, Si 1.1, Mg 0.6, Mn 0.4
7075	AlZnMgCu1,5	Al, Zn 5.5, Mg 2.5, Cu 1.6, Cr 0.25, Mn 0.15

Table 1g. Nickel alloys analysed.

AISI	DIN	Main composition (typical)
	50/50 NiFe	Ni 50, Fe 50
	Duranik. 301	Ni 96.5, Al 4.4, Fe 0.3, Si 0.5, Ti 0.6
	Invar Nilo 36	Ni 36, Fe 64
	Mumetal	Ni 77, Fe 16.5, Cu 5.0, Cr 1.5
	Ni 99,6	Ni 99.6
	NiCr 80 20	Ni 80, Cr 20
	NiCr20Co18Ti	Ni 59, Cr 19.5, Co 16.5, Ti 2.45, Al 1.45
	NiCr20TiAl	Ni 76, Cr 19.5, Ti 2.4, Al 1.4
	NiCu30Al	Ni 66.5, Cu 29.5, Al 2.7, Fe 1.0, Ti 0.6
	NiCu30Fe	Ni 66.5, Cu 31, Fe 2.5
	NiMo30	Ni, Mo 28, Fe 5.0, Co 2.5, Cr 1.0, V 0.3
	Ni-span C-902	Ni 42, Fe 49.8, Cr 5.2, Ti 2.5, Al 0.5

Table 1h. Copper alloys analysed.

AISI	DIN	Main composition (typical)
	G-CuAl10Fe	Cu, Al 10, Fe 3.0
	G-CuAl10Ni	Cu, Al 10, Ni 5.5, Fe 4.5
	G-CuNi10	Cu, Ni 10, Fe 1.4, Mn 1.25, Nb 0.25, Si 0.20
	G-CuSn 10	Cu, Sn 10.0
	G-CuSn12	Cu, Sn 12
	G-CuSn5Zn5Pb5	Cu, Sn 5.0, Zn 5.0, Pb 5.0
	G-CuZn 40	Cu, Zn 40.0
	G-CuZn15	Cu 85, Zn 15, As 0.05-0.2
	G-CuZn37Pb	Cu 61, Zn 37, Pb 1.5, Al 0.5
	CuAl5	Cu, Al 5.5, Ni 0.4 Mn 0.25
	CuNi10Fe	Cu, Ni 10.0, Fe 1.5, Mn 0.65
	CuNi18Zn20	Cu 62, Ni 18, Zn 19.5, Mn 0.35
	CuNi44Mn	Cu, Ni 44, Mn 1.25, Fe 0.25
	CuSn6,7P0,1	Cu, Sn 6.7, P 0.1
	CuSn8 (P bronze)	Cu, Sn 8.0, P 0.21
	CuZn 15	Cu, Zn 15.0
	CuZn 37	Cu, Zn 37.0, Pb 1.50, Al 0.50
	CuZn 40	Cu, Zn 40.0
	CuZn30 (brass)	Cu, Zn 30
	CuZn40Pb3 (brass)	Cu 57.7, Zn 39.5, Pb 2.75
	E-Cu	Cu 99.90
	E-CuAg	Cu, Ag 0.52

Table 1i. Magnesium alloys analysed.

AISI	DIN	Main composition (typical)
	GD-MgAl9Zn1	Mg, Al 9.0, Zn 0.7, Mn 0.13
	G-MgAl6Zn3	Mg, Al 6.0, Zn 3.0, Mn 0.15
	G-MgAl8Zn1	Mg, Al 7.6, Zn 0.7, Mn 0.13
	G-MgAl9Zn2	Mg, Al 9.0, Zn 2.0, Mn 0.10
	Am100A	Mg, Al 10.0, Mn 0.10
	AM503	Mg, Mn 1.2
	MgAl3Zn	Mg, Al 3.0, Zn 1.0, Mn 0.2
	MgAl6Zn	Mg, Al 6.5, Zn 1.0, Mn 0.1.5
	MgMn 1,5	Mg, Mn 1.5
	MgZn6Zr	Mg, Zn 5.5, Zr 0.45

Both total ecoindicator values and data of the contributing environmental categories, as in Table 2 (for stainless steel 301), were used. In order for the sum of the category values to be equal to the total value, the weighted values (single score) were used, expressed in Points (Pt).

Table 2. Ecoindicator data for stainless steel 301, (X12CrNi 17 7).

Category	Unit	Total	Steel	Scrap	Manganese	Silicon	Ferrochromium
Total	Pt	0.0876	0.0436	0.0103	0.0031	0.0021	0.0285
Carcinogens	Pt	0.0012	0.0011	0.0000	0.0000	0.0000	0.0001
Respiratory organics	Pt	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Respiratory inorganics	Pt	0.0236	0.0169	0.0000	0.0006	0.0005	0.0056
Climate change	Pt	0.0075	0.0038	0.0000	0.0003	0.0002	0.0032
Radiation	Pt	-	-	-	-	-	-
Ozone layer depletion	Pt	0.0000	0.0000	-	-	0.0000	0.0000
Ecotoxicity	Pt	0.0022	0.0022	0.0000	0.0000	0.0000	0.0000
Acidification/ Eutrophication	Pt	0.0030	0.0022	0.0000	0.0001	0.0001	0.0007
Land use	Pt	0.0049	0.0040	0.0002	0.0000	0.0000	0.0006
Minerals	Pt	0.0134	0.0008	0.0100	0.0001	0.0000	0.0025
Fossil fuels	Pt	0.0318	0.0127	0.0000	0.0021	0.0012	0.0158

Data on the amounts of elements put in to each material, such as Table 3 (for stainless steel 301), were also collected from SimaPro to an Excel sheet. Amount and type of recycled material (scrap) is a very important piece of information, since it is included and accounted for in the ecoindicator values.

Table 3. Input data for stainless steel 301, (X12CrNi 17 7).

Name	Amount	Unit
Steel	0.678	kg
Scrap (stainless steel)	0.2	kg
Manganese	0.01	kg
Silicon	0.008	kg
Ferrochromium	0.104	kg

10.2 Analysis B: Source of elements impacts

The purpose of Analysis B consisted of explaining the specific elements impacts by analysing in detail the different element materials. For example what makes some elements show a higher environmental impact, and why are the impacts divided as they are in the environmental impact categories.

Data of inputs and outputs in production of the different element materials was collected from SimaPro. The information consisted of amounts and environmental load of substances and emissions in production, as well as use of land area and resources. Table 4 shows the top four substances total loads for production of nickel.

Table 4. Analysing 1kg Nickel. The top four substances total loads.

Substance	Compartment	Unit	Total load
Total of all		Point	3.84
SO_2	Air	Point	2.29
Nickel	Raw	Point	0.577
Natural gas	Raw	Point	0.238
Crude oil	Raw	Point	0.236

11 Analysis and Result

11.1 Analysis A

Each element has a specific coefficient value that represents the environmental impact of one kg of the element, according to the Eco-Indicator 99 method. The amount of an element in the material, together with the coefficient, gives the environmental impact of that specific element in the material. The sum of all elements impacts gives the ecoindicator value of the material, according to Equation 1.

$$EI99_j = \sum_i(\alpha_i\, c_w^{i,j}) \tag{1}$$

for any material j, where α_i is the coefficient for element i in the material j, and $c_w^{i,j}$ is the amount of element i in material j.

Consideration has also been taken to the use of recycled material, in the analysis. This makes Equation 1 inconclusive for such materials since the environmental load then is smaller. There are specific coefficient values for recycled material listed as: Scrap steel, Scrap iron, Scrap Al, Scrap Pb. To take into account these coefficient values in

the calculations, the amount of scrap (p_r) has to be included, in percentage (%), in the equation.

$$EI99_j = (1 - p_r) * \sum_i(\alpha_i \, c_w^{i,j}) + p_r * \alpha_r \qquad\qquad (2)$$

where p_r is the percentage of recycled material (scrap) used, and α_r is the coefficient value.

To get the specific coefficients for the elements represented in this one material, the element impacts in Table 2 was divided by the amounts in Table 3. The same procedure was used for all the materials. But since the coefficient for an element in one material is the same as the coefficient for that element in another material, it was only necessary to calculate the coefficients for the 'new' elements for each material.

The result of Analysis A is shown in Table 5. An example of how to calculate the environmental value for a material, using equation 1, is found in Appendix 1a, Example 1. And examples using equation 2 are found in Appendix 1b-d, Examples 2-4 for three different materials.

Table 5. Contribution to the ecoindicator from individual element (Point/kg). Total values, and partial from the individual environmental loading categories.

| Element	Total EI99	Carcinogenity	Respiratory (organics)	Respiratory (inorganics)	Climate change	Ionizing radiation	Ozone layer depletion	Ecotoxicity	Acidification/ Eutrophication	Land-use	Minerals	Fossil fuels
Scrap St. Steel	**0.051**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.050	0.000
Scrap Iron	**0.008**	0.000	0.000	0.002	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.002
Scrap Al	**0.194**	0.000	0.000	0.039	0.007	0.000	0.000	0.001	0.003	0.042	0.057	0.046
Scrap Pb	**0.176**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.175	0.000
Mn	**0.311**	0.000	0.000	0.056	0.027	0.000	0.000	0.001	0.006	0.005	0.009	0.208
Si	**0.258**	0.000	0.000	0.068	0.030	0.000	0.000	0.001	0.009	0.004	0.000	0.146
Cr[4]	**0.392**	0.001	0.000	0.077	0.044	0.000	0.000	0.000	0.009	0.008	0.034	0.217
Cr	**0.570**	0.001	0.000	0.118	0.068	0.000	0.000	0.000	0.014	0.011	0.024	0.334
Mo	**2.708**	0.000	0.000	0.104	0.059	0.000	0.000	0.000	0.012	1.181	1.074	0.282
Ni	**3.841**	0.001	0.000	2.439	0.146	0.000	0.000	0.000	0.155	0.006	0.576	0.521
V	**1.620**	0.000	0.000	0.325	0.181	0.000	0.000	0.000	0.038	0.216	0.000	0.857
Al	**0.629**	0.035	0.000	0.176	0.071	0.000	0.000	0.004	0.013	0.025	0.044	0.261
Ti	**1.930**	0.000	0.000	0.461	0.247	0.000	0.000	0.001	0.055	0.006	0.000	1.160
Pb	**0.425**	0.000	0.000	0.073	0.011	0.000	0.000	0.001	0.005	0.008	0.267	0.059
Cu	**2.366**	0.000	0.000	1.016	0.041	0.000	0.000	0.000	0.066	0.074	0.892	0.277
Mg	**0.669**	0.000	0.000	0.231	0.102	0.000	0.000	0.001	0.026	0.005	0.000	0.305
Zn	**0.435**	0.015	0.000	0.114	0.026	0.000	0.000	0.031	0.012	0.013	0.102	0.123
Sn	**16.500**	0.000	0.000	0.168	0.080	0.000	0.000	0.003	0.021	0.008	15.875	0.386
Fe[5]	**0.064**	0.002	0.000	0.025	0.006	0.000	0.000	0.003	0.003	0.006	0.001	0.019
Fe	**0.069**	0.001	0.000	0.027	0.006	0.000	0.000	0.002	0.004	0.007	0.001	0.022
Co	**6.364**	0.000	0.000	0.091	0.051	0.000	0.000	0.000	0.011	5.945	0.000	0.244

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[4] Cr from ferrochromium
[5] Applicable for steels (Fe-rest)

There are two values for chromium shown in Table 5: one elemental chromium value and one value for chromium extracted from ferrochromium, which has a slightly lower environmental impact. The amount of chromium in ferrochromium is defined as 70% (average). The Fe-part (30%) is excluded in the value and does not have to be adjusted for when using the value in calculations.

Calculated values are compared with LCA values from IdeMat in Figures 1-6. The closer the markers are to the ideal 1:1 line, the better Eq. (2) describes the data points. In the six diagrams, values for different types of alloys are presented. The number of analysed materials for each type is given in brackets. That adds up to a total of 156 metals (listed in Tables 1a-i):
1. Cast irons (8)
2. Stainless steels (18)
3. Other steels (54)
4. Titanium alloys (4) and aluminium alloys (23)
5. Copper alloys (22) and nickel alloys (12)
6. Magnesium alloys (10) and zinc alloys (5)
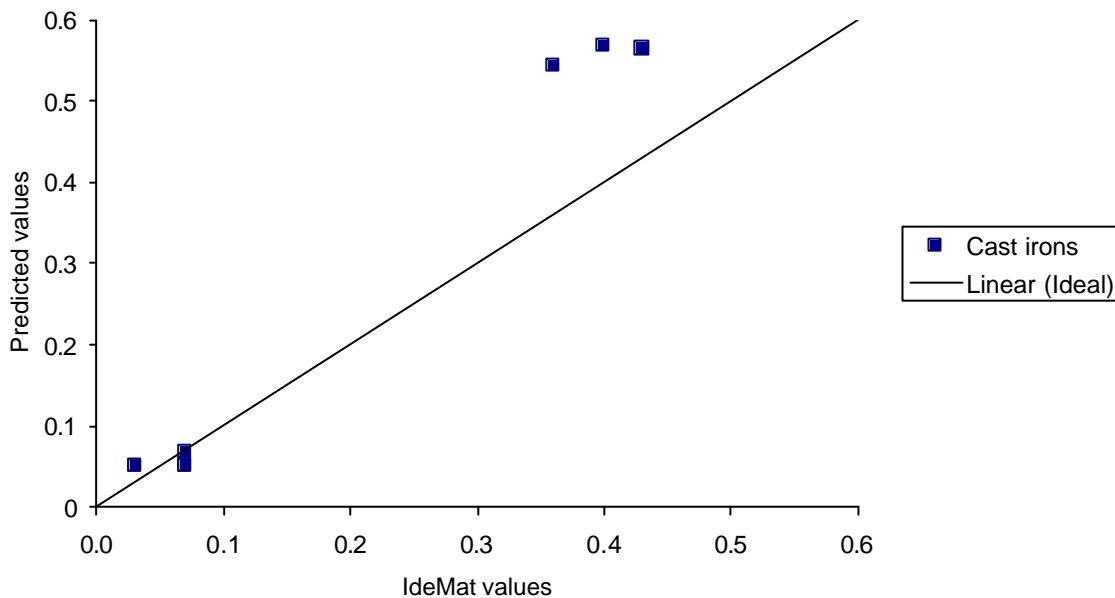
Figure 1. Cast irons (8 materials). The predicted EcoIndicator 99 values are calculated according to equation 2, with a 67% use of recycled material. Units Pt/kg.

The results for high alloyed cast irons did not agree totally with equation 2. The use of recycled material is 67%, and there are three or more different elements in each material. The four irons above 0.3 (Pt/kg) contain nickel, which greatly affects the value.
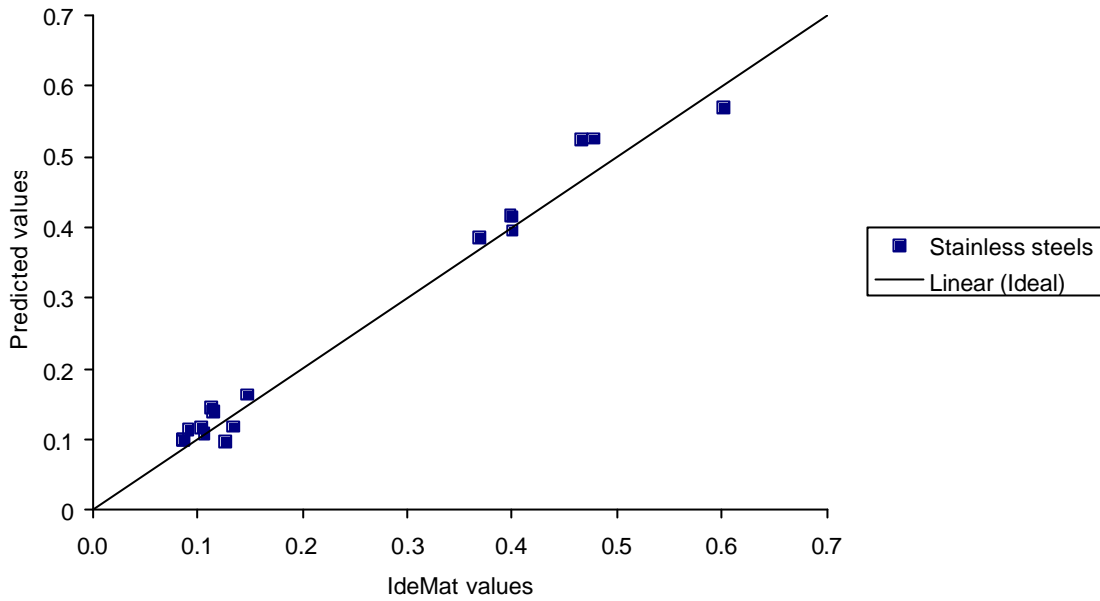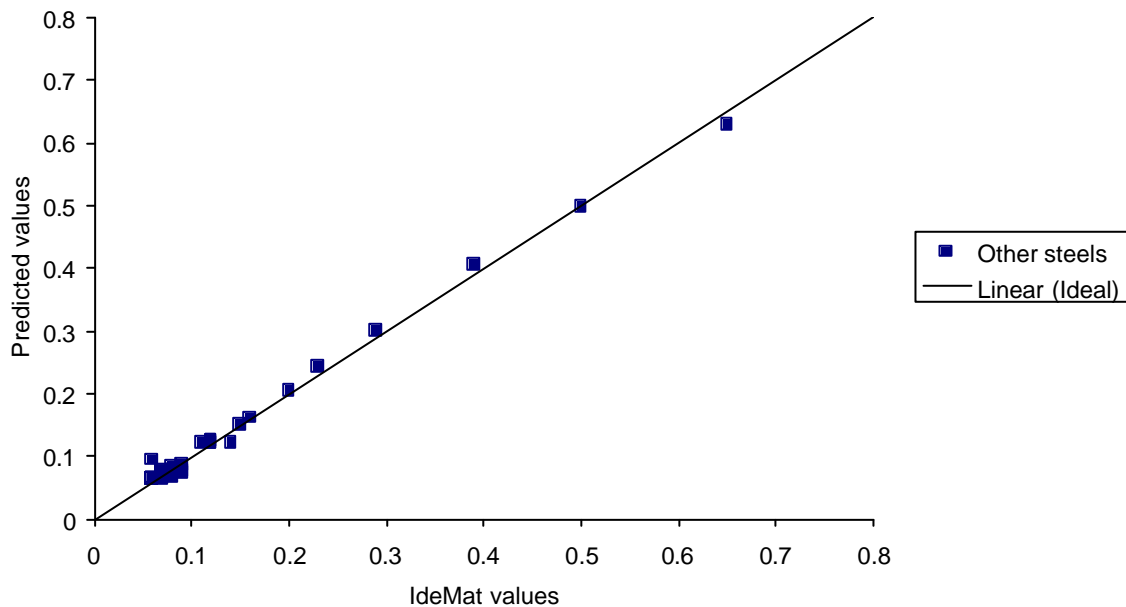
Figure 2. Stainless steels (18 materials). The predicted values are calculated according to equation 2, with a 20% use of recycled material.

The results for stainless steels did agree with equation 2. There are up to six different elements involved in each materials composition. More elements brings more components to the equation. There is also a 20% use of recycled material, perhaps making more room for deviations. The steels with a higher value (seven above 0.3 Pt/kg) are austenitic steels or others, with a higher grade of nickel.

Figure 3. Other steels (54 materials). The predicted values are calculated according to equation 1.

The results for category 'Other steels' (besides stainless steels) did agree with equation 1. There are a similar number of elements in the materials compositions, compared to stainless steels, but no use of recycled material. Some steels show a higher value (three above 0.4 Pt/kg). The reason is the higher grade of nickel in these steels.
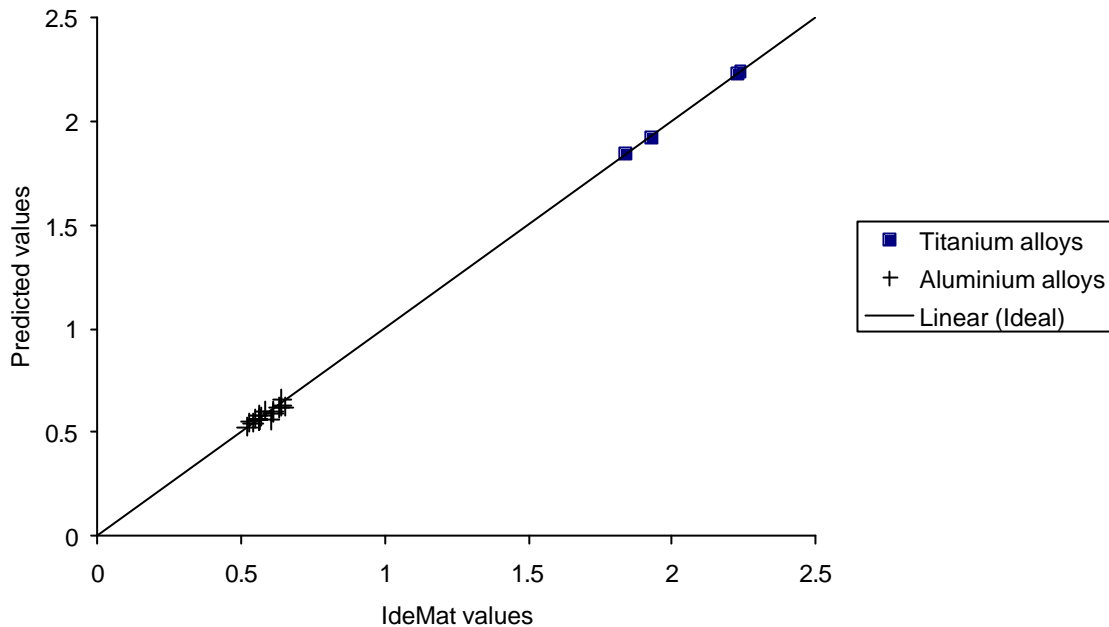
Figure 4. Aluminium alloys (23 materials), and Titanium alloys (4 materials). The predicted values for Ti alloys are calculated according to equation 1. And equation 2 is used for Al alloys, with a 15% use of recycled material.

The results for aluminium alloys are also consistent with equation 2. There is a 15% use of recycled material for these metals.

The results for titanium alloys did agree with equation 1. There are between one and five different elements in the materials, but no use of recycled material is compensated for. Calculations are made for only four materials.
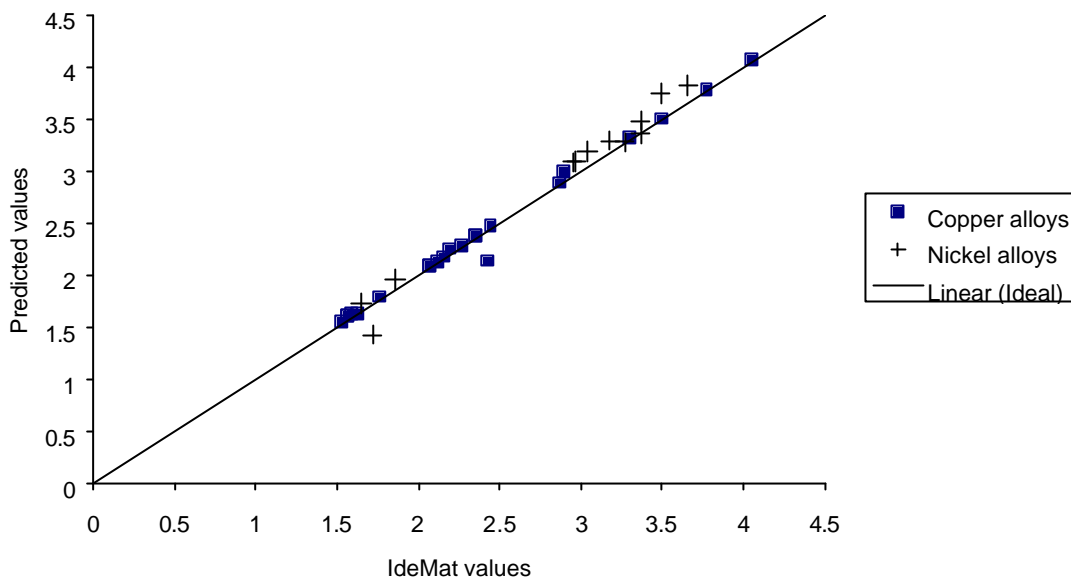
Figure 5. Copper alloys (22 materials), and Nickel alloys (12 materials). The predicted values are calculated from equation 1 for both Cu and Ni alloys.

The results for all copper alloys, but one, did agree with equation 1. There is no use of recycled material compensated for, and a varied number of elements in the compositions.

The results for nickel alloys did generally agree with equation 1. There are but a couple of materials that deviate. The number of elements in the materials vary, and there is no use of recycled material.
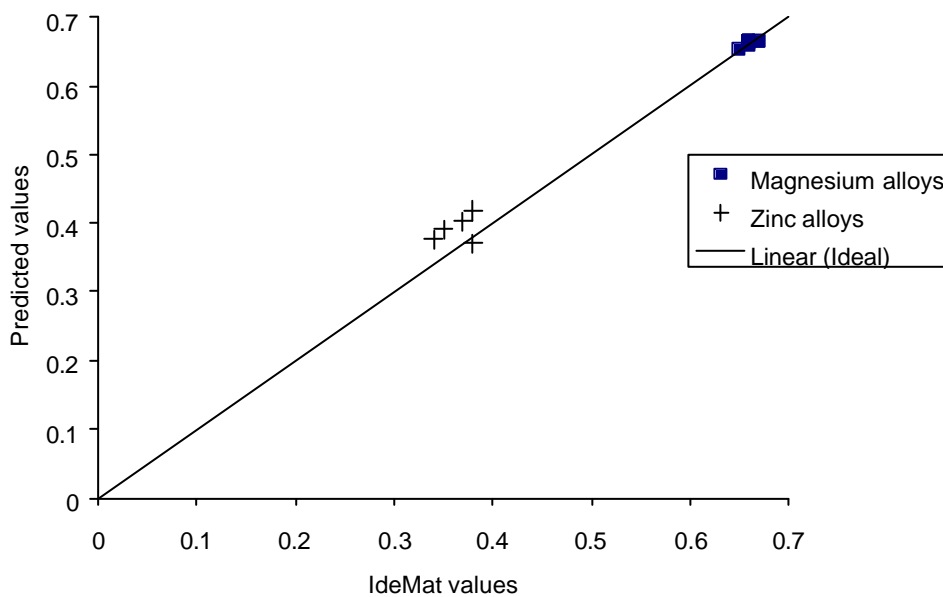
Figure 6. Magnesium alloys (10 materials), and Zinc alloys (5 materials). Predicted values for Mg alloys are calculated using equation 1, and equation 2 for Zn alloys, with a 25% use of recycled material.

The results for magnesium alloys did agree with equation 1. There are approximately four different elements in each material, and no use of recycled material.

The results for zinc alloys did not agree with equation 2. All five, but one, materials are above the ideal line, in a linear way, suggesting a systematic deviation in either the composition data or an element component. There is 25% use of recycled material, and three or more elements in the materials. The number of zinc alloys are only 5.

As well as total ecoindicator value, the elements also have coefficients for each one of the environmental loading categories that the ecoindicator value is divided into. The environmental impact categories are:
- Carcinogenity
- Respiratory effects (organics and inorganics)
- Climate change
- Ionizing radiation
- Ozone layer depletion
- Ecotoxicity
- Acidification/Eutrophication
- Land-use
- Minerals
- Fossil fuels

This makes it possible to calculate the impact on a specific category, for example how much the material or an element in the material affects the climate or how carcinogenic it is. It can also be used to see in what category the environmental impact lies for each element.

Looking at the total EI99 values in Table 5 shows a few element values that have higher values than the rest:
- Molybdenum (Mo)
- Nickel (Ni)
- Copper (Cu)
- Tin (Sn)
- Cobolt (Co)

Mo has a total EI99 value of 2.7 Pt/kg, originating mainly from categories "Land-use" and "Minerals" with 83% of the total load.

Ni has a total impact of 3.8 Pt/kg, mainly coming from the category "Respiratory effects (inorganics)" representing 63%. Additional 29% comes from categories "Minerals" and "Fossil fuels".

Cu's total value is 2.3 Pt/kg, where 81% comes from "Respiratory effects (inorganics)" and "Minerals". The rest are smaller contributions divided between the other categories.

Sn shows the single largest total impact value of 13.5 Pt/kg. 96% of the load comes from the "Minerals" category.

Last Co which has a total value of 6.3. It comes with 93% from one single category: "Land-use".

The most common categories are:
- Respiratory effects (inorganics)
- Land-use
- Minerals
- Fossil fuels

where 96% of the elements load originates from.

Some categories are only marginally represented amongst the analysed metals. Three categories even have zero-values:
- Respiratory effects (organics)
- Ionizing radiation
- Ozone layer depletion

11.2 Analysis B

The task in Analysis B was to find the origin of the environmental load. Each element has a number of origins that contribute to the coefficient value. These origins are: substances, emissions, land-use and use of resources. Each origin brings an environmental load that derives to one or more of the environmental loading categories. One way of calculating the impact of the material is: for each element in the material, the impacts of the different origins are calculated by the sum of impacts to each category. In other words: the materials total impact is the sum of each elements impact, which is the sum of each origins impact for that element. And each origins impact derives from different categories. A total of three sums: element, origin and category:

$$EI99_j = \sum_i \{ \sum_e [\sum_c (\beta_{i,e,c} \, c_w^{i,j})] \}$$ (3)

where $\beta_{i,e,c}$ is origin e's impact on category c for element i in the material j, and $c_w^{i,j}$ is the amount of element i in material j. Origins (e) are emissions, substances, use of resources and land-use, that provide an environmental load.

Use of recycled material is compensated for here as well. It is made in similar ways as before, where the used recycled material (scrap) can be seen as an element with its own origins (emissions, substances, etc) that contribute to the environmental impact value. The equation is adjusted:

$$EI99_j = (1 - p_r) * \sum_i \{ \sum_e [\sum_c (\beta_{i,e,c} \, c_w^{i,j})] \} + \sum_e [\sum_c (\beta_{e,c} \, p_r)]_{scrap}$$ (4)

where p_r is the percentage of recycled material (scrap) used in the material, and $\beta_{r,e,c}$ is origin e's impact on category c for the recycled material.

For each element material, data of all present substances were found in either one or more loading categories. Where a substance was found in more than one loading category, the score had to be divided between these. And since this data was not weighted, it was not given in the same unit (Point), and it had to be weighted to be compatible. A weight factor was calculated, for each category in question, by dividing the weighted score of an element in one category, expressed in Point (Pt), with the non-weighted score of the same element in that

category. The non-weighted scores of the substances were multiplied with the weight factor for the category to get comparable data.

The result of Analysis B is shown in Appendix 2, tables 1-21. An example of how to calculate the origins for the total environmental load, using equation 3, is found in Appendix 3a, Example 5. And an example using equation 4 is found in Appendix 3b, Example 6.

12 Evaluation and discussion

As demonstrated above, the environmental impact for a material, according to the ecoindicator, is dependant on its single elements. A materials ecoindicator value, representing the impact, is the sum of environmental coefficients specific for each element multiplied with the amounts of the elements (Equation 1 and 2). The impact of an arbitrary material, with the use of the equations, can be used in materials selection purposes.

Table 5, of elements contributions to the ecoindicator, shows three environmental categories with no load from any element: Respiratory effects (organics), Ionizing radiation and Ozone layer depletion.

- Respiratory effects are divided between the organics and inorganics in Eco-Indicator 99. And Respiratory effects (organics) represent a negligible impact, since there is very little organic materia involved that are hazardous to respiratory organs (lungs), for the analysed metals, compared to the inorganic substances.
- Ionizing radiation has no contribution because none of the metals in the analysis are radioactive or emit radioactive substances in production.
- Ozone layer depletion is not a burning issue as before, since the Montreal Protocol was accepted in 1987. The treaty serves as an international objective to protect the ozone layer globally, by eliminating the production and consumption of ozone depleting chemicals such. This results in very little or no emission of substances such as CFCs and HCFCs, that contributes to the ozone layer depletion category.

13 Further work

This work only looked at metal materials. It would be very interesting to complement the work with other types of materials, such as polymers, ceramics and laminates, which would widen the materials selection.

Another obvious and interesting continuation is to look at and analyse data from other ecoindicators, such as EPS and Ecopoint.

14 Acknowledgements

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16 Appendices

16.1 Appendix 1a. Example 1 for CuZn30 (brass)

Metal		Containing	Calculated value	SimaPro-value	IdeMat-value
CuZn30 (brass)	=	Cu rest, Zn 30, (0% recycled)	**1.786**	**1.784**	**1.77**
		Equation: $0.3*\alpha_{Zn} + 0.7*\alpha_{Cu}$			

Environmental categories:		
	Carcinogenity	0.005
	Respiratory (organics)	0.000
	Respiratory (inorganics)	0.745
	Climate change	0.036
	Ionizing Radiation	0.000
	Ozone layer depletion	0.000
	Ecotoxicity	0.009
	Acidification / Eutrophication	0.049
	Land-use	0.056
	Minerals	0.655
	Fossil fuels	0.231
	Sum	*1.786*

CuZn30 has a composition of Cu 70 ($c_w{}^{Cu}$) and Zn 30 ($c_w{}^{Zn}$), resulting in an equation for the total environmental load:

$$EI99_0 = 0.70*\alpha_{Cu} + 0.30*\alpha_{Zn} = 1.786$$

α_{Cu} and α_{Zn} are 2.366 and 0.435 (Pt/kg).

The result from the equation shows good comparison with the corresponding data from SimaPro and IdeMat.

Appendix 1b. Example 2 for X5CrNi 18 10 (aust.) (304)

Metal	Containing	Calculated value	SimaPro-value	IdeMat-value
X5CrNi 18 10 (aust.)(304) =	Fe rest, Cr 18.0-20.0, Ni 8.0-10.5, Si 0.5, Mn <2.0, 20% recycled	**0.394**	**0.401**	**0.38**

Equation: $(0.19 \cdot \alpha_{Cr} + 0.0925 \cdot \alpha_{Ni} + 0.005 \cdot \alpha_{Si} + 0.01 \cdot \alpha_{Mn} + 0.7025 \cdot \alpha_{Steel}) \cdot 0.8 + 0.2 \cdot \alpha_{Scrap\ steel}$

Environmental categories:	
Carcinogenity	0.001
Resp. organics	0.000
Resp. inorganics	0.207
Climate change	0.021
Ionizing Radiation	0.000
Ozone layer depletion	0.000
Ecotoxicity	0.002
Acidification/Eutrophication	0.015
Land-use	0.005
Minerals	0.059
Fossil fuels	0.084
Sum	*0.394*

X5CrNi 18 10 (304) has composition[6]: Fe 70.25 (c_w^{Fe}), Cr 19 (c_w^{Cr}), Ni 9.25 (c_w^{Ni}), Si 0.5 (c_w^{Si}), Mn 1.0 (c_w^{Mn}). The environmental load is calculated to be 0.394 (Pt/kg), with 20% use of recycled material:

$$EI99 = (0.19 \cdot \alpha_{Cr} + 0.0925 \cdot \alpha_{Ni} + 0.005 \cdot \alpha_{Si} + 0.01 \cdot \alpha_{Mn} + 0.7025 \cdot \alpha_{Fe}) \cdot 0.80 + 0.20 \cdot \alpha_r = 0.394$$

The scrap-coefficient used for this material is $\alpha_{Scrap\ steel}$ and its total load is 0.051 (Pt/kg). 20% of $\alpha_{Scrap\ steel}$ equals 0.010. The impact is smaller compared to the save from using recycled material, which is 0.0958. Comparing the calculated value shows that it lies in between the data from SimaPro and IdeMat, which are 0.401 and 0.38.

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[6] The amounts are calculated averages from data of compositions collected from IdeMat. For example if the amount of an element for a steel is specified as 18.0-20.0% Cr in IdeMat, the average, 19.0% is used. When the maximum amount of an element is specified, half of that amount is used. For example Mn<2.0% means that in the equation Mn is represented with 1.0%. When a minimum is specified in IdeMat, it is also used as the average value. For example if Si>1.0%, the used amount of Si is 1.0%.

Appendix 1c. Example 3 for X12Cr 13 (mart.) (416)

Metal		Containing	Calculated value	SimaPro-value	IdeMat-value
X12Cr13 (mart.) (416)	=	Fe rest, C <0.15, Cr 12.0-14.0, Si <1.0, Mn <1.25, 20% recycled	**0.097**	**0.088**	**0.08**

Equation: $(0.13*\alpha_{Cr} + 0.005*\alpha_{Si} + 0.006125*\alpha_{Mn} + 0.8575*\alpha_{Steel})*0.8 + 0.2*\alpha_{Scrap\ steel}$

Environmental categories:

Carcinogenity	0.001
Resp. organics	0.000
Resp. inorganics	0.026
Climate change	0.009
Ionizing Radiation	0.000
Ozone layer depletion	0.000
Ecotoxicity	0.002
Acidification/Eutrophication	0.003
Land-use	0.005
Minerals	0.014
Fossil fuels	0.037
Sum	*0.097*

X12Cr 13 (416) has composition[6]: Fe 85.875 (c_w^{Fe}), Cr 13 (c_w^{Cr}), Si 0.5 (c_w^{Si}), Mn 0.625 (c_w^{Mn}) and with 20% use of recycled material (p_r), the environmental load is 0.097 (Pt/kg):

$$EI99 = (0.13*\alpha_{Cr} + 0.05*\alpha_{Si} + 0.0625*\alpha_{Mn} + 0.85875*\alpha_{Fe})*0.80 + 0.20*\alpha_r = 0.097$$

The use of 20% recycled material reduces the value with 0.011 (Points/kg), which would be 0.109 using no recycled material.

The data for the same material in SimaPro and IdeMat are slightly smaller than the calcuculated value.

Appendix 1d. Example 4 for AlMg 4,5 Mn 0,5 (5182)

Metal		Containing	Calculated value	IdeMat-value	SimaPro-value
AlMg4,5Mn0,4 (5182)	=	Al rest, Mg 4.5, Mn 0.4, 15% recycled	**0.564**	**0.564**	**0.56**

Equation: $(0.045*\alpha_{Mg} + 0.004*\alpha_{Mn} + 0.951*\alpha_{Al})*0.85 + 0.15*\alpha_{Scrap\ Al}$

Environmental categories:

Carcinogenity	0.028
Resp. organics	0.000
Resp. inorganics	0.157
Climate change	0.062
Ionizing Radiation	0.000
Ozone layer depletion	0.000
Ecotoxicity	0.003
Acidification/Eutrophication	0.012
Land-use	0.027
Minerals	0.044
Fossil fuels	0.230
Sum	*0.563*

AlMg 4.5 Mn 0.5 (5182) has composition[6]: Al 95.1 ($c_w{}^{Al}$), Mg 4.5 ($c_w{}^{Mg}$), Mn 0.4 ($c_w{}^{Mn}$) and with 15% use of recycled material (p_r) the environmental load is 0.564:

$$EI99 = (0.045*\alpha_{Mg} + 0.004*\alpha_{Mn} + 0.951*\alpha_{Al})*0.85 + 0.15*\alpha_r = 0.564$$

The scrap-coefficient used for this material is $\alpha_{Scrap\ Al}$, since the material is an aluminium alloy.

Comparison with the data from SimaPro and IdeMat shows good agreement.

16.2 Appendix 2. Elements impacts origins (tables 1-21)

These tables show, for each element, the emissions/substances/origins that cause the environmental impact and in what impact category.

16.2.1 Scrap Stainless Steel (Point/kg)

	Minerals	Others	Total
Ni (in ore)	0.045		
Cr (in ore)	0.004		
Others	0.001		
Total	0.050	0.001	**0.051**

16.2.2 Scrap Iron (Point/kg)

	Respiratory (inorganics)	Fossil fuels	Minerals	Others	Total
NOx	0.002				
Crude oil		0.002			
Iron (in ore)			0.001		
Others					
Total	0.002	0.002	0.001	0.002	**0.008**

16.2.3 Scrap Aluminium (Point/kg)

	Minerals	Fossil fuels	Land-use	Respiratory (inorganics)	Others	Total
Al (in ore)	0.057					
Occupied as industrial area			0.041			
SO$_2$				0.030		
Crude oil		0.028				
Natural gas		0.018				
Others		0.001	0.001	0.009		
Total	0.057	0.046	0.042	0.039	0.010	**0.194**

16.2.4 Scrap Lead (Point/kg)

	Minerals	Others	Total
Pb (in ore)	0.175		
Others			
Total	0.175	0.001	**0.176**

16.2.5 Manganese (Point/kg)

	Fossil fuels	Respiratory (inorganics)	Climate change	Others	Total
Crude oil	0.1766				
Natural gas	0.0317				
SOx		0.0297			
CO_2			0.0273		
NO_2		0.0245			
Others		0.002			
Total	0.208	0.056	0.027	0.021	**0.312**

16.2.6 Silicon (Point/kg)

	Fossil fuels	Respiratory (inorganics)	Climate change	Others	Total
Natural gas	0.0839				
Crude oil	0.0572				
CO_2			0.0297		
NO_2		0.0287			
SOx		0.0253			
NOx		0.0146			
Others	0.005				
Total	0.146	0.068	0.030	0.014	**0.258**

16.2.7 Chromium (Point/kg)

	Fossil fuels	Respiratory (inorganics)	Climate change	Others	Total
Natural gas	0.1914				
Crude oil	0.126				
CO_2			0.0675		
NO_2		0.0634			
SOx		0.0564			
Others	0.017				
Total	0.334	0.118	0.068	0.048	**0.568**

16.2.8 Ferro Chromium (Point/kg)

	Fossil fuels	Respiratory (inorganics)	Climate change	Minerals	Others	Total
Natural gas	0.070					
Crude oil	0.073					
CO_2			0.031			
NO_2		0.029				
SOx		0.025				
Cr (in ore)				0.024		
Others	0.074	0.023	0.013	0.010		
Total	0.217	0.077	0.044	0.034	0.020	**0.392**

16.2.9 Molybdenum (Point/kg)

	Land-use	Minerals	Fossil fuels	Respiratory (inorganics)	Climate change	Others	Total
Conversion to urban land	1.18						
Mo (in ore)		1.07					
Natural gas			0.14				
Crude oil			0.114				
CO_2					0.0585		
NO_2				0.0575			
SOx				0.0508			
Others	0.001	0.004	0.028				
Total	1.181	1.074	0.282	0.104	0.059	0.008	**2.708**

16.2.10   Nickel (Point/kg)

	Respiratory (inorganics)	Minerals	Fossil fuels	Acidification/ Eutrophication	Climate change	Others	Total
SO_2	2.166			0.124			
Ni (in ore)		0.577					
Natural gas			0.238				
Crude oil			0.236				
SOx	0.140			0.008			
CO_2					0.146		
NO_2	0.117			0.023			
Others	0.015		0.047	0.001			
Total	2.439	0.576	0.521	0.155	0.146	0.004	**3.841**

16.2.11   Vanadium (Point/kg)

	Fossil fuels	Respiratory (inorganics)	Land-use	Climate change	Acidification/ Eutrophication	Others	Total
Natural gas	0.444						
Crude oil	0.363						
Conversion to urban land			0.211				
NO_2		0.154			0.029		
CO_2				0.181			
SOx		0.152			0.009		
Others	0.050	0.019	0.005				
Total	0.857	0.325	0.216	0.181	0.038	0.003	**1.620**

16.2.12   Aluminium (Point/kg)

	Fossil fuels	Respiratory (inorganics)	Climate change	Minerals	Carcino-genity	Land-use	Others	Total
Crude oil	0.195							
SO_2		0.085						
CO_2			0.053					
NOx		0.043						
Dust		0.048						
Bauxite				0.044				
Natural gas	0.055							
Occupied as arable land						0.025		
Ni					0.017			
As					0.014			
CFC-14			0.013					
Others	0.010		0.005		0.004			
Total	0.261	0.176	0.071	0.044	0.035	0.025	0.017	**0.629**

16.2.13   Titanium (Point/kg)

	Fossil fuels	Respiratory (inorganics)	Climate change	Acidification/ Eutrophication	Others	Total
Natural gas	0.607					
Crude oil	0.512					
NO_2		0.210		0.040		
CO_2			0.247			
SOx		0.208		0.012		
Coal	0.043					
Dust		0.024				
NOx		0.014		0.003		
Others		0.005				
Total	1.160	0.461	0.247	0.055	0.007	**1.930**

16.2.14   Lead (Point/kg)

	Minerals	Respiratory (inorganics)	Fossil fuels	Others	Total
Pb (in ore)	0.266				
SO_2		0.058			
Natural gas			0.022		
Crude oil			0.036		
Others	0.001	0.015	0.001		
Total	0.267	0.073	0.059	0.026	**0.425**

16.2.15   Copper (Point/kg)

	Respiratory (inorganics)	Minerals	Fossil fuels	Land-use	Acidification/ Eutrophication	Climate change	Others	Total
SO_2	0.955				0.055			
Cu (in ore)		0.891						
Crude oil			0.245					
NOx	0.057				0.011			
Conversion to urban land				0.047				
CO_2						0.041		
Natural gas			0.030					
Conversion to industrial area				0.023				
Others	0.004	0.001	0.002	0.004				
Total	1.016	0.892	0.277	0.074	0.066	0.041	0.000	2.366

16.2.16   Magnesium (Point/kg)

	Fossil fuels	Respiratory (inorganics)	Climate change	Acidification/ Eutrophication	Others	Total
Natural gas	0.265					
SO_2		0.140		0.008		
NOx		0.090		0.018		
CO_2			0.102			
Coal	0.025					
Crude oil	0.016					
Others		0.001				
Total	0.305	0.231	0.102	0.026	0.005	**0.669**

16.2.17   Zinc (Point/kg)

	Fossil fuels	Respiratory (inorganics)	Minerals	Ecotoxicity	Climate change	Carcino-genity	Others	Total
Zn (in ore)			0.102					
SO_2		0.076						
Natural gas	0.080							
NOx		0.040						
Zn				0.029				
CO_2					0.024			
Crude oil	0.038							
Ni						0.007		
As						0.006		
Others	0.005			0.002	0.002	0.003		
Total	0.123	0.114	0.102	0.031	0.026	0.015	0.024	**0.435**

16.2.18   Tin (Point/kg)

	Minerals	Fossil fuels	Respiratory (inorganics)	Climate change	Acidification/ Eutrophication	Others	Total
Sn (in ore)	15.900						
Natural gas		0.193					
Crude oil		0.180					
CO_2				0.080			
NO_2			0.066		0.013		
SOx			0.066		0.004		
NOx			0.020		0.004		
Coal		0.014					
Others			0.015				
Total	15.845	0.386	0.168	0.080	0.021	0.000	**16.500**

16.2.19   Iron (Point/kg)

	Respiratory (inorganics)	Fossil fuels	Others	Total
NOx	0.019			
Crude oil		0.015		
SO_2	0.009			
Others		0.007		
Total	0.027	0.022	0.020	**0.069**

16.2.20   Steel (Fe) (Point/kg)

	Respiratory (inorganics)	Fossil fuels	Others	Total
NOx	0.014			
Crude oil		0.013		
SO_2	0.008			
Others	0.005	0.009		
Total	0.027	0.022	0.015	**0.064**

16.2.21   Cobalt (Point/kg)

	Land-use	Fossil fuels	Respiratory (inorganics)	Climate change	Others	Total
Conversion to urban land	5.930					
Natural gas		0.122				
Crude oil		0.113				
CO_2				0.051		
NO_2			0.042			
SOx			0.042			
Conversion to industrial area						
Coal		0.009				
Others	0.015	0.001	0.005			
Total	5.945	0.244	0.091	0.051	0.033	**6.364**

16.3 Appendix 3a. Example 5 for CuZn30 (brass)

Metal		**Containing**		**Equation (for SO_2)**							
CuZn30 (brass) =		Cu rest, Zn 30		$\{\beta_{Cu}*0.70 + \beta_{Zn}*0.30\}_{Respiratory} + \{\beta_{Cu}*0.70\}_{Acidification}$							

	Respiratory (inorganics)	Minerals	Fossil fuels	Land-use	Ecotoxicity	Climate change	Acidification/ Eutrophication	Carcino-genity	Others	**Total value**	**SimaPro value**
Zn (in ore)		0.0306								**0.0306**	**0.0307**
Cu (in ore)		0.6237								**0.6237**	**0.624**
SO_2	0.6913						0.0385			**0.7298**	**0.731**
Natural gas			0.045							**0.045**	**0.0451**
NOx	0.0519						0.0077			**0.0596**	**0.0593**
Zn					0.0087					**0.0087**	**0.00876**
CO_2						0.0359				**0.0359**	**0.036**
Crude oil			0.1829							**0.1829**	**0.1831**
Conversion[7]				0.0329						**0.0329**	**0.0338**
Conversion[8]				0.0161						**0.0161**	**0.0161**
Ni								0.0021		**0.0021**	**0.00201**
As								0.0018		**0.0018**	**0.00167**
Others	0.0028	0.0007	0.0029	0.0028	0.0006	0.0006		0.0009	0.0072	**0.0185**	**0.01246**
Total	0.746	0.655	0.2308	0.0518	0.0093	0.0365	0.0462	0.0048	0.0072	**1.7876**	**1.784**

CuZn30 (brass) has a composition of Cu 70 ($c_w{}^{Cu}$) and Zn 30 ($c_w{}^{Zn}$). Tables 15 (Cu) and 17 (Zn) in Appendix 4 are weighted, according to composition, and put together. The number of listed origins (emissions, substances, etc) for CuZn30's load is not all, but the most significant. Each one has an equation, and the sum of these equals the total load for CuZn30. The equation for emission SO_2 is:

$$EI99_{SO2}= \{\beta_{cu}*0.70 + \beta_{Zn}*0.30\}_{Resp.} + \{\beta_{cu}*0.70 + \beta_{Zn}*0.30\}_{Acid.}= 0.7298$$

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[7] Conversion to urban land
[8] Conversion to industrial area

where: $\beta_{Cu, Resp.} = 0.955$

$\beta_{Zn, Resp.} = 0.076$

$\beta_{Cu, Acid.} = 0.055$

$\beta_{Zn, Acid.} = 0$, because the impact on category "Acidification/Eutrophication" for zinc is so small, that it is not represented

Emission of SO_2 affects both categories "Respiratory effects (inorganics)" and "Acidification/Eutrophication". The equation for CO_2, which only effects "Climate change", is shorter:

$$EI99_{CO2} = \{\beta_{Cu}*0.70 + \beta_{Zn}*0.30\}_{Climate} = 0.0359$$

where: $\beta_{Cu, Climate} = 0.041$

$\beta_{Zn, Climate} = 0.024$

The sums of the remaining equations are found in the example. Adding up all equations for the different origins results in a total load of 1.7867 Pt/kg. The calculated value from Example 1 in Appendix 1a of CuZn30 is 1.786, and the value from SimaPro is 1.784.

The element data are collected from Appendix 2.

16.4 Appendix 3b. Example 6 for X5CrNi 18 10 (aust.) (304)

Metal		Containing		Equation (for Ni, in ore)				
X5CrNi 18 10 (aust.) (304) $=$		Fe rest, Cr 18.0-20.0, Ni 8.0-10.5, Si 0.5, Mn <2.0, 20% recycled		$\{\beta_{Ni}*0.0925*0.80 + \beta_r*0.20\}_{Minerals}$				

TOTAL	**Respiratory (inorganics)**	**Minerals**	**Fossil fuels**	**Acidification/ Eutrophication**	**Climate change**	**Others**	**Total value**	**SimaPro value**
SO_2	0.164780			0.009176			**0.173956**	**0.188**
Ni (in ore)		0.051698					**0.051698**	**0.0552**
Cr (in ore)		0.004448					**0.004448**	**0.00443**
NO_x	0.007926						**0.007926**	**0.00808**
Natural gas			0.028841				**0.028841**	**0.0309**
Crude oil			0.037508				**0.037508**	**0.041768**
SO_x	0.014499			0.000592			**0.015091**	**0.0164**
CO_2					0.015853		**0.015853**	**0.0199**
NO_2	0.013377			0.001702			**0.015079**	**0.0178**
Others	0.007432	0.001720	0.019804	0.000074	0.001976	0.012190	**0.043196**	**0.018522**
Total	0.208014	0.057866	0.086153	0.011544	0.017829	0.012190	**0.393514**	**0.401**

X5CrNi 18 10 (304) has composition[6]: Fe 70.25 (c_w^{Fe}), Cr 19 (c_w^{Cr}), Ni 9.25 (c_w^{Ni}), Si 0.5 (c_w^{Si}), Mn 1.0 (c_w^{Mn}) and 20% recycled material (p_r). It takes ten equations to calculate the total load. Equations for the origins: SO_2, Ni (in ore), Cr (in ore), NO_x, natural gas, crude oil, SO_x, CO_2, NO_2 and others. The equation for SO_2 is:

$$EI99_{SO2}= \{ \beta_{Ni}*0.0925 + \beta_{Fe}*0.7025 \}_{Resp.}*0.80 + \{ \beta_{Ni}*0.0925 + \beta_{Fe}*0.7025 \}_{Acid.}*0.80 = 0.173956$$

where $\beta_{Ni, Resp.}= 2.166$
$\beta_{Fe, Resp.}= 0.008$
$\beta_{Ni, Acid.}= 0.124$
$\beta_{Fe, Acid.}= 0$, because the impact on category "Acidification/Eutrophication" for iron is so small, that it is not represented

And for Ni (in ore):

$$EI99_{Ni \text{ (in ore)}}= \{ (\beta_{Ni}*0.0925)*0.80 + \beta_r*0.20 \}_{Minerals} = 0.051698$$

where $\beta_{Ni, Minerals}= 0.577$
$\beta_{r, Minerals}= 0.045$

The sums of the rest of the equations are presented in the example. The total value is 0.394 (Pt/kg), which can be compared to the calculated value in Example 2, Appendix 1b: 0.394, and the value from SimaPro: 0.401.

The element data are collected from Appendix 2.