treeze Ltd., Kanzleistrasse 4, CH-8610 Uster, www.treeze.ch

LCA of climate friendly construction materials

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Authors
Martina Alig, Rolf Frischknecht, Luana Krebs, Livia Ramseier, Philippe Stolz

Commissioners
Bundesamt für Energie BFE, Amt für Hochbauten der Stadt Zürich AHB

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Authors	Martina Alig, Rolf Frischknecht, Luana Krebs, Livia Ramseier, Philippe Stolz treeze Ltd., fair life cycle thinking Kanzleistr. 4, CH-8610 Uster www.treeze.ch Phone +41 44 940 61 91, Fax +41 44 940 61 94 info@treeze.ch
Commissioner	Bundesamt für Energie BFE, Amt für Hochbauten der Stadt Zürich AHB
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Abbreviations

a	annum (year)
AHB	Amt für Hochbauten
AI	Artificial Intelligence
ARA	Abwasserreinigungsanlage; engl. wastewater treatment plant
BFE	Bundesamt für Energie, engl. Swiss Federal Office of Energy
CED	Cumulative Energy Demand
CFC	Chlorofluorocarbons
CH	Switzerland
DB	Deutsche Bahn; engl. German railways
DTI	Danish Technological Institute
EAF	electric arc furnace
EPD	Environmental Product Declaration
EPS	expanded polystyrene
EU	European Union
FGD	flue gas desulfurization
FOEN	Federal Office for the Environment
GHG	Greenhouse gas
GLO	Global
GWP	Global warming potential
HBI	hot-briquetted iron
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
KBOB	Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren; engl. Coordination Group for Construction and Property Services
KVA	Kehrichtverbrennungsanlage; engl. municipal solid waste incineration
LCA	life cycle assessment
LCI	life cycle inventory
LCIA	life cycle impact assessment
MAGF	Microwave Assisted Gas Firing
MSWI	Municipal solid waste incineration
NMVOC	non-methane volatile organic compounds
PE	Polyethylene
PFC	Perfluorocarbon
PLA	Polylactic acid
PUR	Polyurethane
PVC	Polyvinylchloride

RER	Europe
SBB	Schweizerische Bundesbahnen; engl. Swiss railways
szff	Schweizerische Zentrale Fenster und Fassaden
SZS	Stahlbau Zentrum Schweiz
tkm	ton kilometre, unit for transport services
UBP	Umweltbelastungspunkte; engl. eco-points
WWTP	Wastewater treatment plant
XPS	extruded polystyrene

Summary

Introduction

This report deals with life cycle assessments of future production of construction materials. In view of the massive greenhouse gas reductions that will be needed over the next two to three decades to achieve the goals of the Paris Climate Convention, it is inevitable that greenhouse gas emissions will also be significantly reduced in the building sector - not only in the operation of buildings, but also in their construction and dismantling. Life cycle inventory data of the future production of mineral and metal materials, wood and plastics used in structural engineering in and for Switzerland are in the focus of this report. Futhermore, the report also covers life cycle inventory data of future energy supply and transport services.

Methods

Information about the technological development of manufacturing processes, transport services and energy supply were collected in interviews with representatives from associations and pioneering companies and with desk top research. Data and information collected were consolidated and complemented with assumptions where necessary and used to establish life cycle inventory datasets. The datasets were established according to the methodological approach of the Swiss platform “Life Cycle Assessment data in construction”. The following construction materials were analysed: cement (clinker) and concrete; bricks; gypsum plaster boards; float glass; aluminium; copper; nickel; steel; zinc; wood materials (three layered laminated board, glue laminated timber, particle board and soft board); glass wool; rock wool; linoleum; and plastic materials (PE, PVC, EPS- and XPS-insulation as well as PLA).

The functional unit and reference flow used in the life cycle inventories of construction materials is 1 kg at the factory gate. The product systems encompass the extraction of the raw materials, their processing to construction materials, and their disposal. The use phase of the construction materials is excluded. The study refers to the time period between 2030 and 2050. The following environmental performance indicators were assessed: Cumulative energy demand (non-renewable and renewable); greenhouse gas emissions; and overall environmental impact.

The LCI data established in this project were applied on two building case studies: the office building of the Swiss Federal Office for Spacial Development (ARE) in Ittigen, Bern and the residential building Rautistrasse in Zurich were assessed according to SIA 2040 to evaluate the effects of the changes in construction material production on the environmental impacts of buildings.

Results

With future construction materials manufacture, substantial reductions in their environmental impacts are possible. On average, greenhouse gas emissions are reduced by 65 %. The average reduction of the non-renewable primary energy demand is 48 %; the average reduction of the overall environmental impact is 38 %. Substantial changes

in the production process itself were only considered for a few materials, as detailed and quantified target paths towards a climate-friendly or even net zero greenhouse gas emission manufacturing of construction materials were only available for a few of the industries considered. Most of the targets are of a more general nature and mainly involve a switch to renewable energy sources (in most cases electricity based on renewable energy sources or biogas), which is in consequence the measure considered in the future production of most of the building materials. For most materials the increase in energy efficiency is rather modest.

If substantial and unavoidable process-related greenhouse gas emissions occurred during the production of a construction material, a CCS system was assumed to be installed irrespective of the size of the production plant.

The environmental impacts of construction, use and end of life of the office building ARE and the residential building Rautistrasse were assessed using the life cycle inventories of future construction material manufacture. Future construction materials cover about 70 % of the mass of the office building and about 96 % of the mass of the residential building. Greenhouse gas emissions of construction and end of life of these two buildings can be reduced by around 50-60 %; the non-renewable primary energy demand by around 40 % and the overall environmental impact by about a third. The environmental impacts of the future office building ARE are 42 % (non-renewable energy demand) and 61 % (greenhouse gas emissions) lower, the environmental impacts of the future scenario residential building Rautistrasse 45 % (non-renewable energy demand) and 55 % (greenhouse gas emissions) lower than the corresponding SIA 2040 target values. This is very impressive and promising but not sufficient.

Recommendations for the different industries

For *cement and concrete* production, the geogenic CO_2 emissions during clinker production contribute most to the total greenhouse gas emissions. For a production congruent with the Paris Agreement, a way must be found to avoid, capture or neutralize these emissions. There are several pilot projects investigating on carbon capture technologies which should be pursued further. A major lever for reducing greenhouse gas emissions is also the clinker content in concrete. In the area of energy supply, further progress in energy efficiency should be made; a greenhouse gas neutral energy supply should be strived for.

For *brick* production, microwave-assisted gas firing is a promising technology that would make it possible to increase energy efficiency and facilitate the switch to renewable energy sources (electricity based on renewable energy sources in combination with biogas). The process-related CO_2 emissions generated during the firing of bricks still pose a challenge, as there is no solution for small-scale carbon capture and storage yet.

For *gypsum plaster boards*, no indication for innovative technological development in the manufacturing could be found. The replacement of fossil energy sources by biogenic sources reduces the greenhouse gas emissions by not more than a third – more measures need to be found. Furthermore, the use of FGD gypsum must be evaluated, since FGD gypsum is a by-product of the process of desulfurization of combustion gases from fossil fuels (coal, lignite, and oil) and might not be available to the same extent as today in a carbon neutral economy.

For *float glass* there are several promising technical developments (e.g. electric melting, oxyfuel combustion). The British glass sector has published a quantified reduction path. This knowledge should be used and implemented consistently. Open questions concern the process-related CO_2 emissions during melting, as there is no solution for small-scale carbon capture and storage yet. One way to reduce these emissions is to increase the proportion of recycled glass.

For *aluminium*, there are production methods available today which significantly lower the greenhouse gas emissions. They are mainly based on the use of renewable electricity in aluminium electrolysis. To achieve greenhouse gas neutral production, further improvement measures (e.g. with regard to the anodes) would have to be implemented and in particular the entire energy supply (including heat) would have to be converted to 100 % renewable energy sources. Carbon capture and storage in aluminium smelters is considered to be technically challenging.

For *copper*, no quantitative data on future production or mitigation paths were available. However, severals companies / mines are working towards a carbon-free production and there are mines presently preparing to use 100 % renewable energy. Since the use of fossil fuels is the main source of greenhouse gas emissions from copper production, the transition to renewable energy carriers and the improvement of the energy efficiency must be adressed with priority.

For *nickel* production either, no specific information could be obtained on future production. However, the same measures as for copper are central: increasing energy efficiency and replacing fossil fuels with renewable ones.

For the *European steel* production, there is a new production route with hydrogen direct reduction steelmaking. When producing the hydrogen necessary for this process by electrolysis of water, steel production can be completely driven with renewable electricity. The hydrogen direct reduction steelmaking process design is similar to the traditional steelmaking route and is based on existing technologies. Obstacles for the implementation might be the availability of renewable electricity resp. hydrogen produced via electrolysis.

For *steel production for the Swiss market*, no quantitative information on future production could be obtained. The Swiss steel industry is mainly pursuing measures to increase energy efficiency and improve yields in scrap reycling.

For *zinc* production, no specific information could be obtained on future production. However, the same measures as for copper and nickel are central: increasing energy efficiency and replacing fossil fuels with renewable ones. Additionally, the implementation of most recent production methods worldwide could significantly reduce heavy metal and other toxic emissions.

For *wood materials*, the transistion to renewable energy carriers in forest machinery and industrial processes is central. Most of the relevant technologies are available, questions still remain regarding the availability of renewable energy sources (ethanol and biogas).

For *glass wool*, no futher improvements of the energy efficiency can be expected. Already today, the melting of the raw materials is done using electricity as energy source. In order to achieve more climate friendly production, natural gas used in the curing oven can be replaced by biogas, if the availability of sustainably produced biogas is given.

For the manufacture of future *rock wool*, no detailed information was available. Therefore, the same procedure as for glass wool was applied: replacement of fossil fuels (hard coal coke and natural gas) by biogas. This measure is technically feasible today, if there is enough sustainably produced biogas. Another strategy would be the electrification of the production process.

Linoleum can be produced with electricity and biogas as sole energy carriers, which allows the use of 100 % renewable energy carriers if using a corresponding electricity mix. For climate-neutral production, also the agricultural and industrial processes to obtain the linseed oil used for the linoleum must be carried out without emitting significant amounts of greenhouse gases.

For the *plastic materials* assessed, no quantitative information was available about their future production. Potential measures are to foster the use of renewable and recycled feedstock at the level of production. In order to achieve greenhouse gas-neutral production, appropriate reduction paths should be developed and quantified so that the degree to which the targets have been achieved can be continuously monitored.

Limitations and outlook

The present analysis refers exclusively to the primary production of building materials and current material losses in construction and manufacturing building elements. The environmental impact of building materials may also be reduced by other measures, such as increasing the proportion of recycled feedstock materials or increasing the material efficiency. There are also other measures at building level, for example the optimisation of the building design, use of low-impact building materials and completely different construction methods or re-use of entire building components. Such measures have not been considered in this report.

The current SIA 2040 target values represent an intermediate goal of the 2000-Watt-society as defined in 2014. With the new goal of the 2000-Watt-society launched in 2020 (net zero greenhouse gas emissions by 2050), construction material industries need to reduce the greenhouse gas emissions in their supply chains to close to zero. These emission reductions require binding committments to the 1.5°C target and substantial changes in the production processes of construction material industries and their supply chains. Since such changes in production processes often involve major investments, clear signals from the Swiss Federal Council and a reliable legal framework issued by the Swiss Federal Parliament and the Cantons are needed for facilitating the transition to net zero greenhouse gas emission buildings and construction material production within the next two to three decades.

Zusammenfassung

Einführung

Angesichts der massiven Treibhausgas-Reduktionen, die in den nächsten zwei bis drei Jahrzehnten erforderlich sein werden, um die Ziele der Pariser Klimakonvention zu erreichen, ist es unumgänglich, dass auch im Gebäudesektor die Treibhausgas-Emissionen deutlich reduziert werden - nicht nur im Betrieb von Gebäuden, sondern auch bei deren Errichtung und Rückbau. Im Zentrum des Berichts stehen Sachbilanzdaten zur zukünftigen Produktion von mineralischen und metallischen Werkstoffen, Holz und Kunststoffen für den Schweizer Hochbau. Darüber hinaus umfasst der Bericht auch Sachbilanzdaten der zukünftigen Energieversorgung und Transportdienstleistungen.

Methodik

In Interviews mit Vertretern von Verbänden und Pionierunternehmen sowie mittels Literaturrecherche wurden Informationen über die technologische Entwicklung von Produktionsprozessen, Transportdienstleistungen und Energieversorgung gesammelt. Die zusammengestellten Daten und Informationen wurden konsolidiert, gegebenenfalls durch Annahmen ergänzt und zur Erstellung von Sachbilanzdatensätzen verwendet. Die Datensätze wurden nach dem methodischen Ansatz der Schweizer Plattform "Ökobilanzdaten im Baubereich" erstellt. Folgende Baumaterialien wurden analysiert: Zement (Klinker) und Beton; Backsteine; Gipskartonplatten; Flachglas; Aluminium; Kupfer; Nickel; Stahl; Zink; Holzwerkstoffe (Dreischicht-Laminatplatten, Brettschichtholz, Spanplatten und Weichplatten); Glaswolle; Steinwolle; Linoleum und Kunststoffe (PE, PVC, EPS- und XPS-Dämmung sowie PLA).

Die funktionelle Einheit und der Referenzfluss in den erstellten Datensätzen zur zukünftigen Produktion von Baumaterialien ist 1 kg Baumaterial ab Werkstor. Die Systemgrenze umfasst die Gewinnung der Rohstoffe, ihre Verarbeitung zu Baustoffen und ihre Entsorgung nach Ende der Nutzungsdauer. Die Nutzungsphase der Baumaterialien wurde nicht betrachtet. Die Studie bezieht sich auf eine Situation im Zeitraum zwischen 2030 und 2050. Folgende Umweltindikatoren wurden analysiert: Kumulierter Energieaufwand (nicht erneuerbar und erneuerbar); Treibhausgasemissionen und Gesamtumweltbelastung.

Die in diesem Projekt ermittelten Ökobilanzdaten wurden auf zwei Gebäudefallstudien angewendet: Das Bürogebäude des Bundesamtes für Raumentwicklung (ARE) in Ittigen und das Wohngebäude Rautistrasse in Zürich wurden gemäss SIA 2040 modelliert und bewertet, um die Auswirkungen der Veränderungen in der Baumaterialproduktion auf die Umweltwirkungen von Gebäuden zu beurteilen.

Resultate

Mit zukünftigen Produktionsweisen können die Umweltwirkungen der Baumaterialherstellung wesentlich verringert werden. Im Durchschnitt liegen die spezifischen Treibhausgasemissionen um 65 %, der nicht erneuerbarer Primärenergiebedarf um 48 % und die Gesamtumweltbelastung um 38 % tiefer als heute. Erhebliche Veränderungen im

Produktionsprozess selbst wurden nur für wenige Materialien berücksichtigt, da detaillierte und quantifizierte Zielpfade hin zu einer klimafreundlichen oder sogar treibhausgasneutralen Herstellung von Baumaterialien nur für wenige der betrachteten Branchen zur Verfügung standen. Der Grossteil der vorhandenen Branchenziele sind allgemeinerer Natur und beinhalten hauptsächlich eine Umstellung auf erneuerbare Energiequellen (in den meisten Fällen Elektrizität auf der Grundlage erneuerbarer Energiequellen oder Biogas). Dies ist folglich die Massnahme, die bei der künftigen Produktion der Baumaterialien am häufigsten betrachtet wurde. Die zukünftige Steigerung der Energieeffizienz ist bei den meisten Materialien eher bescheiden.

Wenn bei der Herstellung eines Baustoffs erhebliche und unvermeidbare prozessbedingte CO_2-Emissionen anfallen, wurde unabhängig von der Grösse der Produktionsanlage die Installation eines CCS-Systems berücksichtigt.

Mit den erstellten Ökobilanzdatensätzen zur zukünftigen Produktion von Baumaterialien wurden die zukünftigen Umweltwirkungen von Erstellung, Nutzung und Rückbau des Bürogebäudes ARE und des Wohngebäudes Rautistrasse berechnet. Die zukünftigen Baumaterialien decken dabei etwa 70 % der Gebäudemasse des Bürogebäudes und etwa 96 % der Gebäudemasse des Wohngebäudes ab. Die Treibhausgasemissionen beim Bau und Rückbau dieser beiden Gebäude können um rund 50-60 %, der nicht-erneuerbare Energiebedarf um etwa 40 % und die Gesamtumweltbelastung um circa ein Drittel gesenkt werden. Die Umweltwirkungen des zukünftigen Bürogebäudes ARE sind um 42 % (nicht-erneuerbarer Energiebedarf) und 61 % (Treibhausgasemissionen), die Umweltwirkungen des zukünftigen Wohngebäudes Rautistrasse um 45 % (nicht-erneuerbarer Energiebedarf) und 55 % (Treibhausgasemissionen) geringer als die entsprechenden Zielwerte des Merkblatts SIA 2040. Dies ist beachtlich und vielversprechend, aber nicht ausreichend.

Empfehlungen für die einzelnen Branchen

Bei der *Zement- und Betonproduktion* tragen die geogenen CO_2-Emissionen bei der Klinkerherstellung am meisten zu den gesamten Treibhausgasemissionen bei. Für eine mit dem Pariser Abkommen kompatible Produktion muss ein Weg gefunden werden, diese Emissionen zu vermeiden, aufzufangen oder zu neutralisieren. Aktuell laufen mehrere Pilotprojekte, welche verschiedene Technologien zur Kohlendioxidabscheidung untersuchen. Diese sollten weiter verfolgt werden. Ein wichtiger Hebel zur Reduktion der Treibhausgasemissionen ist auch der Klinkeranteil im Beton. Weitere Fortschritte sollten bei der Energieeffizienz erzielt werden; und eine treibhausgasneutrale Energieversorgung ist anzustreben.

Für die *Backsteinproduktion* ist die mikrowellenunterstützte Gasfeuerung eine vielversprechende Technologie, welche eine Steigerung der Energieeffizienz ermöglicht und den Umstieg auf erneuerbare Energiequellen (Strom auf Basis erneuerbarer Energiequellen in Kombination mit Biogas) erleichtert. Die prozessbedingten CO_2-Emissionen, die beim Brennen von Backsteinen entstehen, stellen nach wie vor eine Herausforderung dar, da es noch keine Lösung für die Kohlenstoffabscheidung und -speicherung in kleinem Massstab gibt.

Für *Gipskartonplatten* konnten keine Anhaltspunkte für innovative technologische Entwicklungen bei der Herstellung gefunden werden. Der Ersatz fossiler Energieträger durch biogene Quellen reduziert die Treibhausgasemissionen um nicht mehr als ein Drittel. Weitere Massnahmen sind nötig. Darüber hinaus muss der Einsatz von REA-Gips evaluiert werden, da REA-Gips ein Nebenprodukt der Entschwefelung von Verbrennungsgasen aus fossilen Energieträgern (Kohle, Braunkohle und Öl) ist und möglicherweise in einer kohlenstoffneutralen Wirtschaft nicht im gleichen Umfang zur Verfügung steht wie heute.

Für *Flachglas* gibt es mehrere vielversprechende technische Entwicklungen (z.B. elektrisches Schmelzen, Oxyfuel-Verbrennung). Der britische Glassektor hat einen quantifizierten Reduktionspfad veröffentlicht. Dieses Wissen soll konsequent genutzt und umgesetzt werden. Offene Fragen betreffen die prozessbedingten CO_2-Emissionen beim Schmelzen, da es noch keine Lösung für die Kohlenstoffabscheidung und -speicherung im kleinen Massstab gibt. Eine Möglichkeit, diese Emissionen zu reduzieren, ist die Erhöhung des Anteils von Recyclingglas.

Für *Aluminium* gibt es schon heute Produktionsmethoden, die die Treibhausgas-emissionen deutlich senken. Sie basieren hauptsächlich auf der Verwendung von erneuerbarer Elektrizität in der Aluminiumelektrolyse. Um eine treibhausgasneutrale Produktion zu erreichen, müssten weitere Verbesserungsmassnahmen (z.B. in Bezug auf die Anoden) umgesetzt und insbesondere die gesamte Energieversorgung (inkl. Wärme) auf 100 % erneuerbare Energieträger umgestellt werden. Die Kohlenstoffabscheidung und -speicherung in Aluminiumhütten gilt als technisch anspruchsvoll.

Für *Kupfer* lagen keine quantitativen Daten über die zukünftige Produktion oder konkrete Absenkpfade vor. Verschiedene Unternehmen/Minen arbeiten jedoch auf eine treibhausgasneutrale Produktion hin, und es gibt Minen, die sich gegenwärtig auf die Nutzung von 100 % erneuerbarer Energie ausrichten. Da die Nutzung fossiler Brennstoffe die Hauptquelle der Treibhausgasemissionen aus der Kupferproduktion ist, muss der Übergang zu erneuerbaren Energieträgern und die Verbesserung der Energieeffizienz vorrangig angegangen werden.

Auch für die *Nickelproduktion* konnten keine spezifischen Informationen über die zukünftige Produktion ermittelt werden. Im Mittelpunkt stehen jedoch die gleichen Massnahmen wie bei Kupfer: die Steigerung der Energieeffizienz und der Ersatz fossiler durch erneuerbare Energieträger.

Für die *europäische Stahlproduktion* gibt es mit der Eisenherstellung mittels Direkt-reduktion auf der Basis von Wasserstoff einen neuen Produktionsweg. Wenn der für diesen Prozess notwendige Wasserstoff mittels Elektrolyse von Wasser hergestellt wird, kann die Stahlproduktion vollständig mit erneuerbarer Elektrizität betrieben werden. Das System des Wasserstoff-Direktreduktions-Stahlerzeugungsprozesses ähnelt dem traditionellen Stahlerzeugungsweg und basiert auf bestehenden Technologien. Hindernisse für die Umsetzung könnten die Verfügbarkeit von erneuerbarer Elektrizität bzw. von durch Elektrolyse erzeugtem Wasserstoff sein.

Für die *Stahlproduktion für den Schweizer Markt* (100 % Elektrostahl) konnten keine quantitativen Informationen über die zukünftige Produktion ermittelt werden. Die

Schweizer Stahlindustrie verfolgt vor allem Massnahmen zur Steigerung der Energieeffizienz und zur Verbesserung der Ausbeute beim Schrottrecycling.

Für die *Zinkproduktion* liegen keine spezifischen Informationen über die zukünftige Produktion vor. Im Zentrum stehen jedoch die gleichen Massnahmen wie bei Kupfer und Nickel: die Steigerung der Energieeffizienz und der Ersatz fossiler durch erneuerbare Energieträger. Darüber hinaus könnte die Einführung neuester Produktionsmethoden weltweit die Emissionen von Schwermetallen und anderen toxischen Stoffen erheblich reduzieren.

Bei *Holz- und Holzwerkstoffen* ist der Umstieg auf erneuerbare Energieträger bei Forstmaschinen und industriellen Prozessen zentral. Die meisten der relevanten Technologien sind verfügbar, es bestehen allerding noch Fragen bezüglich der Verfügbarkeit der erneuerbaren Energiequellen (Ethanol und Biogas).

Bei *Glaswolle* sind keine weiteren Verbesserungen der Energieeffizienz zu erwarten. Bereits heute erfolgt das Schmelzen der Rohstoffe mit Strom als Energiequelle. Um eine klimafreundlichere Produktion zu erreichen, kann das im Härteofen verwendete Erdgas durch Biogas ersetzt werden, wenn die Verfügbarkeit von nachhaltig erzeugtem Biogas gegeben ist.

Zur Herstellung der zukünftigen *Steinwolle* lagen keine detaillierten Informationen vor. Daher wurde das gleiche Vorgehen gewählt wie bei der Glaswolle: Ersatz der fossilen Brennstoffe (Steinkohlenkoks und Erdgas) durch Biogas. Diese Maßnahme ist technisch machbar, Voraussetzung ist, dass genügend nachhaltig erzeugtes Biogas zur Verfügung steht. Eine andere Strategie ist die Elektrifizierung des Produktionsprozesses.

Linoleum kann mit Strom und Biogas als alleinige Energieträger hergestellt werden, was bei entsprechendem Strommix den Einsatz von 100 % erneuerbaren Energieträgern ermöglicht. Für eine klimaneutrale Produktion müssten auch die landwirtschaftlichen und industriellen Prozesse zur Gewinnung des für das Linoleum verwendeten Leinöls ohne nennenswerten Ausstoss von Treibhausgasen erfolgen.

Für die untersuchten *Kunststoffe* lagen keine quantitativen Angaben über ihre zukünftige Produktion vor. Mögliche Massnahmen sind die Förderung des Einsatzes von erneuerbaren und recycelten Rohstoffen auf der Ebene der Produktion. Um eine treibhausgasneutrale Produktion zu erreichen, sollten geeignete Reduktionspfade entwickelt und quantifiziert werden, so dass der Grad der Zielerreichung kontinuierlich überwacht werden kann.

Einschränkungen und Ausblick

Die vorliegende Analyse bezieht sich ausschliesslich auf die Primärproduktion von Baumaterialien (mit Ausnahme der Stahlprofile für den Schweizer Markt, die zu 100 % aus Stahlschrott hergestellt werden) und die aktuellen Materialverluste bei der Herstellung und Verarbeitung von Bauelementen. Die Umweltwirkungen von Baumaterialien können auch durch andere Massnahmen reduziert werden, wie z.B. die Erhöhung des Anteils von rezyklierten Ausgangsmaterialien oder die Erhöhung der Materialeffizienz. Auch auf Gebäudeebene gibt es weitere Massnahmen, zum Beispiel die Optimierung des Gebäudedesigns, die Verwendung emissionsarmer Baumaterialien, die Berücksichtigung alternativer Bauweisen oder die Wiederverwendung ganzer Bauelemente. Solche Massnahmen waren nicht Gegenstand der Untersuchungen und sind deshalb in diesem Bericht nicht berücksichtigt worden.

Die aktuellen Zielwerte gemäss SIA 2040 stellen ein im Jahr 2014 definiertes Zwischenziel der 2000-Watt-Gesellschaft dar. Mit dem neuen, im Jahr 2020 eingeführten Ziel der 2000-Watt-Gesellschaft (Netto-Null-Treibhausgasemissionen bis 2050) muss die Baustoffindustrie die Treibhausgasemissionen bei sich und in ihren Lieferketten auf nahezu Null senken. Diese Emissionsreduktion auf netto Null erfordert eine verbindliche Verpflichtung auf das 1,5°C-Ziel und wesentliche Veränderungen in den Produktionsprozessen. Da solche Veränderungen in den Produktionsprozessen oft mit grossen Investitionen verbunden sind, braucht es klare Signale des Bundesrates und einen verlässlichen Rechtsrahmen von Parlament und Kantonen, um den Übergang zu Netto-Null-Treibhausgasemissionsgebäuden und -baustoffproduktion innerhalb der nächsten zwei bis drei Jahrzehnte zu ermöglichen.

Résumé

Introduction

Compte tenu des réductions massives d’émissions de gaz à effet de serre qu’il faudra faire ces deux ou trois prochaines décennies afin d’atteindre les objectifs de l’Accord de Paris sur le climat, il est impératif que le secteur du bâtiment réduise également ses émissions, non seulement celles imputées à l’exploitation des bâtiments, mais aussi celles liées à leur construction et à leur démantèlement. Ce rapport s’intéresse aux données d’inventaire de cycle de vie (ICV) de la future fabrication de matériaux minéraux et métalliques, de bois et de matières plastiques dans le secteur du bâtiment en Suisse. Il contient en outre les données d’ICV relatives au futur approvisionnement en énergie et aux services de transport.

Méthodologie

Nous avons procédé à des entretiens avec des représentants d’associations et d’entreprises pionnières dans le domaine, ainsi qu’à des recherches bibliographiques, afin de récolter des informations sur le développement technologique des processus de fabrication, des services de transport et de l’approvisionnement en énergie. Après avoir consolidé les données et les informations recueillies, nous les avons complétées, le cas échéant, avec des hypothèses, et utilisées pour obtenir des ensembles de données d’ICV. Ces données ont été compilées selon l’approche méthodologique de la Plate-forme suisse de données des écobilans dans la construction. Nous avons analysé les matériaux de construction suivants: le ciment (clinker) et le béton, les briques, les plaques de plâtre, le verre plat, l’aluminium, le cuivre, le nickel, l’acier, le zinc, les matériaux dérivés du bois (panneaux de particules à trois couches, bois lamellé collé, panneaux agglomérés et panneaux de fibres tendres), la laine de verre, la laine minérale, le linoléum et les matières plastiques (polyéthylène, PVC, panneaux isolants en EPS et XPS, ainsi que le PLA).

L’unité fonctionnelle et le flux de référence utilisés pour les données compilées sur la fabrication future de matériaux de construction sont le kilo de matériaux à la sortie de l’usine. Le système couvre l’extraction des matières premières, leur transformation en matériaux de construction et leur élimination à la fin de la durée d’utilisation. La phase d’utilisation n’a pas été prise en considération. L’étude cible la situation sur une période allant de 2030 à 2050. Les indices environnementaux suivants ont été analysés: la consommation d’énergie cumulée (renouvelable et non renouvelable), les émissions de gaz à effet de serre et la charge environnementale totale.

Les données des écobilans calculées dans le cadre de ce projet ont été appliquées à deux études de cas, le bâtiment administratif de l’Office fédéral du développement territorial (ARE), à Ittigen, et un immeuble de logements à la Rautistrasse, à Zurich. Les deux bâtiments ont été modélisés et expertisés selon la norme SIA 2040 pour évaluer les incidences des changements dans la fabrication des matériaux de construction sur l’impact environnemental des bâtiments.

Résultats

Les modes de fabrication futurs permettent de réduire considérablement l’impact environnemental des matériaux de construction. Les émissions de gaz à effet de serre spécifiques sont en moyenne inférieures de 65 % aux émissions actuelles. Les besoins en énergie primaire sont, pour leur part, inférieurs de 48 % aux besoins actuels et la charge environnementale totale est inférieure de 38 % à la charge actuelle. Les changements significatifs dans le processus de fabrication ont été pris en compte pour quelques matériaux seulement. En effet, des objectifs détaillés et quantifiés en vue d’une production de matériaux de construction respectueuse du climat, voire neutre en émissions de gaz à effet de serre, n’étaient disponibles que pour un nombre restreint des secteurs pris en considération. La majorité des objectifs sectoriels existants sont généraux et visent principalement un passage à des sources d’énergies renouvelables (dans la plupart des cas, à un approvisionnement en électricité provenant d’énergies renouvelables ou du biogaz). Par conséquent, il s’agit de la mesure prise le plus souvent en compte dans la future fabrication de matériaux de construction. L’augmentation future de l’efficacité énergétique est négligeable pour la plupart des matériaux.

Si le processus de fabrication d’un matériau de construction est source d’importantes et inévitables émissions de CO_2, l’installation d’un système de séquestration géologique du CO_2 indépendamment de la taille de l’usine de fabrication a été envisagée.

L’impact environnemental futur de la construction, de l’utilisation et du démantèlement du bâtiment administratif de l’ARE et de l’immeuble d’habitation à la Rautistrasse a été calculé à l’aide des données d’écobilans de la future fabrication des matériaux de construction. Les futurs matériaux de construction représentent environ 70 % de la masse du bâtiment administratif et environ 96 % de celle de l’immeuble d’habitation. Il est possible de diminuer les émissions de gaz à effet de serre lors de la construction et du démantèlement de ces deux bâtiments d’environ 50 à 60 %, les besoins en énergies non renouvelables d’environ 40 % et la charge environnementale totale d’environ un tiers. L’impact environnemental du futur bâtiment administratif de l’ARE est inférieur de 42 % (consommation d’énergies non renouvelables) et de 61 % (émissions de gaz à effet de serre), celui du futur bâtiment de la Rautistrasse, de 45 % (consommation d’énergies non renouvelables) et de 55 % (émissions de gaz à effet de serre) aux valeurs cibles inscrites dans la fiche technique SIA 2040. Même si ces résultats sont remarquables et prometteurs, ils ne sont pas suffisants.

Recommandations pour chaque secteur

Pour le *ciment et le béton*, ce sont les émissions de CO_2 géogènes libérées lors de la fabrication du clinker qui contribuent majoritairement aux émissions de gaz à effet de serre. Pour que la production soit compatible avec les accords de Paris, il faut trouver un moyen d’éviter, de capturer ou de neutraliser ces émissions. Plusieurs projets pilotes sont en cours pour étudier diverses technologies de capture du dioxyde de carbone. Il convient de les approfondir. La proportion de clinker dans le béton est également un levier important pour réduire les gaz à effet de serre. Il faudra réaliser des progrès supplémentaires en matière d’efficacité énergétique et rechercher une solution d’approvisionnement en énergie neutre en émissions de gaz à effet de serre.

Pour la *fabrication des briques*, la cuisson au gaz assistée de micro-ondes est une technologie prometteuse, car elle permet d'augmenter l'efficacité énergétique et de faciliter l'utilisation de sources d'énergies renouvelables (approvisionnement en électricité provenant de sources d'énergies renouvelables combinées au biogaz). Le CO_2 émis lors du processus de cuisson des briques représente toujours un défi, car il n'existe encore aucune solution à petite échelle pour capter et stocker le dioxyde de carbone.

Pour les *plaques de plâtre*, il n'a pas été possible de trouver le moindre indice de développement technologique innovant lié à leur fabrication. Remplacer les carburants fossiles par des bioénergies réduit de moins d'un tiers les émissions de gaz à effet de serre. D'autres mesures sont nécessaires. L'utilisation de gypse de désulfuration doit en outre être évaluée, car ce type de gypse est un sous-produit de la désulfuration des gaz de combustion émis par les combustibles fossiles (charbon, lignite et pétrole). Il pourrait donc ne pas être disponible en aussi grande quantité qu'aujourd'hui dans une économie neutre en émissions de carbone.

Pour le *verre plat*, il existe de nombreuses innovations technologiques prometteuses (par ex. la fusion électrique ou l'oxycombustion). Le secteur du verre en Grande-Bretagne a publié des objectifs de réduction chiffrés. Il faut utiliser ces connaissances et les mettre en œuvre de manière cohérente. Les questions restées sans réponses concernent les émissions de CO_2 libérées lors du processus de fusion, car il n'existe encore aucune solution à petite échelle pour capter et stocker le dioxyde de carbone. Augmenter la proportion de verre recyclé est une solution pour réduire ces émissions.

Pour l'*aluminium*, il existe déjà aujourd'hui des modes de production permettant de réduire drastiquement les émissions de gaz à effet de serre. Ils se fondent principalement sur l'utilisation d'électricité provenant d'énergies renouvelables pour l'électrolyse de l'aluminium. Afin de parvenir à une production neutre en émissions de gaz à effet de serre, d'autres mesures d'amélioration sont nécessaires (par ex. en ce qui concerne les anodes). Il faut en particulier que l'intégralité de l'approvisionnement énergétique (y compris la chaleur) provienne de sources d'énergies renouvelables. La capture et le stockage du dioxyde de carbone dans les fonderies d'aluminium sont techniquement complexes.

Pour le *cuivre*, il n'existe aucune donnée quantitative sur la production future ou les objectifs concrets de réduction des émissions. Diverses entreprises et diverses mines travaillent à une production neutre en émissions de gaz à effet de serre. Certaines mines se tournent actuellement vers une utilisation à 100 % d'énergies renouvelables. L'utilisation de combustibles fossiles dans la production du cuivre étant la source principale des émissions de gaz à effet de serre, le passage à des énergies renouvelables et l'amélioration de l'efficacité énergétique doivent être une priorité.

Pour le *nickel* non plus, aucune information spécifique à la production future n'a pu être obtenue. Les mesures essentielles sont toutefois les mêmes que celles qui s'appliquent pour le cuivre: l'augmentation de l'efficacité énergétique et le remplacement des énergies fossiles par des énergies renouvelables.

Pour la *production européenne d'acier*, une nouvelle voie a été trouvée grâce à la réduction directe du minerai de fer à l'hydrogène. La production d'acier peut alors être entièrement réalisée grâce aux énergies renouvelables, à condition que l'hydrogène nécessaire au processus soit produit par électrolyse de l'eau. Le processus de réduction directe du minerai de fer à l'hydrogène ressemble à celui de la fabrication traditionnelle et se fonde sur des technologies existantes. Les seuls obstacles à sa mise en œuvre peuvent être la disponibilité d'électricité issue de sources d'énergies renouvelables et d'hydrogène produit par électrolyse.

Pour l'*acier destiné au marché suisse* (100 % d'acier électrique), aucune information quantitative sur la production future n'a pu être obtenue. L'industrie suisse de l'acier prend surtout des mesures dans le but d'augmenter l'efficacité énergétique et d'améliorer le rendement lors du recyclage.

Pour le *zinc*, il n'existe aucune information spécifique sur la production future. Les mesures principales sont toutefois les mêmes que celles qui s'appliquent pour le cuivre et le nickel: l'augmentation de l'efficacité énergétique et le remplacement des énergies fossiles par des énergies renouvelables. L'introduction de tout nouveaux modes de production a en outre permis de réduire drastiquement à l'échelle mondiale les émissions de métaux lourds et d'autres substances toxiques.

Pour les *matériaux en bois et leurs dérivés*, le passage à des énergies renouvelables est capital dans le domaine des machines forestières et des processus industriels. La plupart des technologies importantes sont disponibles. Il reste toutefois des questions ouvertes sur la disponibilité des sources d'énergies renouvelables (éthanol et biogaz).

Pour la *laine de verre*, aucune autre amélioration de l'efficacité énergétique n'est attendue. La fusion des matières premières se fait déjà grâce à du courant issu de sources d'énergies renouvelables. Pour une production encore plus respectueuse de l'environnement, le gaz naturel utilisé dans le four de recuit peut être remplacé par du biogaz, à condition que du biogaz produit selon des méthodes durables soit disponible.

Pour la *laine de pierre*, il n'existe aucune information sur la production future. Par conséquent, la même procédure que celle appliquée à la laine de verre a été choisie, à savoir le remplacement des combustibles fossiles (coke et gaz naturel) par du biogaz. Cette mesure est techniquement possible, à condition d'avoir à disposition une quantité suffisante de biogaz produit selon des méthodes durables. Une autre stratégie réside dans l'électrification des processus de fabrication.

Le *linoléum* peut être fabriqué avec de l'électricité et du biogaz comme seules sources d'énergie, ce qui permet l'utilisation de sources d'énergies 100 % renouvelables avec le mix électrique approprié. Pour une production neutre envers le climat, il ne devrait pas y avoir non plus d'émissions notables de gaz à effet de serre dans les processus agricoles et industriels d'extraction de l'huile de lin utilisée dans sa fabrication.

Pour les *matières plastiques* examinées, il n'existe aucune donnée quantitative sur la production future. Une éventuelle mesure à adopter consisterait à encourager, au niveau de la fabrication, l'utilisation de matières premières renouvelables et recyclables. Pour parvenir à une production neutre en émissions de gaz à effet de serre, il faudrait élaborer et chiffrer des objectifs de réduction, de sorte à pouvoir évaluer en continu le degré d'atteinte de ces objectifs.

Limites et perspectives

La présente analyse s’intéresse uniquement à la production primaire de matériaux de construction (à l’exception des profils d’acier destinés au marché suisse, produits à 100 % à partir de débris d’acier) et aux pertes actuelles dans la fabrication et le traitement des éléments de construction. L’impact environnemental des matériaux de construction peut également être réduit grâce à d’autres mesures, telles que l’augmentation de la proportion de matières premières recyclées ou l’amélioration de l’efficacité des matériaux. Il existe également d’autres mesures au niveau des bâtiments, par exemple l’optimisation de la conception du bâtiment, l’utilisation de matériaux de construction à faibles émissions, l’intégration de modes de constructions alternatifs ou la réutilisation d’éléments de construction entiers. Nos recherches ne portaient pas sur de telles mesures; ces dernières ne sont donc pas prises en considération dans le présent rapport.

Les valeurs cibles actuelles fixées par la norme SIA 2040 représentent un objectif intermédiaire de la société à 2000 watts défini en 2014. Avec le nouvel objectif de la société à 2000 watts introduit en 2020 (zéro émission nette de gaz à effet de serre à l’horizon 2050), l’industrie des matériaux de construction doit réduire les émissions de gaz à effet de serre dans ses propres installations et dans ses chaînes logistiques à un niveau proche de zéro. Cette réduction des émissions nettes à zéro nécessite un engagement contraignant dans l’objectif de limiter le réchauffement à 1,5 C° et des changements essentiels dans les processus de fabrication. Comme de tels changements exigent souvent de lourds investissements, il faut un signal clair de la part du Conseil fédéral et l’élaboration d’un cadre juridique fiable par le Parlement et les cantons afin de permettre une transition vers des bâtiments et une fabrication des matériaux de construction à émissions nettes de gaz à effet de serre nulles dans les deux à trois prochaines décennies.

Sintesi

Introduzione

In considerazione della necessità di una forte riduzione delle emissioni di gas a effetto serra nei prossimi due-tre decenni per raggiungere gli obiettivi posti nel quadro dell'Accordo di Parigi sul clima, è indispensabile ridurre sensibilmente tali emissioni anche nel settore edilizio, non solo nell'esercizio degli immobili, ma anche per quanto riguarda la costruzione e lo smantellamento. Il rapporto è incentrato sulla valutazione del ciclo di vita della futura produzione di materiali minerali e metallici, di legno e materie plastiche per le opere di edilizia svizzere. Comprende inoltre la valutazione del ciclo di vita dell'approvvigionamento energetico e delle prestazioni nell'ambito dei trasporti nel futuro.

Metodologia

Tramite interviste condotte con rappresentanti di associazioni mantello e imprese pionieristiche e una ricerca bibliografica sono state raccolte informazioni sullo sviluppo tecnologico dei processi di produzione, delle prestazioni di trasporto e dell'approvvigionamento energetico. I dati e le informazioni riassunti sono stati elaborati, laddove necessario completati con ipotesi e poi impiegati ai fini dell'allestimento delle serie di dati per la valutazione dei cicli di vita. Le serie di dati sono state elaborate secondo l'approccio metodico della piattaforma svizzera «Dati dell’ecobilancio nel settore della costruzione». Sono stati analizzati i seguenti materiali di costruzione: cemento (clinker) e calcestruzzo; mattoni; pannelli di cartongesso; vetro piano; alluminio; rame; nichel; acciaio; zinco; materiali in legno (pannelli in laminato a 3 strati, legno lamellare, truciolati e pannelli in fibra di legno morbida); lana di vetro; lana di roccia; linoleum e materie plastiche (PE, PVC, pannelli isolanti EPS e XPS nonché PLA).

Nelle serie di dati elaborate per la futura produzione di materiali di costruzione, l'unità funzionale e il flusso di riferimento si basano su 1 kg di materiale di costruzione in uscita dalla fabbrica. Sono stati considerati l'estrazione delle materie prime, la loro trasformazione in materiali da costruzione e lo smaltimento al termine della fase di utilizzo. Non si è invece tenuto conto della fase di utilizzo dei materiali da costruzione. Lo studio si riferisce a un'ipotetica situazione nel periodo tra il 2030 e il 2050. Sono stati analizzati i seguenti indicatori ambientali: dispendio energetico cumulato (energia non rinnovabile ed energia rinnovabile); emissioni di gas a effetto serra e impatto complessivo sull'ambiente.

I dati dell'ecobilancio rilevati nel quadro del presente progetto sono stati applicati a due studi di casi concernenti edifici, ovvero l'edificio amministrativo dell'Ufficio federale dello sviluppo territoriale (ARE) a Ittigen e la casa d'abitazione situata in Rautistrasse a Zurigo. Entrambi gli edifici sono stati modellati e analizzati secondo la norma SIA 2040 per valutare le ripercussioni sull'impatto ambientale degli edifici dovute alle modifiche apportate nella produzione di materiali da costruzione.

Risultati

Tramite i futuri metodi di produzione sarà possibile ridurre sensibilmente l'impatto ambientale della produzione di materiali da costruzione. Rispetto alla situazione attuale, nella media i valori sarebbero inferiori: le emissioni di gas a effetto serra specifiche nella misura del 65 per cento, il fabbisogno di energia primaria da fonti non rinnovabili del 48 per cento e l'impatto complessivo sull'ambiente del 38 per cento. Si è tenuto conto dei cambiamenti significativi del processo di produzione soltanto per un numero esiguo di materiali, perché obiettivi dettagliati e quantificabili miranti a una produzione di materiali da costruzione rispettosa del clima o addirittura neutra riguardo all'emissione di gas a effetto serra erano disponibili solo per pochi dei settori considerati. Gran parte degli obiettivi dei singoli rami economici sono di natura generale e consistono principalmente nel passaggio a fonti di energia rinnovabili (soprattutto elettricità derivata da fonti di energia rinnovabili o biogas). Questa è quindi la misura considerata con più frequenza nella futura produzione di materiali da costruzione. Per quasi tutti i materiali il futuro aumento dell'efficienza energetica è piuttosto modesto.

Se nel quadro del processo di fabbricazione di un materiale da costruzione è risultata un'importante e inevitabile emissione di CO_2, è stata considerata l'installazione di un sistema CCS per la cattura e lo stoccaggio, indipendentemente dalla grandezza dell'impianto di produzione.

Sulla base delle serie di dati concernenti l'ecobilancio per la futura produzione di materiali da costruzione è stato calcolato l'impatto ambientale della realizzazione, dell'utilizzo e dello smantellamento dell'edificio amministrativo dell'ARE e della casa d'abitazione in Rautistrasse. I futuri materiali da costruzione coprono circa il 70 per cento della massa dell'edificio dell'ARE e circa il 96 per cento di quella dell'abitazione. Le emissioni di gas a effetto serra durante la costruzione e lo smantellamento dei due edifici potrebbero essere ridotte di circa il 50-60 per cento, il fabbisogno energetico da fonti non rinnovabili di circa il 40 per cento e l'impatto complessivo sull'ambiente di circa un terzo. Rispetto ai relativi valori target del quaderno tecnico SIA 2040, l'impatto ambientale del futuro edificio dell'ARE è inferiore del 42 per cento (fabbisogno energetico da fonti non rinnovabili) e del 61 per cento (emissioni di gas a effetto serra), mentre l'impatto ambientale della futura abitazione in Rautistrasse è inferiore del 45 per cento (fabbisogno energetico da fonti non rinnovabili) e del 55 per cento (emissioni di gas a effetto serra). Ciò è considerevole e promettente, ma comunque non sufficiente.

Raccomandazioni per i singoli rami economici

Nella *produzione di cemento e calcestruzzo* contribuiscono maggiormente al totale delle emissioni di gas a effetto serra le emissioni di CO_2 geogene liberate durante la fabbricazione di clinker. Per una produzione conforme all'Accordo di Parigi è necessario trovare una soluzione per evitare, catturare o neutralizzare queste emissioni. Al momento sono in corso vari progetti pilota che analizzano diverse tecnologie per la separazione del diossido di carbonio. Questi progetti dovrebbe essere ulteriormente approfonditi. Anche la percentuale di clinker contenuta nel calcestruzzo rappresenta uno strumento importante per ridurre le emissioni di gas a effetto serra. Altri progressi dovrebbero essere fatti nell'ambito dell'efficienza energetica ed è auspicabile un approvvigionamento energetico neutro dal punto di vista delle emissioni di gas a effetto serra.

Per la *produzione di mattoni* la combustione a gas che utilizza le microonde è una tecnologia promettente che consente di aumentare l'efficienza energetica e di semplificare il passaggio a fonti di energia rinnovabili (elettricità sulla base di fonti di energia rinnovabili in combinazione con biogas). Le emissioni di CO_2 liberate nel processo di combustione dei mattoni rappresentano tuttora una sfida perché non è ancora stata trovata una soluzione per la separazione e lo stoccaggio del carbonio in piccola scala.

In merito ai *pannelli di cartongesso* non è stato possibile trovare spunti per sviluppi tecnologici innovativi legati alla loro produzione. La sostituzione dei combustibili fossili con fonti biogeniche riduce le emissioni di gas a effetto serra di solo un terzo. S'impongono quindi ulteriori misure. È inoltre necessario valutare l'impiego di gesso REA, perché si tratta di un sottoprodotto della desolforazione di gas di combustione dei combustibili fossili (carbone, lignite e olio) e nel contesto di una futura economia climaticamente neutra probabilmente non sarà più disponibile nella stessa misura di oggi.

Per quanto riguarda il *vetro piano* esistono vari sviluppi tecnologici promettenti (ad es. fusione elettrica, ossicombustione). In tale contesto, il settore britannico del gas ha pubblicato un piano quantificato volto alla riduzione delle emissioni. Queste conoscenze devono essere sfruttate e applicate sistematicamente. Rimangono in sospeso questioni sulle emissioni di CO_2 liberate nel processo di fusione perché non è ancora stata trovata una soluzione per la separazione e lo stoccaggio del carbonio in piccola scala. Si potrebbe ridurre queste emissioni attraverso l'aumento della percentuale di vetro riciclato.

Nel caso dell'*alluminio* ci sono già metodi di produzione che riescono a ridurre sensibilmente le emissioni di gas a effetto serra. Essi si basano prevalentemente sull'impiego di elettricità generata da fonti rinnovabili nel processo di produzione dell'alluminio mediante elettrolisi. Al fine di ottenere una produzione neutra dal profilo delle emissioni di gas a effetto serra sarebbe necessario adottare ulteriori misure (ad es. per quanto riguarda gli anodi) e, in particolare, convertire l'intero approvvigionamento energetico (compreso il calore) a fonti di energia rinnovabili al 100 per cento. La separazione e lo stoccaggio del carbonio nelle raffinerie di allumina è considerata un'operazione complessa sotto il profilo tecnico.

In quanto al *rame* non sono disponibili dati quantitativi in merito alla futura produzione o a piani concreti di riduzione delle emissioni. Diverse imprese/miniere mirano a una produzione neutra dal profilo delle emissioni di gas a effetto serra; attualmente alcune miniere si orientano allo sfruttamento di fonti di energia rinnovabili al 100 per cento. Tenuto conto che nella produzione del rame l'utilizzo di combustibili fossili costituisce la fonte principale delle emissioni di gas a effetto serra, deve essere accordata la massima priorità al passaggio a fonti energetiche rinnovabili e al miglioramento dell'efficienza energetica.

Nemmeno per la *produzione di nichel* è stato possibile individuare informazioni specifiche sulla futura produzione. Si tratta comunque di priorizzare le stesse misure da adottare nel caso del rame, ovvero l'aumento dell'efficienza energetica e la sostituzione dei combustibili fossili con fonti rinnovabili.

Attraverso la riduzione diretta delle emissioni nella fabbricazione del ferro con l'utilizzo dell'idrogeno, si è aperta una nuova prospettiva per la *produzione siderurgica europea*. Se l'idrogeno necessario a tal fine viene prodotto mediante elettrolisi dell'acqua, la produzione siderurgica può essere gestita completamente con elettricità generata da fonti rinnovabili. Il sistema di tale processo è simile al percorso tradizionale della produzione siderurgica e si basa su tecnologie esistenti. La sua attuazione dipenderà tuttavia dalla disponibilità di elettricità generata da fonti rinnovabili e quindi di idrogeno generato mediante elettrolisi.

Per contro non è stato possibile individuare informazioni quantitative sulla futura *produzione siderurgica per il mercato svizzero* (100 % acciaio elettrico). L'industria siderurgica svizzera mira soprattutto ad aumentare l'efficienza energetica e a migliorare lo sfruttamento del riciclaggio di rottami.

Per quanto riguarda la *produzione di zinco* non è stato possibile individuare informazioni specifiche sulla futura produzione. Si tratta comunque di priorizzare le stesse misure menzionate nel caso del rame e del nichel, ovvero l'aumento dell'efficienza energetica e la sostituzione dei compustibili fossili con fonti rinnovabili. L'introduzione di nuovi metodi di produzione potrebbe altresì ridurre sensibilmente, a livello mondiale, le emissioni di metalli pesanti e di altre sostanze tossiche.

Nel caso del *legno e dei materiali in legno* il passaggio a fonti rinnovabili nell'impiego delle macchine forestali e nei processi industriali costituisce un elemento centrale. La maggior parte delle tecnologie rilevanti sono disponibili, ma ci sono ancora domande in sospeso in merito alla disponibilità delle fonti di energia rinnovabili (etanolo e biogas).

Per la *lana di vetro* non si prevedono ulteriori miglioramenti dell'efficienza energetica. Infatti, la fusione delle materie prime avviene già oggi usando l'elettricità quale fonte di energia. Al fine di raggiungere una produzione più rispettosa del clima, il gas naturale impiegato nel forno per l'indurimento può essere sostituito con biogas, a condizione che sia data la disponibilità di biogas generato in modo sostenibile.

Per la futura produzione di *lana di roccia* non sono emerse informazioni dettagliate. Perciò si è optato per la stessa procedura applicata alla lana di vetro: sostituzione dei combustibili fossili (coke di carbone e gas naturale) con biogas. Questa misura è adottabile sotto il profilo tecnico, a condizione che sia disponibile sufficiente biogas generato in modo sostenibile. Una strategia alternativa consiste nell'elettrificazione del processo di produzione.

Il *linoleum* può essere fabbricato mediante elettricità e biogas quali uniche fonti di energia, consentendo l'impiego al 100 per cento di fonti rinnovabili nel caso in cui si opti per il mix di energia appropriato. Per una produzione neutrale dal punto di vista climatico anche i processi agricoli e industriali finalizzati a estrarre l'olio di lino impiegato per il linoleum dovrebbero essere eseguiti senza emissioni rilevanti di gas a effetto serra.

Riguardo alle *materie plastiche* analizzate non erano disponibili dati quantitativi in merito a una futura produzione. Un'eventuale misura da adottare sarebbe la promozione, a livello di produzione, dell'utilizzo di materie prime rinnovabili e riciclate. Per raggiungere una produzione neutra riguardo alle emissioni di gas a effetto serra, sarebbe necessario sviluppare e quantificare piani di riduzione adatti, affinché il grado di raggiungimento degli obiettivi possa essere costantemente monitorato.

Limiti e prospettive

La presente analisi si riferisce esclusivamente alla produzione primaria di materiali da costruzione (ad eccezione dei profilati d'acciaio per il mercato svizzero, prodotti al 100 % a partire da rottami d'acciaio) e alle attuali perdite di materiale durante la produzione ed elaborazione di elementi da costruzione. L'impatto ambientale dei materiali da costruzione può essere limitato anche attraverso altre misure quali l'aumento della percentuale di materie riciclate o dell'uso efficiente dei materiali. Anche a livello edile esistono altre misure come ad esempio l'ottimizzazione del design edile, dell'impiego di materiali da costruzione a emissioni ridotte, la considerazione di metodi di costruzione alternativi o il riutilizzo di interi elementi da costruzione. Nel presente rapporto non si è tenuto conto di misure simili perché non erano oggetto delle analisi.

Gli attuali valori target del quaderno tecnico SIA 2040 illustrano un obiettivo intermedio della «Società a 2000 watt» definito nel 2014.Con il nuovo obiettivo della «Società a 2000 watt» (emissioni nette di gas a effetto serra pari a zero entro il 2050), introdotto nel 2020, l'industria dei materiali da costruzione deve contribuire a portare le emissioni di gas a effetto serra possibilmente pari a zero (anche per le sue catene di fornitura). Una simile riduzione di emissioni richiede un impegno vincolante per il raggiungimento dell'obiettivo di limitare l'aumento massimo della temperatura a 1,5 gradi Celsius e cambiamenti essenziali dei processi di produzione. Poiché siffatti cambiamenti spesso sono legati a importanti investimenti, sono necessari segnali espliciti da parte del Consiglio federale così come l'elaborazione di un quadro giuridico affidabile da parte del Parlamento e dei Cantoni, per consentire nei prossimi due-tre decenni il passaggio verso la costruzione di edifici e la produzione dei relativi materiali con emissioni nette di gas a effetto serra pari a zero.

Contents

1 Introduction and background

1.1 Background

In the past decades a lot of successful efforts were made to reduce the energy consumption, the environmental impacts and greenhouse gas emissions caused during the operation of buildings. There have also been substantial improvements in energy efficiency and, consequently, greenhouse gas emissions in the production of building materials. Since 2010, however, a stagnation can be observed (see e.g. Agora Energiewende & Wuppertal Institut 2019). No such trend could be observed in the primary energy demand, greenhouse gas emissions and environmental impacts in the construction of whole buildings. The improvements in materials were probably compensated or even outweighed by heavier and more complex construction.

The Paris Agreement on climate change mitigation, signed in 2015 (UNFCCC 2015) calls for a global and massive reduction in greenhouse gas emissions in the next decades. Measures regarding buildings have a high priority given the substantial share of greenhouse gas emissions in a country caused by buildings and their supply chains. The reduction of greenhouse gas emissions required by the Paris Agreement will have further consequences on the production and manufacturing processes of construction materials.

The SIA technical bulletin 2040 “SIA energy efficiency path” does not pay attention to future developments except for individual mobility, where a specific consumption of 3 litres per 100 km are assumed. The results presented in this report close this gap. The report and its supporting material provide data and information on the environmental impacts and greenhouse gas emissions of future fuel and electricity supply, transport services and construction material manufacture.

1.2 Contents of this report

The goal and scope of the assessments are described in Chapter 2, including the general procedure, the members of the advisory group, the objects of investigation, the purpose of the study, the functional unit, the system boundary, data gathering procedure, allocation approaches applied and impact assessment methods used. Chapter 3 contains a description of the life cycle inventories on future production of construction materials established within this project as well as their environmental performance for the indicators analysed. Chapter 4 describes the life cycle inventories and the environmental performance of the carbon capture and storage systems (CCS) used within this project. Chapter 5 and 6 show the life cycle inventories and the environmental performance of future electricity supply and transport services, respectively. In Chapter 7, the LCI data established in this project is applied on two building case studies to evaluate the effects of the changes in construction material production on the environmental impacts of the buildings. Chapter 8 discusses the availability of biogas and wood. The conclusion of this project are summed up in Chapter 9, which also gives an outlook on possible next steps.

2 Goal and Scope Definition

2.1 Outline of the Study

The report deals with life cycle assessments of future production of construction materials relevant in structural engineering. Similar work on this topic was performed within the European NEEDS research project and published more than ten years ago (Frischknecht et al. 2007a). Frischknecht et al. (2015a) published more recent work on the LCA of future supply chains of PV electricity.

Mineral and metal materials, wood and plastics produced and/or used in Switzerland are in the focus of the assessments. Recent publications and announcements about climate friendly or even climate neutral manufacturing of construction materials show the potential to substantially lower the environmental impacts and greenhouse gas emissions (CDP & SBT 2018; ETC 2018a, b, c).

The report also covers life cycle inventory data of future transport services, in particular lorry, railways and ship, as well as the future energy supply, including the electricity mixes of Switzerland, Europe and other selected countries or organisations.

The analysis refers exclusively to the primary production of building materials and current material losses in construction and manufacturing of building elements. Further aspects of sustainable construction such as increasing the proportion of recycled feedstock materials, increasing the material efficiency or the lifetime of the buildings, optimisation of the building design, use of low-impact building materials and completely different construction methods, re-use of entire building components or circular economy, were not considered.

2.2 General procedure

Information about the technological development of manufacturing processes, transport services and energy supply were collected in interviews with representatives from associations and pioneering companies and with desk top research. The technological development considered in this project contributes to a variable extent to the fulfilment of the Paris Agreement (UNFCCC 2015), which requires a substantial reduction in the greenhouse gas emissions worldwide to increase the likeliness to remain below 1.5°C increase of the world average temperature.

Data and information collected were consolidated and complemented with assumptions where necessary and used to establish life cycle inventory datasets. The datasets were established according to the methodological approach of the Life Cycle Assessment data in the construction sector (KBOB et al. 2018, 2017b). They are compliant with LCA data used in building assessments according to SIA 2040 and SIA 2032 (SIA 2010, 2017).

The life cycle inventory data were processed to be compatible with the LCI data of the KBOB recommendation 2009/1:2016 and its follow-up version expected to be published in 2021. They are made available electronically, using a standard data format.

The LCI data established in this project were applied on two case studies: the office building of the Swiss Federal Office for Spacial Development (ARE) in Ittigen, Bern and the residential building Rautistrasse in Zürich were assessed according to the SIA 2040 to evaluate the effects of the changes in construction material production on the environmental impacts of the buildings.

2.3 Advisory group

An advisory group was established in this project. It commented on the goal and scope definition of the analyses, on the life cycle inventories of climate friendly production of construction materials and on draft versions of this report.

The following experts were member of the advisory group:

- Claudio Menn, BFE (chair);
- Patric Fischli-Boson, SZS;
- Michael Pöll, AHB of the City of Zürich;
- Ruedi Räss, Ziegelindustrie Schweiz;
- Hansueli Schmid, Lignum;
- Martin Tschan, cemsuisse;
- Dino Rossi, szff.

2.4 Objects of Investigation

This report covers the life cycle inventories of climate friendly production of construction materials, provision of transport services, as well as supply of fuels and electricity. The following construction materials were analysed:

- cement (clinker) and concrete;
- bricks;
- gypsum plaster boards;
- float glass;
- aluminium;
- copper;
- nickel;
- steel;
- zinc;
- wood materials (three layered laminated board, glue laminated timber, particle board and soft board);
- glass wool

- rock wool;
- linoleum;
- plastic materials (in particular PE, PVC, EPS- and XPS-insulation; PLA).

The transport services cover the transport means lorry, cargo train and cargo ship (inland and ocean). The supply of electricity covers Switzerland, Europe, China and South America. Besides, a global renewable electricity mix was established. The supply of fuels includes gasoline, diesel, light fuel oil and natural gas.

2.5 Purpose of the study

The life cycle inventories described in this report are meant to be used in future oriented environmental assessments of buildings. They shall not be used to compare the environmental impacts caused by the different construction materials because comparisons based on 1 kg of construction materials are misleading. Meaningful comparisons are possible only on the basis of the required quantities of the variants to be compared for a specific equivalent use. That is why the LCI data established in this project are applied on two case study buildings allowing the environmental impacts of current and future production to be compared.

The study considers only the environmental dimension of sustainability and does not include the economic and social dimensions. It therefore does not represent a complete sustainability assessment.

2.6 Functional Units

The functional unit and reference flow used in the life cycle inventories of construction materials is 1 kg at the factory gate, of fuels and electricity supply is kWh final energy and kWh electricity at low voltage, respectively, and of transport services is 1 tkm goods shipped.

The functional unit and reference flow used in the buildings assessments is 1 m^2 energy reference area and year.

2.7 System Boundary and cut-off rules applied

2.7.1 System boundaries

The life cycle assessments carried out within this study follow a cradle to gate approach and additionally include end of life treatment (see Fig. 2.1). The product systems of the construction materials analysed encompass the extraction of the raw materials, its processing to construction materials, and their disposal. The use phase of the construction materials is excluded. Transport services, energy supply chains and infrastructures are included, packaging is not.

For the building case studies, the whole life cycle comprising construction, use and disposal is taken into account.

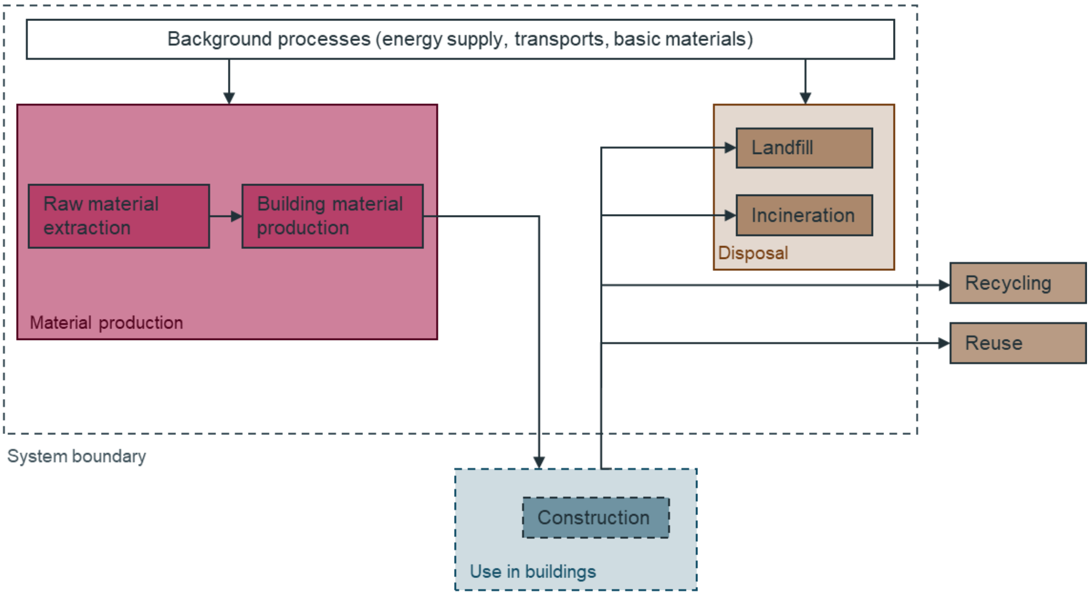

Fig. 2.1: Simplified process flow chart. The simplified chart shows the most important process steps. The use of the construction materials in buildings is outside the system boundary, but will be taken into account in the buildings case studies (see Chapter 7).

The carbonation of concrete binds CO_2 from the atmosphere. This effect can be observed during the use phase of cement- and lime-based construction products e.g. in buildings and is not included in the life cycle assessments of the single construction materials (see Fig. 2.1). However, it is quantified and reported in the case studies carried out within this project. A carbonation effect can also be observed with bricks (see p + f Sursee 2017), but this is not considered in this study.

The temporary storage of carbon in wood and wood products in buildings is not taken into account.

2.7.2 Cut-off rules

Cut-off decisions are taken based on the experience of the authors of this report. As far as possible all relevant inputs are accounted for. Capital goods are included. Process specific emissions such as NMVOC or pentane are included as far as indicated by the companies and associations. They are included independent of their contribution to the cumulative emissions of the respective substance (no threshold of a mass based cut-off is applied). If specific cut-off decisions have been made, these are described with the respective material.

2.8 Data Gathering and Data Quality

Data about construction material production were gathered in desk-top researches, questionnaires completed by associations and pioneering companies as well as interviews.

Data about future transport services and energy supply (fuels and electricity) were compiled from public reports, scenarios and forecasts.

The primary source of background inventory data used in this study is the UVEK LCI data DQRv2 (KBOB et al. 2018). These data are based on ecoinvent data v2.2 (ecoinvent Centre 2010). Updated data on transport services (Frischknecht et al. 2016) and on the Swiss electricity mixes 2014 (Messmer & Frischknecht 2016b) have been added to the UVEK LCI data DQRv2:2018.

Time reference

The study refers to the future, more precisely to the time period between 2030 and 2050. More information and deviations from this time period is given in the description of the manufacturing process of the individual construction materials, of the transport services and the energy supply chains modelled.

Geographical coverage

All data refer to European conditions. Some background data referring to country specific conditions are used as estimation for European conditions. Where the future production of Swiss suppliers is likely to be distinctly different from the production of European manufacturers, Swiss production will be modelled.

Technical reference

The technical specifications of the construction materials produced in a climate friendly way in the future are considered equivalent to those of currently produced construction materials.

Uncertainty assessment

In order to evaluate the uncertainty of the data used, Monte Carlo analyses are performed.

2.9 Allocation

2.9.1 Multi-output processes

Selected construction materials are produced in multi-output processes or rely on raw materials co-produced with other raw materials.

In UVEK LCA data DQRv2:2018 allocation based on economic revenues is used in most cases. In multi-output processes that produce heat and electricity allocation is based on exergy content. Mass allocation is applied in the remaining multi-output datasets. In the product systems analysed, co-products in the background do not contribute significantly to the overall results. Hence, no sensitivity analyses related to allocation in multi-output processes are performed.

When plastics or wood products are disposed of in an incineration, heat and electricity can be produced as by-product to the waste treatment service. Those by-products leave the system without burdens (see also Section 2.9.2 below) and without giving rise for credits. The emissions from incineration are fully attributed to the products disposed of.

2.9.2 Recycling according to the current KBOB guidelines

Recycling of materials is modelled according to the current KBOB guidelines (KBOB et al. 2017a) which require the recycled content approach. The recycled content approach represents the concept of strong sustainability (see also Frischknecht 2007, Frischknecht 2010). Materials to be recycled leave the system neither with burdens nor with credits. Materials made from secondary raw materials bear the loads of scrap collection, sorting and refining. This gives an incentive to use recycled materials in the product systems under study.

Recycling is one option to reduce the environmental impacts of material manufacture. The focus of the research was on primary production and its potential to reduce the environmental impacts substantially.

2.9.3 Loads and benefits beyond the system boundary

Benefits and burdens outside the product system resulting from the possibility of substitution effects from subsequent use (in particular recycling after dismantling) will be quantified and made available as supplementary information. This is in compliance with the European standard EN 15804+A1 (SN EN 15804 2013). The primary materials and energy being replaced was determined in discussions with the advisory group and reflect a future production similar to the life cycle inventories of the construction materials assessed and documented in this report.

2.10 Life Cycle Impact Assessment

2.10.1 Overview

The environmental performance of climate friendly manufacture of construction materials is assessed with the following impact category indicators:

- Cumulative Energy Demand (Primary Energy Consumption, split into non-renewable and renewable energy, Frischknecht et al. 2015b),
- Greenhouse gas emissions (quantified using the Global Warming Potential, GWP100 according to IPCC 2013),
- Environmental impacts (using the eco-factors 2013 of the ecological scarcity method, Frischknecht & Büsser Knöpfel 2013).

This set of indicators enables a comprehensive analysis of the environmental performance of the product systems under study and the shift of environmental burdens is likely to be avoided. Cumulative energy demand is used to get insights into the efficiency of using energy resources. Climate change is considered because of its large environmental damage potential, its importance in international environmental policy and its relevance for the building sector. The assessment using the ecological scarcity method shows a complete picture of the environmental effects and meets the requirements of a true and fair view in terms of environmental information.

In the following sections the category indicators are described.

2.10.2 Greenhouse gas emissions

All substances that contribute to climate change are assessed according to their global warming potential (GWP) according to the 5th IPCC assessment report (IPCC 2013). The indicator covers the so-called “Kyoto-Substances” CO_2, CH_4, N_2O, PFC, HFC, SF_6 and NF_3. The climate-impacting ozone-depleting substances regulated by the Montreal Protocol are not included. The residence time of the substances in the atmosphere and the expected immission design are considered to determine the global warming potential of a particular greenhouse gas. The potential impact of the emission of one kilogramme of a greenhouse gas integrated over different time horizons (20 and 100 years) on the infrared absorption of the atmosphere is compared to the potential impact of the emission of one kilogramme CO_2. The global warming potential is expressed in kg CO_2-equivalents per kg greenhouse gas. In this study the GWPs based on a time horizon of 100 years are applied.

The additional warming effects of the stratospheric emissions from aircrafts are taken into account according to Fuglestvedt et al. (2010) and Lee et al. (2010). Allocated to the emission of one kilogram of CO_2 emitted by an aircraft, the global warming potential of the vapour trails generated by aircraft, the induced clouds and the water vapour emitted is 0.95 kg CO_2-eq. The global warming potential of CO_2 emissions from burning kerosene by aircrafts is thus 1.95 kg CO_2-eq/kg. The software used for calculating the environmental footprints distinguishes CO_2 emissions according to where they are emitted (upper troposphere and stratosphere vs. on ground and lower troposphere). According to the updated Life Cycle Inventories of Messmer and Frischknecht (2016a), CO_2 emissions at cruising altitude account for 70 % of total emissions for an average flight. For this reason, a global warming potential of 2.35 kg CO_2-eq/kg is used for the CO_2 emitted by aircraft in the upper troposphere and lower stratosphere, while the global warming potential of the CO_2 on the ground and in the troposphere is 1.0 kg CO_2-eq/kg. Related to a flight with 70 % of the emissions at cruising altitude, the rest near the ground, this again results in the 1.95 kg CO_2-eq./kg, which apply to aircraft emissions in general.

2.10.3 Cumulative Energy Demand (CED)

The CED (implementation according to Frischknecht et al. 2007b and Frischknecht et al. 2015b) describes the consumption of fossil, nuclear and renewable energy sources throughout the life cycle of a good or a service. This includes the direct uses as well as the indirect or grey consumption of energy due to the use of, e.g. plastics as construction or raw materials. This method has been developed in the early seventies after the first oil price crisis and has a long tradition (Boustead & Hancock 1979; Pimentel 1973). A CED assessment can be a good starting point in an environmental assessment due to its simplicity in concept and its easy comparability with CED results in other studies. However, it does not valuate environmental impacts and, as a consequence, cannot replace an assessment with the help of a comprehensive impact assessment method such as Ecological Scarcity 2013.

The following two CED indicators are calculated:

- CED, non-renewable (kWh oil-eq.) – fossil and nuclear;

- CED, renewable (kWh oil-eq.) – hydro, solar, wind, geothermal, biomass.

2.10.4 Overall environmental impacts

The environmental impacts are assessed using the Swiss eco-factors 2013 according to the ecological scarcity method (Frischknecht & Büsser Knöpfel 2013). They are based on Switzerland's legally or politically defined environmental goals (distance to target). The ecological scarcity method evaluates resource extraction (energy resources, primary mineral resources, water, land), of emissions in the air, water bodies and soil, of the deposits of residues from waste treatment and of traffic noise. The indirect additional climate change effects of stratospheric emissions from aircrafts are taken into account (see Section 2.10.2). The assessment using the ecological scarcity method shows in eco-points (UBP'13) a complete picture of the environmental effects and is based on Swiss environmental policy. It meets the requirements of a true and fair view in terms of environmental information.

2.11 Key elements of the forecasting approach chosen

The future production performance of the building materials assessed is in first choice based on information from companies or industry associations. If no industry data was available, research reports were used. Only the main inputs and outputs were adapted. The proportion of recycled material used has not been changed. The focus is on domestic production. For building materials that are not produced domestically, the European production was modelled.

Future electricity mixes based on renewable energy sources were modelled for the electricity supply: A future Swiss mix for domestic production and a future European mix for building materials produced in Europe. In addition, the future electricity mixes of other important production countries or regions were also modelled.

For future transports, a mixture between electric lorries and lorries fuelled by biofuel were taken into account. Electric propulsion systems were primarily used for smaller lorries (assumed to be driving shorter distances), for heavy duty transports mainly biofuels were used.

Carbon capture and storage (CCS) systems were taken into account to absorb production-related, geogenic CO_2 emissions in brick, cement, copper, glass and nickel production as well as for the disposal of plastic materials.

3 Future materials production

3.1 Overview

In the following subchapters, the life cycle inventories of the future production of cement and concrete (subchapter 3.2), bricks (subchapter 3.3), gypsum plaster board (subchapter 3.4), float glass (subchapter 3.5), metals (aluminium in subchapter 3.6, copper in subchapter 3.6.4, nickel in subchapter 3.8, steel in subchapter 3.9 and zinc in subchapter 3.10), wood materials (subchapter 3.11), glass wool (subchapter 3.12), linoleum (subchapter 3.140) and plastic materials (subchapter 3.15) are described. Each chapter has four paragraphs. The first paragraph describes the data basis for the production inventories, the second paragraph describes the resulting environmental impacts, the third paragraph critically assesses the quality of the data used and in the fourth paragraph an opinion on the time horizon of the mitigation measures is given, distinguishing between short term (a few years), medium term (10 to 20 years) and longterm (30 years and beyond).

The life cycle inventories of future materials production aim at illustrating the future production processes of building materials from primary raw materials. It is generally assumed that the recycling rate will be the same as today, even though there is a large potential for increasing recycling rates in the construction sector. An increase in the proportion of recycled materials does not fundamentally influence the production processes and is therefore not taken into account. However an increase of recycled materials used in buildings may influence the overall environmental impacts of the building sector.

3.2 Manufacture of cement and concrete

3.2.1 Life cycle inventory

For the future production of cement the production of clinker was adapted. According to Favier et al. (2018) the best available technologies in clinker production require 3.0 MJ energy input/kg clinker. The present energy demand for clinker production is around 3.5[1] to 3.8 MJ/kg clinker. For the future production, the energy demand was reduced to 3.0 MJ energy input/kg clinker by keeping the present fuel mix (Tschümperlin & Frischknecht 2016b). The CO_2 emissions were calculated accordingly. Furthermore, there are several pilot projects investigating on carbon capture technologies to be applied in the clinker production process[2]. To model these efforts, the fossil and biogenic CO_2 emissions of the future clinker production are captured (post combustion) and stored. The life cycle

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[1] cemsuisse 2019

[2] See https://www.norcem.no/en/CCS%20at%20Brevik, https://www.heidelbergcement.com/en/ecra-oxyfuel

inventories of the carbon capture and storage processes applied are described in chapter 4. The life cycle inventory for the future production of clinker is shown in Appendix Tab. A.1.1.

For the future prodcution of lean concrete, concrete for building construction, concrete for civil engineering, concrete for drilled piles and precaste concrete (high performance and standard) biogas is used instead of fossil fuels. The life cycle inventory for the future production of the different concrete types are shown in Appendix A.1.

The life cycle inventories of the present production of lean concrete, concrete for building construction, concrete for civil engineering and concrete for drilled piles are described in more detailed in Tschümperlin and Frischknecht (2016b) and precaste concrete (high performance and standard) in Tschümperlin and Frischknecht (2016a).

3.2.2 Environmental impacts

The environmental impacts of future clinker production are 36 % (CED non renewable) to 81 % (greenhouse gas emissions) lower than the corresponding impacts of present clinker production (Tab. 3.1). The renewable energy demand increases by 340 %.

Tab. 3.1: Environmental impacts of 1 kg present and future production of clinker

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	0.88	0.56	-36%
CED - renewable	*kWh oil-eq.*	0.065	0.29	340%
Greenhouse gas emissions	*kg CO_2-eq.*	0.83	0.16	-81%
Overall environmental impacts	*UBP*	510	190	-64%

The environmental impacts of the present and future production of different concrete types are shown in Tab. 3.2 to Tab. 3.7. The greenhouse gas emissions of the future production of the concretes types are between 76 % (lean concrete, concrete for civil engineering) and 84 % (precast concrete, high performance) lower compared to the corresponding impacts of the present production. The reduction is mainly due to the implementation of CCS in the clinker production.

Additionally to the implementation of CCS the change from fossil fuels to biogas in the concrete production and the adaptation of the electricity mix lead to a decrease of the non renewable energy demand between 44 % (concrete for civil engineering, concrete for drilled piles) and 79 % (precast concrete, high performance). The renewable energy demand increases between 128 % (precast concrete, standard) and 575 % (lean concrete). The overall environmental impacts are reduced by 53 % (lean concrete) to 86 % (precast concrete, high performance).

Tab. 3.2: Environmental impacts of 1 kg present and future production of lean concrete

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	0.085	0.045	-48%
CED - renewable	*kWh oil-eq.*	0.0076	0.052	575%
Greenhouse gas emissions	*kg CO_2-eq.*	0.051	0.012	-76%
Overall environmental impacts	*UBP*	39	18	-53%

Tab. 3.3: Environmental impacts of 1 kg present and future production of concrete for building construction

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	0.14	0.075	-45%
CED - renewable	*kWh oil-eq.*	0.012	0.073	508%
Greenhouse gas emissions	*kg CO_2-eq.*	0.090	0.021	-77%
Overall environmental impacts	*UBP*	66	30	-55%

Tab. 3.4: Environmental impacts of 1 kg present and future production of concrete for civil engineering

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	0.15	0.086	-44%
CED - renewable	*kWh oil-eq.*	0.013	0.078	492%
Greenhouse gas emissions	*kg CO_2-eq.*	0.098	0.023	-76%
Overall environmental impacts	*UBP*	71	33	-54%

Tab. 3.5: Environmental impacts of 1 kg present and future production of concrete for drilled piles

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	0.16	0.091	-44%
CED - renewable	*kWh oil-eq.*	0.014	0.082	475%
Greenhouse gas emissions	*kg CO_2-eq.*	0.11	0.025	-77%
Overall environmental impacts	*UBP*	77	35	-55%

Tab. 3.6: Environmental impacts of 1 kg present and future production of precast concrete, standard concrete

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	0.41	0.14	-67%
CED - renewable	*kWh oil-eq.*	0.088	0.20	129%
Greenhouse gas emissions	*kg CO_2-eq.*	0.16	0.037	-77%
Overall environmental impacts	*UBP*	210	63	-71%

Tab. 3.7: Environmental impacts of 1 kg present and future production of precast concrete, high performance concrete

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	0.70	0.14	-79%
CED - renewable	*kWh oil-eq.*	0.056	0.16	181%
Greenhouse gas emissions	*kg CO_2-eq.*	0.26	0.042	-84%
Overall environmental impacts	*UBP*	450	64	-86%

Process emissions contribute most to the greenhouse gas emissions of present clinker production (see Fig. 3.1). Those emissions are mainly emitted during the calcination of limestone. In future production the reduced energy input reduces the process emissions by 7 %, the emissions from fuels supply by 33 % and those from electricity use by 80 %.

The implementation of CCS of biogenic and fossil CO_2 emissions in the future production of clinker leads to a neutralisation of 82 % of the greenhouse gas emissions emitted during clinker production. 95 % of those emissions stem from geogenic and fossil sources. 5 % of the emissions going to the CCS system come from biogenic sources, which means that - to a small extent - CO_2 is extracted from the atmosphere.

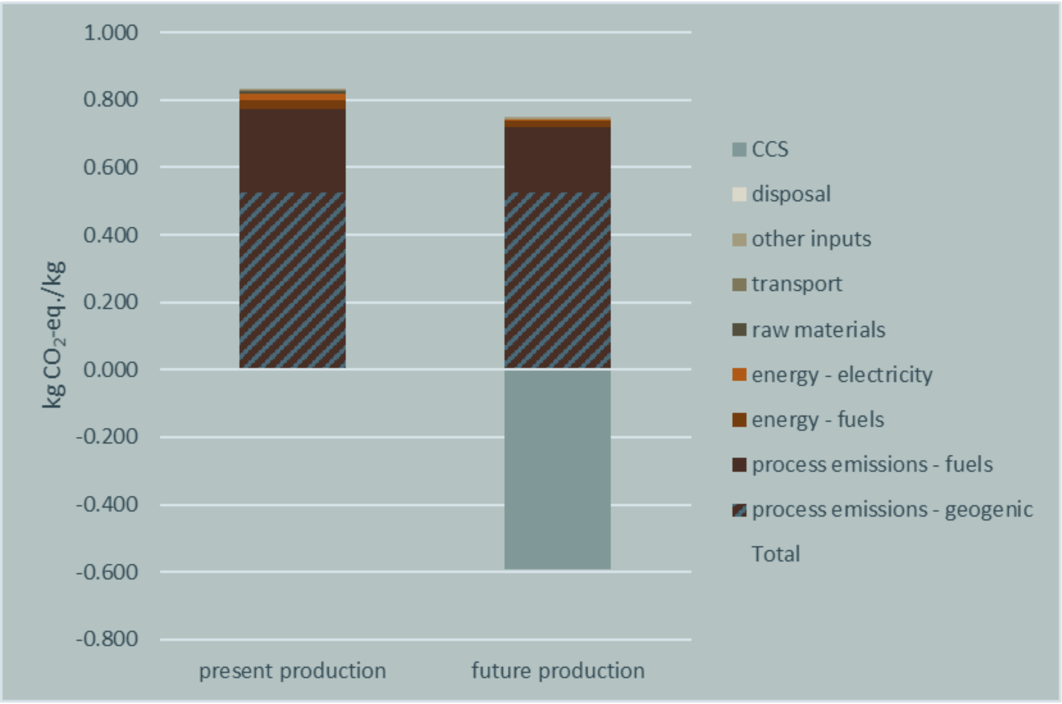

Fig. 3.1: Greenhouse gas emissions of 1 kg present and future clinker production by contributing processes

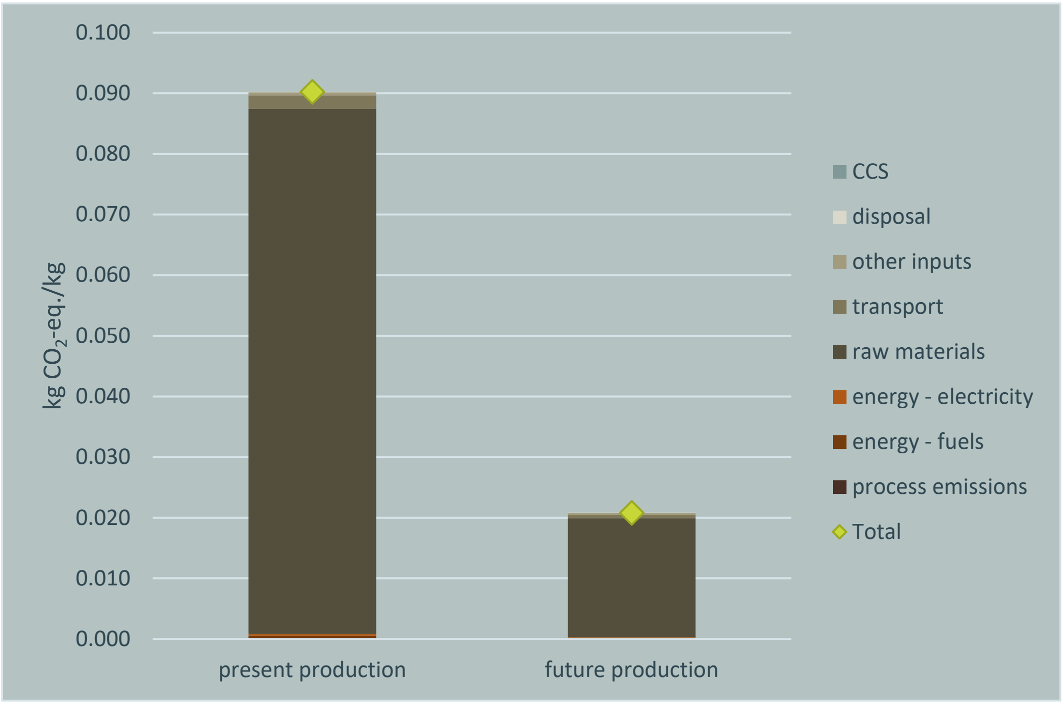

Fig. 3.2: Greenhouse gas emissions of 1 kg present and future concrete for building construction production by contributing processes

As an example, Fig. 3.2 shows the greenhouse gas emissions of 1 kg present and future production of concrete for building construction by contribution processes. The raw materials, i.e. the clinker in the cement, is responsible for the majority of the greenhouse gas emissions in the present production of concrete. The implementation of CCS in the clinker production reduces the greenhouse gas emissions of the raw materials. This is the case for all analysed concrete types. In the shown example of concrete for building construction the greenhouse gas emissions of the raw materials are reduced by 77 %.

3.2.3 Data quality considerations

For future cement clinker production Favier et al. (2018) discuss the use of alternative fuels instead of fossil fuels. In the present production of clinker alternative fuels for example waste products (e.g. discharded tryes, waste oils, animal meal, waste wood) are already used (The European Cement Association 2013). According to Favier et al. (2018) a higher substitiution of fossil fuels with alternative fuels would be technically possible, but serveral factors limit the use of alternative fuels such as the often low calorific value of organic materials or the availabilty of waste. As no specific data on the mix of alternative fuels was available the possible higher share of alternative fuels in the fuel mix was not taken into account.

For the future production of clinker post combustion capture of CO_2 emissions was taken into account. According to IEA et al. (2018) oxy-fuel capture technologies could account for a greater share of captured CO_2 emissions than post combustion technologies by 2050 based on the techno-economic performances of those technologies. As no data was available for the oxy-fuel capture technology in the clinker and cement production, this technology was not taken into account.

The inventory for future concrete production is based on the assumption that fossil fuels will be replaced by biogas. However, there is no indication of how realistic this assumption is. The availability of biogas is discussed in Subchapter 8.1.

Favier et al. (2018) discuss further potential improvements of the cement and concrete production on various levels. However besides the in subchapter 3.2.1 described improvements, no further optimization potentials were taken into account either due to a lack of suitable data for life cycle inventories or their uncertain realisation potentials.

3.2.4 Time horizon for implementation of mitigation measures

The time horizon of the most important mitigation measures in the future manufacture of clinker and concrete is summarised in Tab. 3.8. The implemented energy reduction in the future clinker production according to Favier et al. (2018) represents best available technologies and is therefore feasible today. Obstacles may be mainly economic, such as capital requirement.

Today several pilot projects investigate on carbon capture technologies in the clinker production process (see subchapter 3.2.1). According to Agora Energiewende & Wuppertal Institut (2019) the earliest possible industrial application will be 2025, provided that the technology development proceeds optimal.

The subsitution of fossil fuel by biogas in the future concrete production can theoretically be accoplished in short term. However, the question is whether enough sustainably produced biogas will be available for all consumers (see subchapter 8.1).

Tab. 3.8: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of clinker and concrete (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Energy reduction potential in clinker production	Short term*
CCS in clinker production	Medium to long term
Substitution of fossil fuels by biogas in concrete production	Short term (subject to availability)**

* Energy reduction measures are already being implemented today. The time horizon refers to the introduction of further energy reduction measures.

** This excludes the use of waste fuels - as long as they are available - because they are not used more efficiently elsewhere.

3.3 Manufacture of bricks

3.3.1 Life cycle inventory

The life cycle inventory for future brick production is based on the EPD for “SwissModule” type bricks (p + f Sursee 2017). The use of electricity and fuels was reduced by 1 % and 30 %, respectively, following the reduction potentials according to Fleiter et al. (2015). These reduction potentials comprise the measures “introduction and active use of energy management systems”, “optimised cooling zones” and “waste heat utilisation” as well as “heat recirculation for drying”. Additionally, brick firing was assumed to be microwave assisted (microwave assisted gas firing, MAGF). DTI (2013) has shown that microwave assisted gas firing may achieve a total energy saving of 25 % relative to conventional burning. Remaining energy demand is covered by 44 % of electricity and 56 % of thermal energy. This means a reduction in gas consumption of 50 % to 55 % while reducing heating time by approximately 40 % (DTI 2013). These figures were applied to future brick production. The energy savings are due to a reduced firing time when applying MAGF. The remaining thermal energy demand is covered by biogas, whereas the electricity needed is obtained from the public grid (future Swiss electricity mix).

During brick firing, process-related CO_2-emissions occur. According to the EPD for “SwissModule” type bricks (p + f Sursee 2017) these amount to 119 g CO_2-eq/kg brick. For future brick production, it was assumed that these emissions are captured and fed into an underground storage facility. Since there is only one waste gas stream, it was assumed that with the implementation of a CCS plant, the CO_2 emissions from the fuels (in future production biogas) are also fed into the CCS plant and captured. The life cycle inventories of the carbon capture and storage processes applied are described in chapter 4.

The resulting inventory for future brick production is show in Appendix A.2.

3.3.2 Environmental impacts

The environmental impacts of future brick production are 68 % (overall environmental impacts) to 85 % (greenhouse gas emissions) lower than the corresponding impacts of present bricks production (Tab. 3.9). The renewable energy demand increases by 213 %.

Tab. 3.9: Environmental impacts of 1 kg present and future bricks production

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	0.69	0.11	-84%
CED - renewable	kWh oil-eq.	0.075	0.24	213%
Greenhouse gas emissions	kg CO_2-eq.	0.24	0.036	-85%
Overall environmental impacts	UBP	170	56	-68%

Process emissions cause the biggest contribution to the greenhouse gas emissions of present brick production (Fig. 3.3). These geogenic emissions are inherent to brick firing. In future brick production the reduced firing time with MAGF reduces the process-related CO_2-emissions by 34 %. However, they still form the biggest contribution to the greenhouse gas emissions of brick production.

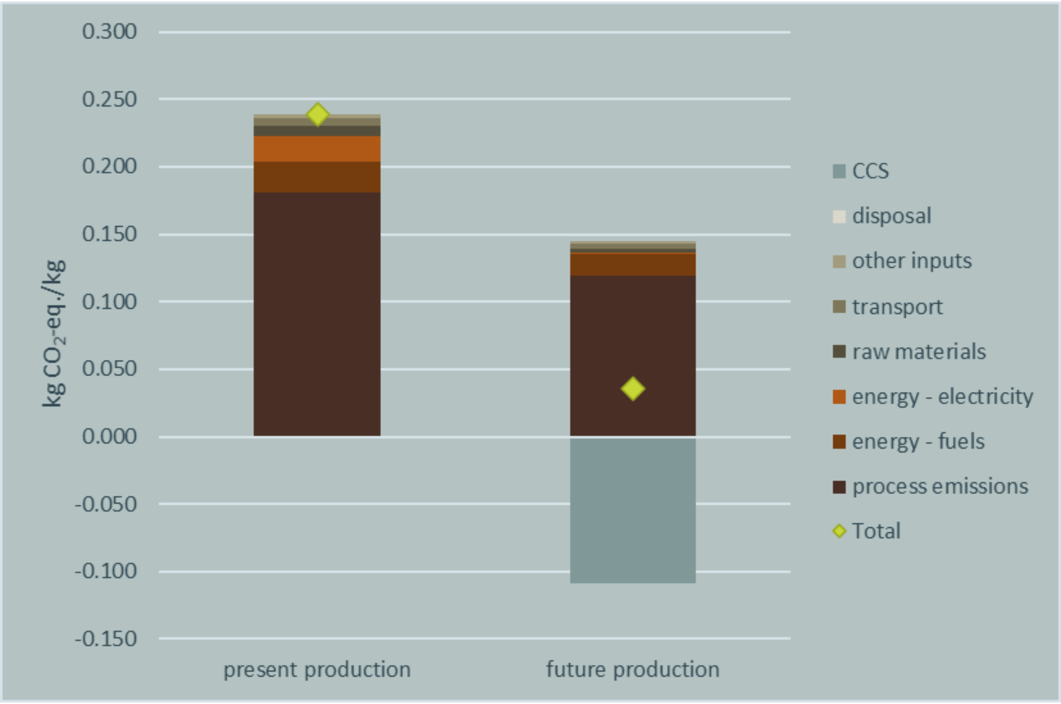

Fig. 3.3: Greenhouse gas emissions of 1 kg present and future bricks production by contributing processes

The use of a CCS system neutralises 92 % of the process-related greenhouse gas emissions. This high reduction rate is achieved because part of the biogenic CO_2

emissions from the biogas used are also absorbed in the CCS system and thus cause a negative greenhouse gas effect, which is deducted from the process emissions. However, 84 % of the CO_2 emissions captured by the CCS system stem from geogenic and fossil sources and only 14 % of the emissions contribute to the negative greenhouse gas effect. The greenhouse gas emissions from fuel use can be reduced by 28 %, the emissions from the use of electricity by 92 %.

3.3.3 Data quality considerations

MAGF has been tested in a pilot plant at the Danish Technological Institute (DTI) with a capacity to burn 200 bricks per batch. However, the ultimate goal of the project, i.e. that MAGF technology is mature and ready for implementation in the industry, has not been achieved. There is still a need for further development and upscaling of the MAGF technology, before it can be commercially implemented in the brick and tile industry (DTI 2013). Therefore, it is not given that the energy savings achieved in the pilot plant and used for future brick production will be reached in commercial plants. The energy savings are primarily attributable to the energy loss from the furnace, which is reduced by a shorter process time (DTI 2013). As the energy loss in a tunnel kiln per brick produced is somewhat smaller than in the pilot plant, the energy saving potential realised in commercial plants might be smaller as well.

In future brick production, the use of biogas and a CCS system is assumed. It remains to be seen whether a company would combine both measures or whether it would not convert to biogas if it used a CCS system.

Apart from improving conventional brick production, there are also totally new concepts for producing bricks. One example is bioMASON[3], where microorganisms are used to produce a biocement. During the procedure, a waste aggregate is mixed with microorganisms, pressed into shape and fed an aqueous solution until hardens to a brick. Such new production processes have the potential to significantly reduce greenhouse gas emissions of brick production. However, as this process is still in an early stage of development it has not been taken into account in the present study.

3.3.4 Time horizon for implementation of mitigation measures

Most of the measures described above can be implemented in short to medium term (Tab. 3.10). The energy reduction potentials according to Fleiter et al. (2015) are technically feasible today. Obstacles may be mainly economic, such as capital requirement or insufficient return on investment.

Microwave assisted gas firing (MAGF) is not yet ready for industrial implementation. There is still a need for further development and upscaling of the MAGF technology, before it can be commercially implemented in the brick and tile industry (DTI 2013). However, as the original project goal was to mature the MAGF technology so that it could be implemented within the Danish brick industry within one year after the end of the

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[3] See https://www.biomason.com, last visited 28.4.2020

project, it can be assumed that the technology will be available at least in the medium term.

Tab. 3.10: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of bricks (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Introduction and active use of energy management systems	Short term*
Optimised cooling zones	Short term*
Waste heat utilisation	Short term*
Heat recirculation for drying	Short term*
Microwave assisted gas firing (MAGF)	Medium term
Substitution of natural gas by biogas	Short term (subject to availability)
Future electricity mix	Long-term (short-term if an electricity product based on renewable energy is purchased)
CCS	Medium to long term

* Energy reduction measures are already being implemented today. The time horizon refers to the introduction of further energy reduction measures.

Natural gas can be substituted by biogas today, the question is whether enough sustainably produced biogas will be available for all consumers (see subchapter 8.1). According to the Swiss Energy Perspectives 2050 (Prognos 2012), the Swiss electricity mix will only be fully based on renewable energy carriers in the year 2050. However, electricity mixes from renewable sources are available and can already be deliberately purchased today. Carbon capture and storage is technically feasible today, several large storage facilities are currently being built e.g. in Norway, the Netherlands or the United Kingdom. Since the economic viability of CCS in small to medium-sized emitting industries is currently not given and transportation infrastructure is missing, CCS solutions are expected to be realised in medium to long term.

3.4 Manufacture of gypsum plaster boards

3.4.1 Life cycle inventory

The life cycle inventory of the present production of gypsum plaster boards is based on average data of the production sites of the members of the German plaster industry association (Bundesverband der Gipsindustrie e.V.), which have been collected in connection with the QualiBOB project (Kasser et al. 2016). The data were provided under the condition of confidentiality. Therefore, no life cycle inventory data on the production of gypsum plasterboards are presented in this report.

In desktop research, no indication for innovative technological development in the manufacturing of gypsum plaster boards could be found. Therefore, the life cycle inventory of future production of gypsum plaster boards focuses on the replacement of fossil energy sources by biogenic sources in the production as well as in the supply chain. Present production of gypsum plaster boards includes the use of β-hemihydrate produced from flue gas desulfurization (FGD) gypsum as raw material. The use of FGD gypsum was replaced by the use of β-hemihydrate from natural gypsum, since FGD gypsum is a by-product of the process of desulfurization of combustion gases from fossil fuels (coal, lignite, and oil).

3.4.2 Environmental impacts

Compared to present production, the future gypsum plaster board production reduces the greenhouse gas emissions by 27 % and the CED non-renewable by 33 % (Tab. 3.11). The overall environmental impacts increase by 3 % and the CED renewable increases by 153 %. Overall, the cumulative energy demand is reduced by nearly 25 %. This is due to the lower

No detailed analysis is provided for gypsum plaster board production, as the production processes and life cycle inventories are confidential. The use of exclusively natural gypsum instead of a mix of natural and FGD gypsum is responsible for the increase in the overall environmental impact as well as the reduction in greenhouse gas emissions.

Tab. 3.11: Environmental impacts of 1 kg present and future gypsum plaster board production

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	1.0	0.68	-33%
CED - renewable	kWh oil-eq.	0.063	0.16	153%
Greenhouse gas emissions	kg CO_2-eq.	0.23	0.17	-27%
Overall environmental impacts	UBP	217	223	3%

3.4.3 Data quality considerations

In the inventory of future gypsum plaster board manufacture, we assumed that fossil energy sources will be replaced by biogas. We have however no indication of how realistic this assumption is. In general, no detailed information on possible future developments was provided by industry representatives.

3.4.4 Time horizon for implementation of mitigation measures

The time horizon of the most important mitigation measures in the future manufacture of gypsum plaster boards is summarised in Tab. 3.12. The replacement of fossil energy sources by biogenic sources in the production as well as in the supply chain can generally be done in the short term. However, the availability of sustainably produced biogas may not be guaranteed as the demand is expected to increase significantly (see subchapter 8.1).

The large deposits of geogenic gypsum in Switzerland make it possible to switch from the use of β-hemihydrate produced from FGD gypsum to β-hemihydrate produced from natural gypsum in the short term.

Tab. 3.12: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of gypsum plaster boards (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Substitution of natural gas by biogas	Short term (subject to availability)
Use of β-hemihydrate from natural gypsum instead of FGD	Short term

3.5 Manufacture of float glass

3.5.1 Life cycle inventory

The life cycle inventory of float glass is based on information and data published in the industrial decarbonisation and energy efficiency roadmap to 2050 for the British glass sector (WSP & Parsons Brinckerhoff & DNV GL 2015). In order to take into account the most ambitious reduction in greenhouse gas emissions, the pathway “Max Tech no CCS” within the scenario “collaborative growth” has been used. Fossil fuels are replaced half by biogas and half by electric melting. In electric furnaces, most of the electrical power is used in the melting process and only relatively low energy losses come from transformers, busbar and control efficiency. According to Meuleman (2017), energy use in electric furnaces is reduced by 35 %. The thermal efficiency was set at 85 %[4]. Electricity is drawn from the European grid (future grid mix). Oxyfuel combustion, another promising future technology, has not been considered, as there are no data available on the fuel input and the related emissions for this process technology.

In addition, the conventionally achievable energy saving potentials according to Fleiter et al. (2015) were taken into account. For float glass, they comprise waste heat utilisation, low NO_X burner, optimized combustion and quick reaction. In combination, those measures lead to a reduction of 15 % in fuel use and 2 % in electricity consumption (mainly used to run auxiliary processes).

During glass production, the decarbonisation of the carbonate raw material results in geogenic CO_2 emissions. In the inventory for future glass production, it was assumed that these process-related CO_2 emissions (200 g CO_2/kg glass) are captured and fed into an underground storage facility. Since there is only one waste gas stream, it was assumed that with the implementation of a CCS plant, the CO_2 emissions from the biogas used as fuel are also fed into the CCS plant and captured accordingly. The life cycle inventories of the carbon capture and storage processes applied are described in chapter 4.

The resulting inventory for future float glass production is show in Appendix A.3.

3.5.2 Environmental impacts

Compared to present production production processes, future float glass production reduces the environmental impacts between 54 % (overall environmental impacts) and

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[4] https://mo-sci.com/electric-furnaces-future-glass-manufacturing; last visited 22.11.2019

80 % (greenhouse gas emissions, see Tab. 3.13). Renewable energy demand increases by 760 %.

Tab. 3.13: Environmental impacts of 1 kg present and future float glass production

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	4.0	1.8	-55%
CED - renewable	kWh oil-eq.	0.13	1.1	760%
Greenhouse gas emissions	kg CO_2-eq.	1.1	0.22	-80%
Overall environmental impacts	UBP	1100	520	-54%

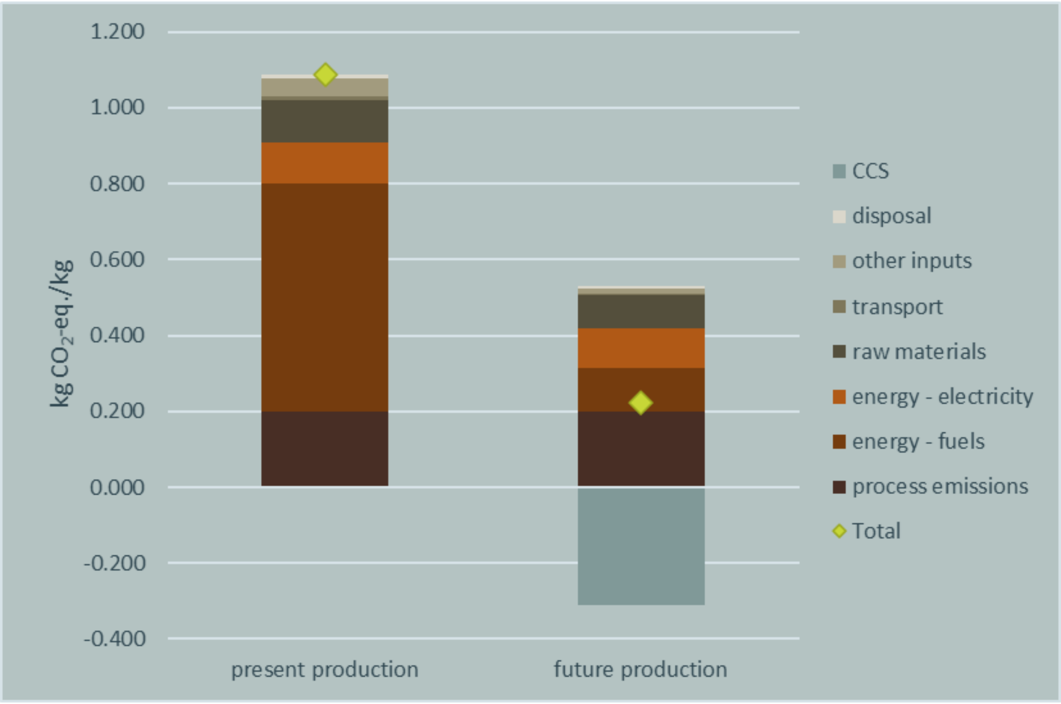

Fig. 3.4: Greenhouse gas emissions of 1 kg present and future float glass production by contributing processes

The largest contribution to the reduction of the greenhouse gas emissions comes from the replacement of fossil fuels by biogas and electric melting. This measure reduces the greenhouse gas emissions from fuels, the largest contributor to greenhouse gas emissions in present float glass production, by 81 % (Fig. 3.4). Greenhouse gas emissions from the use of electricity, on the other hand, remain stable, although the future electricity mix exhibits significantly lower greenhouse gas emissions than the present electricity mix. This is due to the fact that a part of the fossil fuels used are replaced by electricity and therefore the total electricity demand increases by more than four times.

Nearly 20 % of the present greenhouse gas emissions are due to process-related emissions. These emissions remain the same in the future production process, where their share in total greenhouse gas emissions amounts to nearly 40 %. The implementation of a CCS system more than offsets the process-related greenhouse gas emissions (reduction by 155 %). This is due to the fact that also the biogenic CO_2-emissions from the biogas used are fed into the CCS system which leads to a negative greenhouse gas effect. The share of the biogenic CO_2 emissions captured by the CCS system amounts to 49 %, whereas 51 % of the emissions stem from fossil and geogenic sources.

3.5.3 Data quality considerations

In the pathway used, the availability of biogenic materials as substrate for biogas production is assumed not to be constrained. However, biogas from biogenic waste, sewage sludge, slurry and biogenic by-products may be limited. On the other hand, according to Glass for Europe (2013), to date there is no technology available to efficiently operate large scale float glass furnaces using only electricity. It is difficult to assess at the present time, which technology (or combination of technologies) will prevail.

A possible increase in the proportion of secondary glass was not taken into account. An increased share of recycled glass (i.e. lowering the virgin raw materials input and increasing the share of “cullet”, i.e. recycled glass, in the batch) would reduce the process related CO_2 emissions. According to Glass for Europe, the use of one tonne of recycled glass saves 1.2 tonnes of raw materials and 0.3 tonnes of CO_2 in the flat glass industry[5].

In the inventory presented above, it was assumed that the process related CO_2 emissions are captured and stored (CCS). However, according to Glass Alliance Europe (2019), today CCS is limited to a theoretical potential only, as it would require creating extensive transport and storage infrastructures. Taking into account that the glass industry is characterised by small, disseminated units mostly located in brownfields, today the CCS/CCU options in the glass production process are considered to be limited due totechnical constraints (space limitations, presence of acidic compounds, low CO_2 concentration) and the limited market demand for carbon (Glass Alliance Europe 2019).

Additionally, it is unclear whether a company would still introduce a CCS system when switching to renewable energy carriers (electricity and/or biogas) or whether a switch to renewable energy sources would not be without a CCS system.

3.5.4 Time horizon for implementation of mitigation measures

The energy reduction potentials according to Fleiter et al. (2015) are technically feasible today. Obstacles may be mainly economic, such as capital requirement or insufficient return on investment. Moreover, retrofitting of improved process control technologies is often difficult, limiting this option to installing control systems when new equipment is

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[5] https://glassforeurope.com/recycling-of-end-of-life-building-glass/; last visited 20.03.2020

being installed. This is where the long service life of furnaces of 10 to 15 years has an adverse effect.

In the industrial decarbonisation and energy efficiency roadmap to 2050 for the British glass sector (WSP & Parsons Brinckerhoff & DNV GL 2015) it is assumed that with the maximum technical pathway electric melting reaches 50 % of its potential in 2030 and fuel switching to biogas 50 % in 2045. However, both options would actually be available today. Meuleman (2017) states that electrically heated furnace technology is almost as old as regenerative furnace technology and in Sweden, there were operating furnaces as early as 1925. However, the broad introduction of electric furnaces in glass melting still needs more RD&D and demonstration projects. Barriers to electric melting include concerns on the level of grid decarbonisation, high electricity prices compared to natural gas, reliance on one energy source and the rapid wear rate of refractories (WSP & Parsons Brinckerhoff & DNV GL 2015). Therefore the time horizon for the implementation of this mitigation measure is considered to be medium term.

Natural gas can technically be substituted by biogas today. An open question is the availability of sustainably produced biomass (see subchapter 8.1).

CCS is still facing many barriers, such as additional energy requirements for carbon capture, availabiliy of transport networks, access to storage facilities, contaminants in flue gas stream, high capex, need for collaboration, etc. Therefore the time horizon of this mitigation measure is considered to be medium to long term.

Tab. 3.14: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of float glass (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Waste heat utilisation	Short term*
Low NOx burner	Short term*
Optimized combustion	Short term*
Quick reaction	Short term*
Substitution of fossil fuels by biogas	Short term (subject to availability)
Substitution of fossil fuels by electricity	Medium term
CCS	Medium to long term

* Energy reduction measures are already being implemented today. The time horizon refers to the introduction of further energy reduction measures.

3.6 Manufacture of aluminium

3.6.1 Life cycle inventory

The life cycle inventory of the future production of primary aluminium is modeled based on data from Hydro Aluminium AS (Stolz & Frischknecht 2020). The Hydro Reduxa 4.0 aluminium extrusion ingot is produced in three aluminium smelters in Norway (Husnes, Karmoy and Sunndal) and claimed to cause greenhouse gas emissions of maximum 4.0 kgCO_2-eq./kg (Hydro Aluminium AS 2019). This is mainly achieved by using a renewable electricity mix, predominantly consisting of Norwegian hydro power, in aluminium electrolysis. Additionally, the emissions of perfluorocarbons (PFCs; tetrafluoromethane and hexafluoroethane) are significantly lower compared to today's average production of primary aluminium in Europe (EAA 2013; Stolz & Frischknecht 2016).

Hydro Aluminium AS is a vertically integrated company covering the entire production chain from bauxite mining, aluminium oxide production and anode production to aluminium electrolysis and aluminium ingot casting. The unit process life cycle inventories of the manufacture of the Hydro Reduxa 4.0 aluminium extrusion ingot (Hydro Aluminium AS 2019) were obtained from Ostfoldforskning[6]. The data were checked for plausibility and completeness and embedded in UVEK LCI data DQRv2:2018 (KBOB et al. 2018).

The life cycle inventories of the future production of primary aluminium are not shown in the appendix because the data are confidential.

3.6.2 Environmental impacts

Assuming that the use of renewable electricity in aluminium electrolysis becomes standard in the future[7] and that other process optimisations implemented by Hydro Aluminium AS (e.g. regarding the emissions of perfluorocarbons) are adopted by other manufacturers, the greenhouse gas emissions can be reduced by 56 % compared to the current manufacture of primary aluminium (Tab. 3.15). Significant reductions are also expected with regard to the non renewable cumulative energy demand (-65 %) and the overall environmental impacts (-40 %). On the other hand, the renewable cumulative energy demand increases by 113 % due to the use of renewable electricity.

Tab. 3.15: Environmental impacts of 1 kg present and future primary aluminium production

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	44	15	-65%
CED - renewable	kWh oil-eq.	9.6	20	113%
Greenhouse gas emissions	kg CO_2-eq.	9.2	4.0	-56%
Overall environmental impacts	UBP	11000	6700	-40%

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[6] Personal communication Andreas Brekke, Ostfoldforskning, 20.11.2019

[7] Besides Hydro Aluminium AS, there are further aluminium manufacturers producing low-carbon aluminium ingots with maximum 4.0 kgCO_2-eq./kg, e.g. Rio Tinto with RenewAl (https://www.riotinto.com/products/Aluminium; last visited 04.05.2020) and Rusal with ALLOW (https://allow.rusal.com/; last visited 04.05.2020).

The greenhouse gas emission reduction from future aluminium production compared to present production mainly results from the use of renewable electricity in aluminium electrolysis (Fig. 3.5). Further reductions are found in the supply of raw materials and in the process emissions.

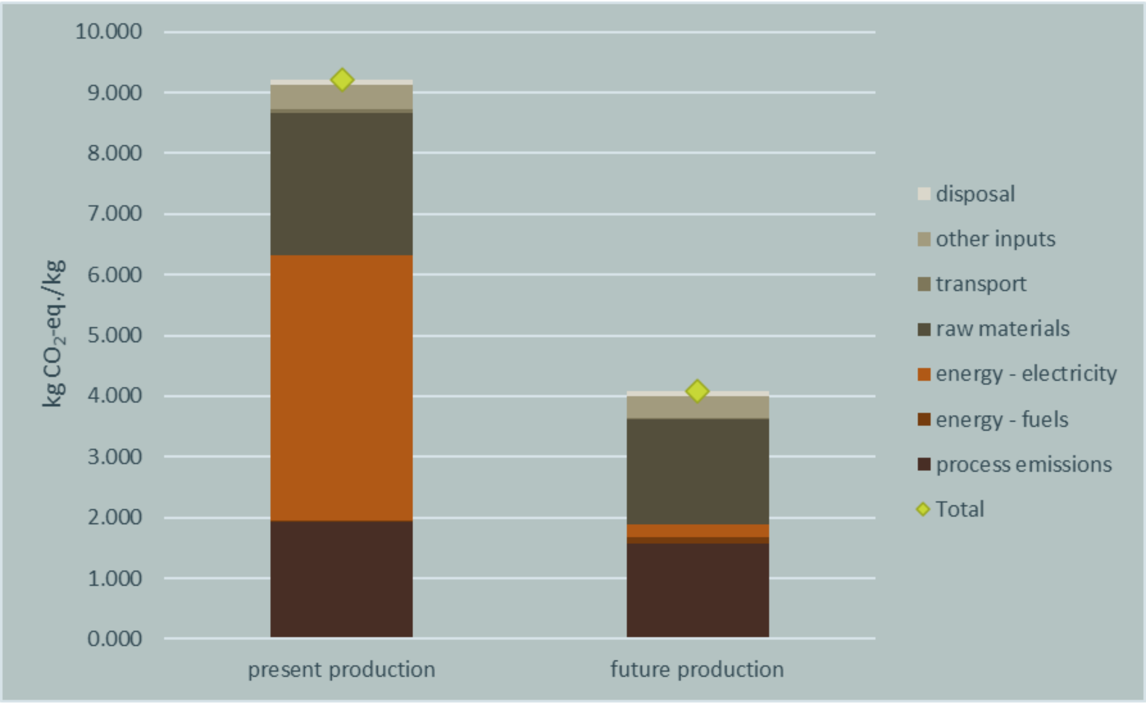

Fig. 3.5: Greenhouse gas emissions of 1 kg present and future primary aluminium production by contributing processes

3.6.3 Data quality considerations

The life cycle inventories of the Hydro Reduxa 4.0 aluminium extrusion ingot are mainly based on recent primary data. The quality of these data is considered as good. Potential further developments in future aluminium manufacture could not be taken into account because data were not available. For instance, inert anodes are being developed in the Elysis project that could avoid fossil CO_2 emissions from the combustion of carbon anodes and increase the anode lifetime by a factor of 30 (European Aluminium 2019). Inert anodes mostly consist of ceramics or metals (Fleiter et al. 2015), but detailed information on their composition and manufacturing efforts were missing. Carbon capture and storage in aluminium smelters is considered to be technically challenging and its economic viability is questioned (European Aluminium 2019).

3.6.4 Time horizon for implementation of mitigation measures

The time horizon of the most important mitigation measures in the future manufacture of aluminium is summarised in Tab. 3.16. The substitution of the current electricity mix used in aluminium electrolysis by a renewable electricity mix can generally be done in the short term. However, renewable electricity may not be available in sufficient quantity in each production country. The transition to an electricity system dominated by renewable energy carriers is a long-term mitigation measure (see also future electricity mixes of important regions in section 5.2.1).

Another relevant mitigation measure in the manufacture of aluminium is the reduction of perfluorocarbon emissions. These emissions are mainly caused by so-called anode effects in the Hall-Héroult electrolytic process, i.e. rapid voltage increases due to an undersupply of alumina ore. A reduction in perfluorocarbon emissions can be achieved by technological and operational changes such as the use of online monitoring of cell operating parameters and optimisations in alumina feeding techniques. These optimisations may also result in a reduction of energy use and an improvement of process performance, which are potential driving forces for their implementation (Cusano et al. 2017). The time horizon for the reduction of PFC emissions is considered as medium-term.

Tab. 3.16: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of aluminium (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Renewable electricity mix	Long-term (short-term if an electricity product based on renewable energy is purchased)
Reduction of PFC emissions	Medium term

3.7 Manufacture of copper

3.7.1 Life cycle inventory

In order to reflect future copper production, both the European copper mix and copper processing were adjusted. For copper processing, the energy saving potentials according to Fleiter et al. (2015) were taken into account, which assume a reduction in electricity demand by 22 % and in fuel demand by 55 % through process optimisation, new burner types and rapid heating. The remaining electricity demand is covered by the future European electricity mix, the remainig fuel demand by biogas.

The European copper mix consists of primary metal imported to Europe, imported copper concentrate (which is processed in Europe) and secondary copper produced in Europe. According to the International Copper Association, South America is the region with the largest identified copper recources. Data on upcoming mines also suggest the highest project and expansion of production capacities in South America[8]. Therefore, Latin America was chosen as the region of origin for the copper to be used in Europe in the future.

For copper benficiation and primary copper production, it was assumed that the production technologies used nowadays in Europe will be common everywhere.

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[8] Personal communication N. Hanson, International Copper Association Ltd., 17.11.2019

Futhermore, the energy saving potentials according to Fleiter et al. (2015) were taken into account. They assume a reduction in electricity use of 10 % and in fuel use of 2 %, mainly through waste heat utilisation and optimised operation. The remaining electricity needs are covered by the future electricity mix of Latin America (see Subchapter 5.2) and the remaining fuel use by biogas. The vehicles in the copper mines run on biofuels (ethanol). Remaining CO_2 emissions (110 g CO_2/kg primary copper) due to lime addition during the production process, are captured and fed into a underground storage facility. The life cycle inventories of the carbon capture and storage processes applied are described in chapter 4.

The energy saving potentials in the production of secondary copper were also taken into account, according to Fleiter et al. (2015): Through optimized operation and improved combustion in flame furnaces and recuperative burners, scrap preheating as well as improved combustion in shaft furnaces the electricity consumption drops by 13 % and the fuel use by 21 %. The remaining electricity needed is covered by the future European grid mix, the fuel used by biogas.

The resulting inventories for copper production are shown in Appendix A.4.

3.7.2 Environmental impacts

Future copper production reduces the greenhouse gas emissions of copper production by 89 % (Tab. 3.17). The non-renewable energy demand is 78 % smaller and also the renewable energy demand is reduced by 19 %. The overall environmental impacts are even reduced by 92 %. Apart from the increased energy efficiency and the replacement of fossil energie carriers with renewable energy sources, this is mainly due to the introduction of the most advanced production technologies nowadays used in Europe everywhere.

Tab. 3.17: Environmental impacts of 1 kg present and future primary copper production

		Future production	**Present production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	13	2.8	-78%
CED - renewable	*kWh oil-eq.*	3.5	2.8	-19%
Greenhouse gas emissions	*kg CO_2-eq.*	3.1	0.35	-89%
Overall environmental impacts	*UBP*	200’000	16000	-92%

The most important contribution to the greenhouse gas emissions of present and future primary copper production stems from the raw materials. This includes above all the mining of copper concentrates. Future copper production reduces the greenhouse gas emissions of the raw materials by 83 %. The second largest contribution comes from the fuels used. This contribution can be reduced by 71 % in future production.

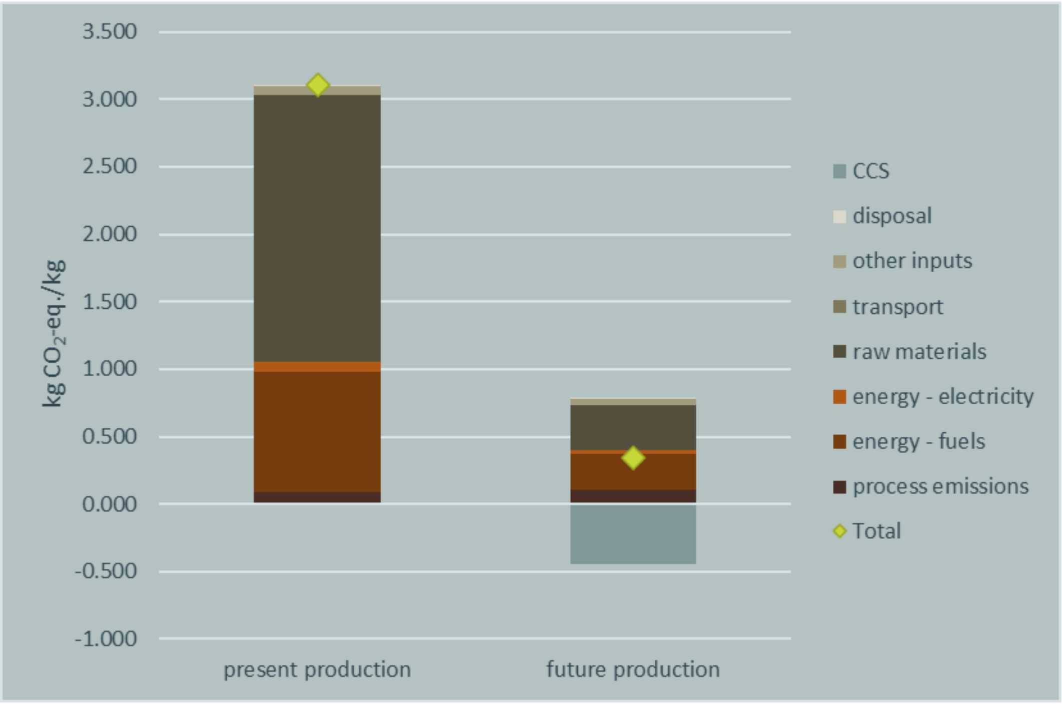

Fig. 3.6: Greenhouse gas emissions of 1 kg present and future primary copper production by contributing processes

Although direct greenhouse gas emissions from lime addition during the production process amount to 110 g CO_2-eq./kg primary copper, they are not really relevant for the total greenhouse gas emissions of primary copper production. They are by far exceeded by emissions from energy consumption and raw material extraction. But as the CO_2 emissions of the biogas used are also fed into the CCS system, this significantly reduces the CO_2 emissions of the overall process (-56 %). Overall, 80 % of the CO_2 emissions fed into the CCS system stem from biogenic sources. This reveals a large potential for abating the process-related CO_2 emissions.

3.7.3 Data quality considerations

The use of South America as the sole region of origin is a simplification. Copper will continue to come from different regions in the future. Besides South America, the regions with the largest copper reserves are North America as well as Asia and Eastern Europe. However, since the data used do not permit any differentiation between the regions of origin, the use of several regions of origin would not increase the accuracy of the results.

For the production of copper concentrate and primary copper, the grid mix of South America was used. Since many mines are located in remote regions and are not connected to the grid, electricity produced locally is in reality more likely to be used (often hydroelectric power). However, the technology used to generate the electricity depends to a large extent on the local conditions. The grid mix used here is therefore exemplary for the use of power from renewable energy resources and does not necessarily reflect the actually expected future electricity mix for copper production. The vehicles in the mines were assumed to run on biofuel. According to N. Hansen, an increase in electric propulsion systems, coupled with AI at most, is also expected[9].

It is unclear whether a refinery producing primary copper would introduce a CCS system when already switching to renewable energy carriers, particularly in view of the fact that greenhouse gas emissions are largely determined by energy use in production.

3.7.4 Time horizon for implementation of mitigation measures

The production technologies assumed to be common worldwide in future production are existing today and already used in Europe. Since the conversion or renewal of existing production facilities requires time, the time horizon for the introduction of the most modern production methods for the entire copper production is estimated to be medium. Waste heat utilization and optimized operation are feasible within existing production plants and therefore the time horizon for the implementation of these measures is estimated to be short term.

Biogas can replace fossil fuels today, the question ist whether enough sustainbly produced biogas is available (see subchapter 8.1). Another possibility is the use of electricity produced from reneweable energy carriers. The national grid mixes will only be completely converesed in long term. However, electricity based on renewable energy carriers can be purchased or produced on site. This will allow to introduce this measure much earlier (short to medium term). The first copper mines are presently preparing to use 100 % renewable electricity[10].

Tab. 3.18: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of primary copper (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Introduction of best available production technology	Medium term
Waste heat utilization	Short term
Optimized operation	Short term
Switch to biogas	Short term (subject to availability)
Future electricity mix	Long-term (short-term if an electricity product based on renewable energy is purchased; medium term if the green electricity is produced on site)
Ethanol-powered vehicles	Medium term
CCS	Medium to long term

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[9] Personal communication N. Hanson, International Copper Association Ltd., 17.11.2019

[10] See e.g. https://www.mining.com/antofagasta-announces-first-mine-use-100-renewable-energy/; last visited 12.06.2020

Ethanol powered engines for heavy duty vehicles are still in development and at present available for lorries. It will take some time until there are mining vehicles powered by biofuels.

CCS is still facing some barriers, such as additional energy requirements for carbon capture, availabiliy of transport networks, access to storage facilities, etc. Therefore the time horizon of this mitigation measure is considered to be medium to long term.

3.8 Manufacture of nickel

3.8.1 Life cycle inventory

To depict future nickel production, the inventory for ferronickel production used in steel production was adapted. Since no specific information could be obtained on future nickel production, adjustments were made in the same way as for copper production: Fossil fuel use for melting (heavy fuel oil), roasting (hard coal) and drying (natural gas) was replaced by the use of biogas, the electricity used is covered by the appropriate future electricity mix. As ferronickel is mainly produced outside of Europe (Wyns & Khandekar 2019), the future global electricity mix according to IEA (2018) was used. For copper processing, the energy saving potentials according to Fleiter et al. (2015) were taken into account. However, there is no information in this study on the energy saving potential in nickel production. Wyns & Khandekar (2019) quantify the economic potential of reduction in final energy consumption for non-ferrous metals in the year 2050 at 12 %. Therefore, the energy demand of nickel production was reduced by this percentage.

Remaining CO_2 emissions (206 g CO_2/kg ferronickel) due to lime addition during the production process are captured and fed into a underground storage facility. The life cycle inventories of the carbon capture and storage processes applied are described in chapter 4.

The resulting inventories for nickel production are shown in Appendix A.5.

3.8.2 Environmental impacts

In future ferronickel production, the reductions in greenhouse gas emissions are highest (-98 %; Tab. 3.19). Non renewable energy demand is reduced by 72 %, the overall environmental impacts by 36 %. Renewable energy demand increases by 87 %.

Tab. 3.19: Environmental impacts of 1 kg present and future ferronickel production

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	35	9.7	-72%
CED - renewable	*kWh oil-eq.*	7.3	14	87%
Greenhouse gas emissions	*kg CO_2-eq.*	9.1	0.15	-98%
Overall environmental impacts	*UBP*	17000	11000	-36%

The greenhouse gas emissions of present ferronickel production are dominated by fuel demand. In future production, the greenhouse gas emissions related to fuel use can be reduced by 69 %, but they remain the most important contributor to total greenhouse gas emissions. The greenhouse gas emissions related to electricity use are reduced by 63 % in future production. All other inputs are not relevant for total greenhouse gas emissions for primary ferronickel production. This also includes direct emissions from lime addition during the production process, although these amount to roughly 200 g CO_2-eq./kg. They are by far exceeded by emissions from energy consumption. As in copper production, the CO_2 emissions of the biogas used are also fed into the CCS system, which nearly eliminates the CO_2 emissions of the overall process (-95 %). In future nickel production, 95 % of the CO_2 emissions fed into the CCS system stem from biogenic sources. This reveals a great potential for abating the greenhouse gas emissions generated during nickel production.

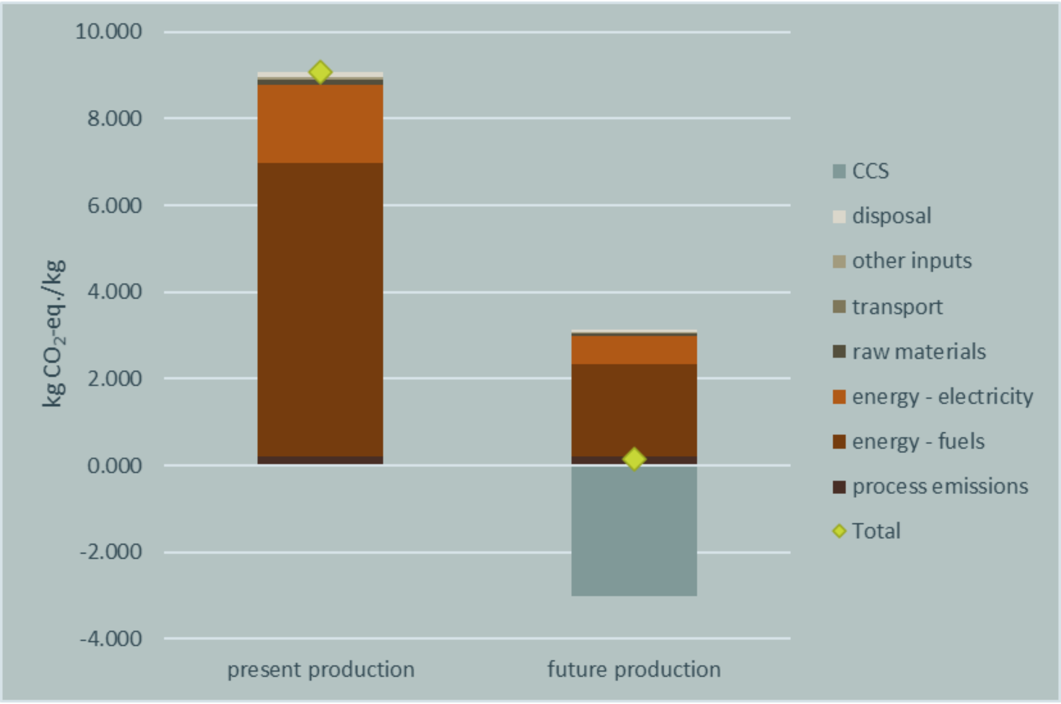

Fig. 3.7: Greenhouse gas emissions of 1 kg present and future ferronickel production by contributing processes

3.8.3 Data quality considerations

The inventory for future nickel production is based on the assumption that fossil fuels will be replaced by biogas. However, there is no indication of how realistic this assumption is. The availability of biogas is discussed in Subchapter 8.1. According to Wyns & Khandekar (2019), various sources of fossil fuels are used in the nickel industry which might be replaced by electricity in the longer term. Electric heating can also be considered as a replacement to the fossil fuel used for heating in auxiliary processes (e.g. boilers and heating). Such further electrification of the nickel production process has not been taken into account in the present study.

The energy saving potential of 12 % apply to non-ferrous metals in general and were used for ferronickel production in the absence of specific data.

Remaining CO_2 emissions were assumed to be captured and stored. However, according to Wyns & Khandekar (2019), carbon capture and storage is not an economically viable option for metals producers on their own, due to the high capital costs vis-à-vis the relatively low emissions. A possible solution might be the use of (forthcoming) existing CO_2 transport and storage infrastructure. However, this is only possible for certain favourable locations e.g. in the vicinity of steel or cement producers. The extent to which CCS will be integrated into future nickel production is therefore still uncertain, particularly in view of the fact that greenhouse gas emissions are largely determined by energy use in production.

3.8.4 Time horizon for implementation of mitigation measures

The energy saving potentials depicted by Wyns & Khandekar (2019) could be realised in short term. Obstacles may be financial criteria such as need of high investments, long investment cycles etc.

Biogas can replace fossil fuels today, the question ist whether enough sustainbly produced biogas is available (see subchapter 8.1). The national grid mixes will only be completely converesed in long term. However, electricity based on renewable energy carriers can be purchased or produced on site. This will allow to introduce this measure much earlier (short to medium term).

Tab. 3.20: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of nickel (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Realisation of energy saving potentials (better, smarter and integrated control systems, increased efficiency of burners, increased heat recovery)	Short term*
Switch to biogas	Short term (subject to availability)
Future electricity mix	Long-term (short-term if an electricity product based on renewable energy is purchased; medium term if the green electricity is produced on site)
CCS	Medium to long term

* Energy reduction measures are already being implemented today. The time horizon refers to the introduction of further energy reduction measures.

CCS is still facing some barriers, such as additional energy requirements for carbon capture, availabiliy of transport networks, access to storage facilities, etc. Therefore the time horizon of this mitigation measure is considered to be medium to long term.

3.9 Manufacture of steel

3.9.1 Life cycle inventory

The life cycle inventory of future production of crude steel is modeled based on hydrogen direct reduction steelmaking (Vogl et al. 2018, Hybrit Development AB 2018). It was divided into three sub-processes, which include iron ore pellet production, production of hot-briquetted iron (HBI) through direct reduction and production of crude steel in electric arc furnace (EAF). All heating necessary to provide energy in the shaft, ore feed and hydrogen feed to the shaft are assumed to be electric. Iron ore pellets are converted into HBI in a reduction shaft using hydrogen generated in an electrolysis as the reducing agent. Afterwards, HBI is melted and converted to liquid steel in an EAF where it is then cast into crude steel slabs.

Remaining CO_2 emissions stem from the extraction and generation of iron ore, lime calcination and the addition of carbon as an essential component of steel. The process of iron ore pelletising was adjusted to the future situation by replacing fossil fuels with biogas. Avoiding emissions from lime calcination would require carbon capture and storage in lime production or substituting the use of lime with slag foaming, sulphur removal or slag basicity adjustment. Possible savings of emissions in connection with lime calcination were not considered in the inventories as this measure is not foreseen in the hybrid project. We assumed that the addition of carbon in the EAF is in the form of pulverised coal, which leads to the emission of 9.1 kg CO_2/t liquid steel. Coal could be replaced by bio-methane or other sources of biogenic carbon.

Modelled energy consumption is based on the assumption that electrolysis, direct reduction in the shaft and EAF are coupled, so that heat can be recovered or used in further processing. However, heat from the EAF outputs is not recovered. By coupling the processes at the same production site no transport of hydrogen and HBI is necessary. Transport services for other materials used in the processes were modeled according to assumptions made in Classen et al. (2009) or using standard distances.

The hydrogen used for the direct reduction of steel is produced via electrolysis of water (Hybrit Development AB 2018). The hydrogen production is modelled according to Tschümperlin and Frischknecht (2017). The production machine is the electrolyser Hogen C30 from the company Proton OnSite. The electricity consumption of the electrolyser was adapted based on the amount of hydrogen used in the steelmaking process (Vogl et al. 2018) and the electricity consumption of this production step (Hybrit Development AB 2018). The future European electricity mix is used to supply the electrolyser (see subchapter 5.2). The electrolyser Hogen C30 produces hydrogen at a pressure of 30 bar (Proton 2013).

In Switzerland, no primary steel is produced. For representing future production of rolled steel in Switzerland, the existing dataset was adapted by using the future (mainly renewable) electricity mix and biogas instead of natural gas. The Swiss steel industry is mainly pursuing measures to increase energy efficiency, which can be increased by 1 to

2 % per year. In addition, scrap recycling is being improved and the yield has been increased from 90 % to 94 %.[11]

The resulting inventories for future steel production are shown in Appendix A.6.

3.9.2 Environmental impacts

With future hydrogen steel production processes, the greenhouse gas emissions are reduced by 62 % compared to present production of converter steel (Tab. 3.21). CED non renewable decreases by 11 %, while the renewable energy demand increases by 2145 % caused by the hydrogen production. The overall environmental impacts decreases by 15 %.

Tab. 3.21: Environmental impacts of 1 kg present converter steel and future hydrogen steel production

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	6.1	5.4	-11%
CED - renewable	kWh oil-eq.	0.15	3.4	2145%
Greenhouse gas emissions	kg CO2-eq.	1.6	0.63	-62%
Overall environmental impacts	UBP	2600	2200	-15%

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[11] Pers. Communication Patric Fischli-Boson, 25.8.2020

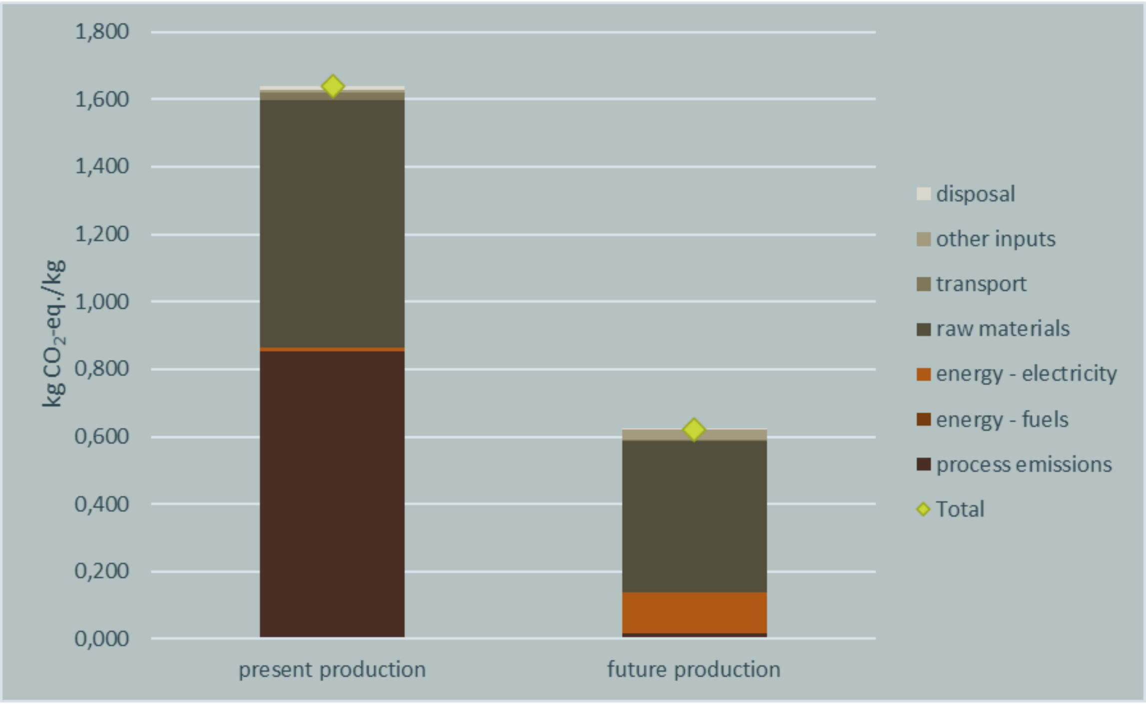

Fig. 3.8: Greenhouse gas emissions of 1 kg present production of converter steel and future production of hydrogen steel by contributing processes

The greenhouse gas emission reduction from future production compared to present production are mainly caused by CO_2 emission reduction associated to the process emissions (Fig. 3.8). In present pig iron production, the use of coke as reducing agent leads to the emission of large quantities of CO_2. In the future production of hydrogen hot briquetted iron, no CO_2 is emitted since hydrogen is used as reduction agent which leads to the emission of water.

Tab. 3.22: Environmental impacts of 1 kg present and future production of rolled steel

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	3.4	1.2	-64%
CED - renewable	kWh oil-eq.	0.25	1.2	400%
Greenhouse gas emissions	kg CO2-eq.	0.72	0.27	-63%
Overall environmental impacts	UBP	960	610	-37%

For rolled steel production, the greenhouse gas emissions can be reduced by 63 % with future production (Tab. 3.22). The non-renewable energy demand is 64 % lower, the overall environmental impact 37 %.

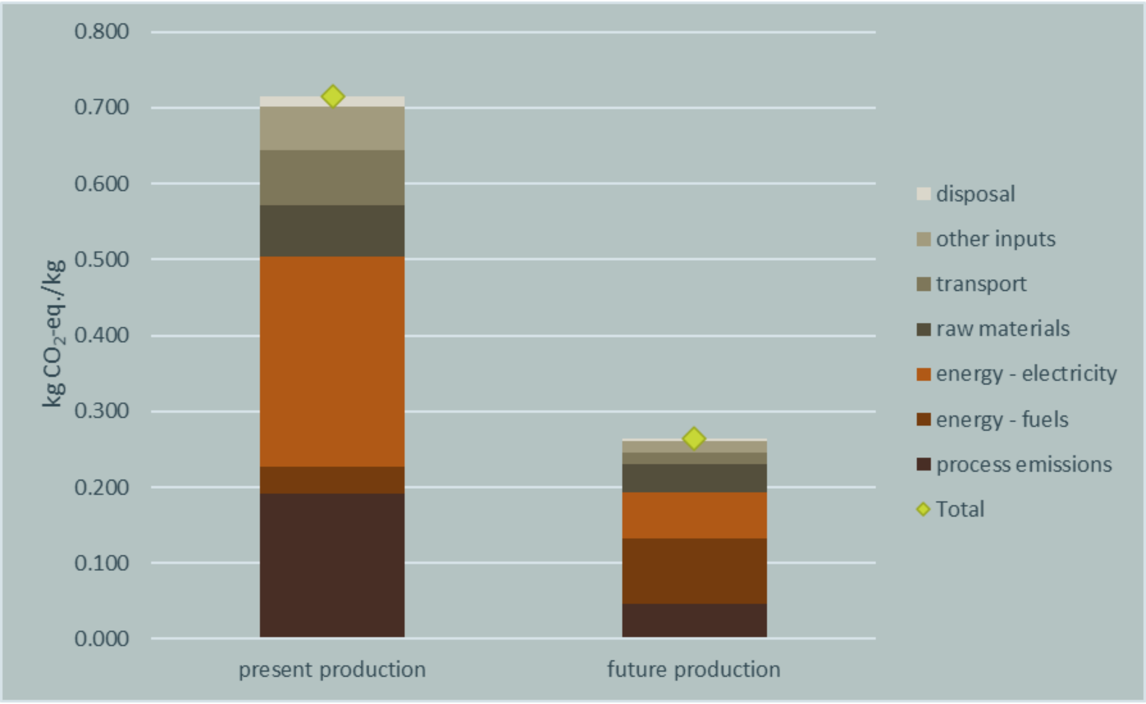

Fig. 3.9: Greenhouse gas emissions of 1 kg present and future production of rolled steel by contributing processes

The reduction in the greenhouse gas emissions is mainly due to the use of the future (mainly renewable) electricity mix and the replacement of natural gas by biogas, which leads to a significant reduction of the process emissions. On the other hand, the emissions from the production of the fuels is slightly higher, which results of methane leakages during biogas production.

3.9.3 Data quality considerations

We assumed that the electrolysis, direct reduction of iron in the shaft and the EAF take place at the same site. This allows an efficient use of energy and reduces logistic expenses. If hydrogen is generated at a different site, additional heating for the hydrogen feed to the reactor would be required. No exact information on additional energy consumption was available. Furthermore, we did not find any information on the type of electrolyser used for hydrogen production.

3.9.4 Time horizon for implementation of mitigation measures

The time horizon of the most important mitigation measures in the future manufacture of steel is summarised in Tab. 3.23. The hydrogen direct reduction steelmaking process design is similar to the traditional steelmaking route (blast furnace - basic oxygen furnace) and is based on existing technologies (Vogl et al. 2018). Therefore, no major, previously unknown technical obstacles need to be dealt with. State-of-the art direct reduction plants need to be adapted to reduction with hydrogen instead of natural gas. Electric arc furnaces are used widely in industry, but the introduction of HBI instead of iron scrap might require minor adaptations in reactor design. Furthermore, existing fossil heat sources in the production system will need to be replaced by fossil-free fuels and technologies for process heat. These changes are considered to be possible in the short term.

Hydrogen production via electrolysis is based on existing technology but needs to be proven on large scale. Electrolyser technology is mature and modular units can be combined to yield large capacities (Vogl et al. 2018). Technology for hydrogen storage, which is crucial to the competitiveness of the process, is still untested. Large scale hydrogen production and storage are considered to be realizable in the medium term.

The future hydrogen direct reduction steelmaking process runs on electricity instead of coal and coke as the traditional steelmaking route (blast furnace - basic oxygen furnace). The supply of renewable energy in sufficient quantity is a long-term mitigation measure (see also future electricity mixes of important regions in section 5.2.1).

Tab. 3.23: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of steel (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Implementation of the hydrogen direct reduction steelmaking route	Short term
Hydrogen production and storage	Medium term
Renewable electricity mix	Long-term (short-term if an electricity product based on renewable energy is purchased

3.10 Manufacture of zinc

3.10.1 Life cycle inventory

For future zinc production, both zinc mining & concentration and the production of primary zinc were adapted. Current figures for energy demand were taken from Genderen et al. (2016). For future zinc mining, electricity demand is covered by the future global electricity mix (see subchapter 5.2).

For future production of primary zinc, the energy demand of the production process was reduced according to Fleiter et al. (2015; 8 % for both electricity and fuels). According to Genderen et al. (2016), currently more than 98 % of primary zinc is generated by hydrometallurgical processes. Electricity demand is covered by the future European electricity mix (see subchapter 5.2), heating energy is supplied by biogas. In addition to the energy requirements, also the heavy metal as well as other toxic emissions (arsenic, dioxin, sulfur dioxide, fluoride) and biological oxygen demand, chemical oxigen demand and total organic carbon in waste waters were adopted from Genderen et al. (2016) for future zinc production.

For both processes, diesel-powered machines were assumed to be ethanol-driven in future.

The resulting inventories for zinc production are shown in Appendix A.7.

3.10.2 Environmental impacts

For future primary zinc production, the reduction in the overall environmental impacts is highest (65 %, see Tab. 3.24). This is due to the fact that new figures for heavy metal and other toxic emissions were taken into account. The greenhouse gas emissions are reduced by 61 %, non-renewable energy demand by 32 %. The renewable energy demand increases by 245 %.

Tab. 3.24: Environmental impacts of 1 kg present and future primary zinc production

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	13	8.9	-32%
CED - renewable	*kWh oil-eq.*	2.2	7.7	245%
Greenhouse gas emissions	*kg CO_2-eq.*	3.2	1.2	-61%
Overall environmental impacts	*UBP*	33000	12000	-65%

In present zinc production, electricity use, raw materials and fuel use determine the greenhouse gas emissions (Fig. 3.10). In future production, those greenhouse gas emissions can be reduced by 56 %, 54 % and 92 %, respectively. As a result, in future zinc production the greenhouse gas emissions from fuel use are nearly eliminated and electricity use as well as raw materials contribute most to greenhouse gas emissions. The contribution of 'other inputs' is almost entirely determined by the steam used for chemical processes.

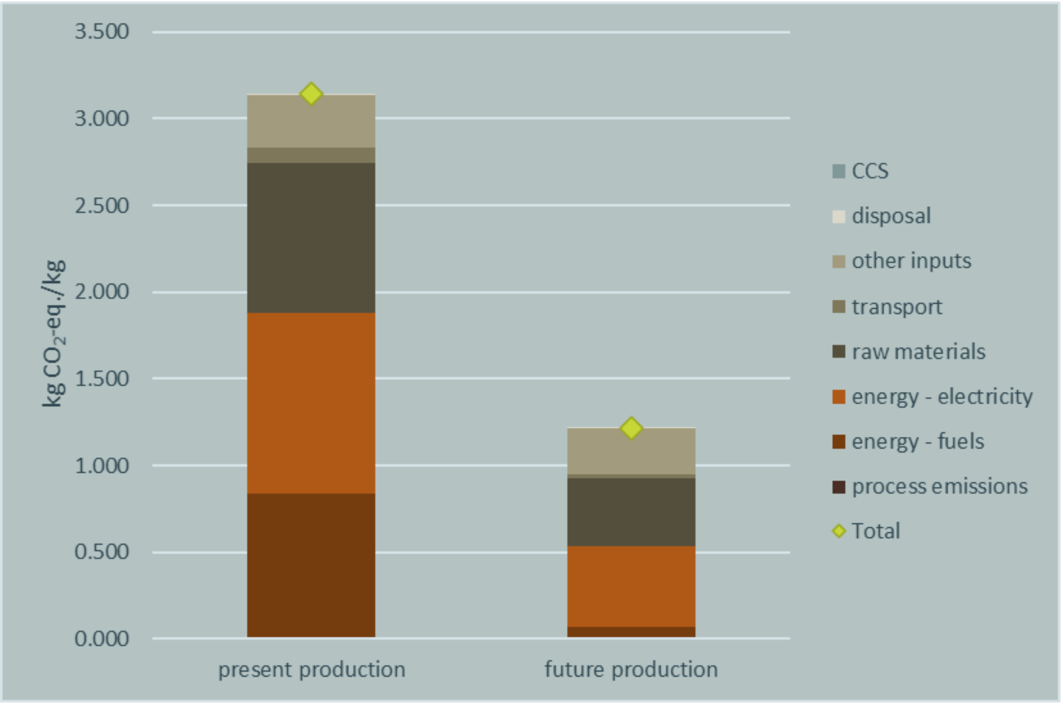

Fig. 3.10: Greenhouse gas emissions of 1 kg present and future primary zinc production by contributing processes

3.10.3 Data quality considerations

For zinc production, there was no information available on future production processes. The life cycle inventories for future zinc production were therefore based on current data, taking into account the energy saving potential according to Fleiter et al. (2015) and covering the remaining energy demand with renewable energy sources (electricity, biogas, ethanol). It has not been substantiated how the future production process will actually take place.

3.10.4 Time horizon for implementation of mitigation measures

Waste heat recovery is a measure used in many industrial processes which can be implemented at short term.

Biogas can replace fossil fuels today, the question ist whether enough sustainbly produced biogas is available (see subchapter 8.1). The national grid mixes will only be completely converesed in long term. However, electricity based on renewable energy carriers can be purchased or produced on site. This will allow to introduce this measure much earlier (short to medium term).

Tab. 3.25: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of zinc (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Waste heat utilisation	Short term*
Switch to biogas	Short term (subject to availability)
Future electricity mix	Long-term (short-term if an electricity product based on renewable energy is purchased; medium term if the green electricity is produced on site)
Ethanol-powered vehicles	Medium term

* Energy reduction measures are already being implemented today. The time horizon refers to the introduction of further energy reduction measures.

Ethanol powered engines for heavy duty vehicles are still in development and at present available for lorries. It will take some time until there are mining vehicles powered by biofuels.

3.11 Manufacture of wood materials

3.11.1 Life cycle inventory

The life cycle inventory of future production of wood materials, i.e. three layered laminated board, glue laminated timber, particle board and soft board is based on information drawn from the Swedish forest sector’s roadmap for fossil free competitiveness (Fossil Free Sweden 2018) and information provided by Lignum[12]. According to these sources, the manufacturing processes of the assessed wood materials are largely optimized. Thus, the forest sector and wood industry are focused on phasing out of fossil energy sources. Accordingly, fossil fuels used in forest machinery and industrial processes were replaced by ethanol or biogas. Heat used during the manufacturing processes will in the future be provided by bioenergy produced from production residues (e.g. branches, tops, stumps, fuelwood)[13].

No information on future production processes was available for the fossil-based binders, so they remained unchanged.

The life cycle inventories of the production of wood materials is shown in Appendix A.8.

3.11.2 Environmental impacts

The environmental impacts of future production of thee layered laminated board are 22 % (overall environmental impacts) to 73 % (CED non renewable) lower than the

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[12] Personal communication with Hansueli Schmid, 30.08.2019

[13] Personal communication with Hansueli Schmid, 30.08.2019

corresponding impacts of present production (Tab. 3.26). The renewable energy demand increases by 27 %.

The largest contribution to the reduction of the greenhouse gas emissions can be attributed to electricity and raw material consumption (Fig. 3.11). The reduction of greenhouse gases emitted through the supply of raw materials is due to the replacement of fossil fuels by biogenic fuels in the entire supply chain.

Tab. 3.26: Environmental impacts of 1 kg present and future production of three layered laminated board

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	2.7	0.73	-73%
CED - renewable	kWh oil-eq.	7.5	9.5	27%
Greenhouse gas emissions	kg CO2-eq.	0.38	0.13	-65%
Overall environmental impacts	UBP	1200	940	-22%

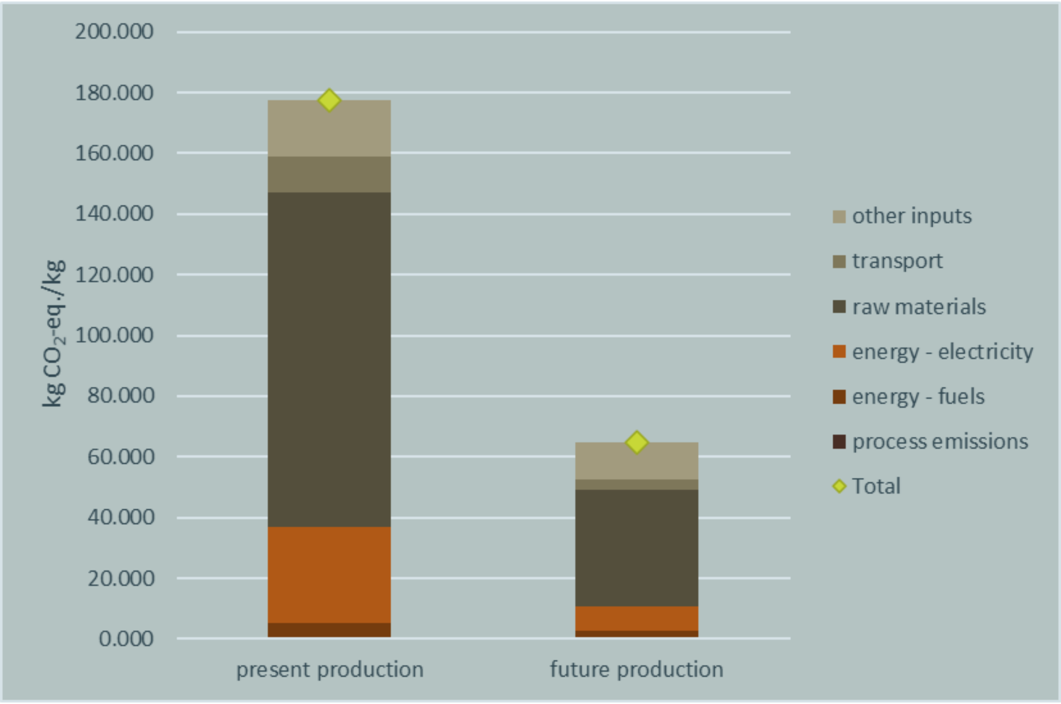

Fig. 3.11: Greenhouse gas emissions of 1 kg present and future three layered laminated board production by contributing processes

Compared to present production of glued laminated timber (in- and outdoor use), the future production reduces the environmental impacts between 21 % (overall environmental impacts) and 64 % (CED non renewable, indoor use, Tab. 3.27 and

Tab. 3.28). Renewable energy demand increases by 17 % for both, the production of glued laminated timber outdoor use as well as indoor use.

Tab. 3.27: Environmental impacts of 1 kg present and future production of glued laminated timber, outdoor use

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	2.2	0.88	-60%
CED - renewable	kWh oil-eq.	7.5	8.8	17%
Greenhouse gas emissions	kg CO2-eq.	0.34	0.17	-50%
Overall environmental impacts	UBP	900	710	-21%

Tab. 3.28: Environmental impacts of 1 kg present and future production of glued laminated timber, indoor use

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	2.0	0.71	-64%
CED - renewable	kWh oil-eq.	7.5	8.8	17%
Greenhouse gas emissions	kg CO2-eq.	0.30	0.14	-55%
Overall environmental impacts	UBP	860	680	-21%

The greenhouse gas emissions of the future production of glued laminated timber, outdoor use and indoor use are lower by 50 % and 55 %, respectively, compared to the corresponding impacts of present production. Main contributors to the reduction are the reduced consumption of electricity and a more environmental friendly supply of raw materials (due to the replacements of fossil fuels in the supply chain, Fig. 3.12 and Fig. 3.13).

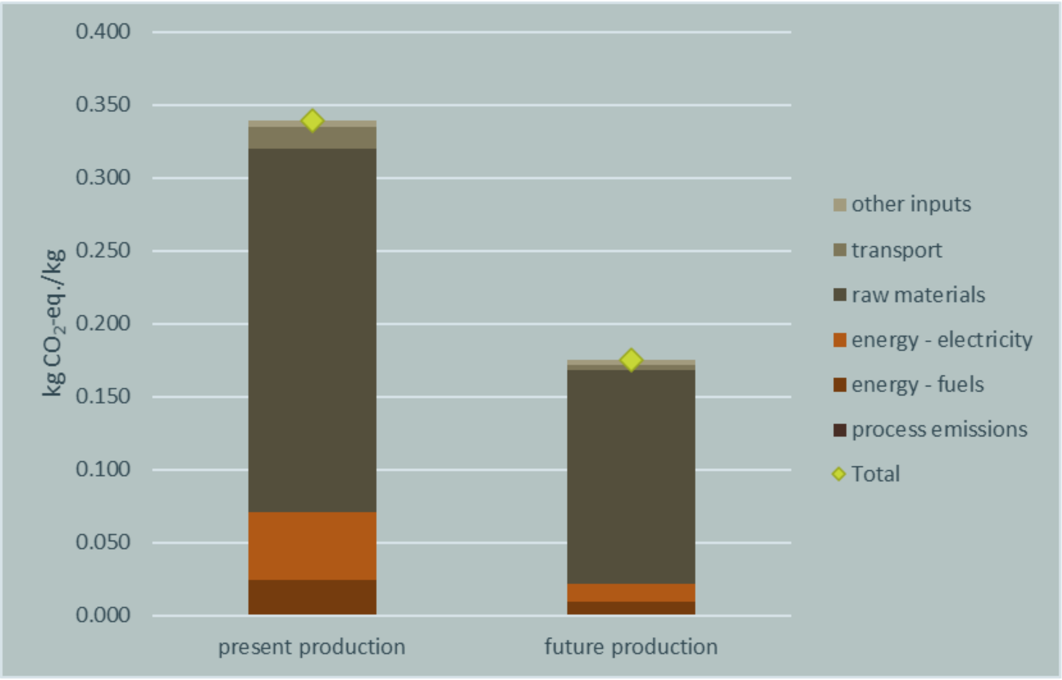

Fig. 3.12: Greenhouse gas emissions of 1 kg present and future glued laminated timber, outdoor use production by contributing processes

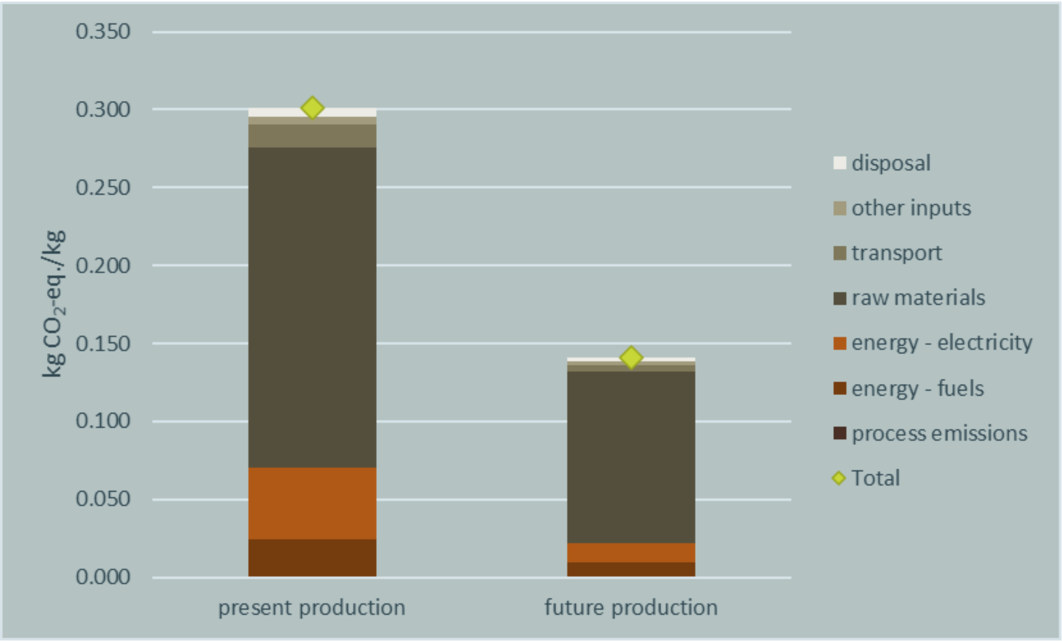

Fig. 3.13: Greenhouse gas emissions of 1 kg present and future glued laminated timber, indoor use production by contributing processes

Future particleboard production leads to between 17 % (CED non renewable) and 27 % (greenhouse gas emissions) lower environmental impacts than present production (Tab. 3.29). The renewable energy demand decreases by 28 %.

Tab. 3.29: Environmental impacts of 1 kg present and future particleboard production

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	2.7	2.3	-17%
CED - renewable	kWh oil-eq.	4.4	3.1	-28%
Greenhouse gas emissions	kg CO2-eq.	0.48	0.35	-27%
Overall environmental impacts	UBP	600	470	-21%

Large contributions to the greenhouse gas emissions in present and future production of particleboards stem from the supply of raw materials and the consumption of electricity (Fig. 3.14). The reduction of greenhouse gas emissions with future production processes is achieved through the reduction of emissions connected to a switch from fossil fuels to biogenic sources (applies for the supply chain of raw materials and energy consumption).

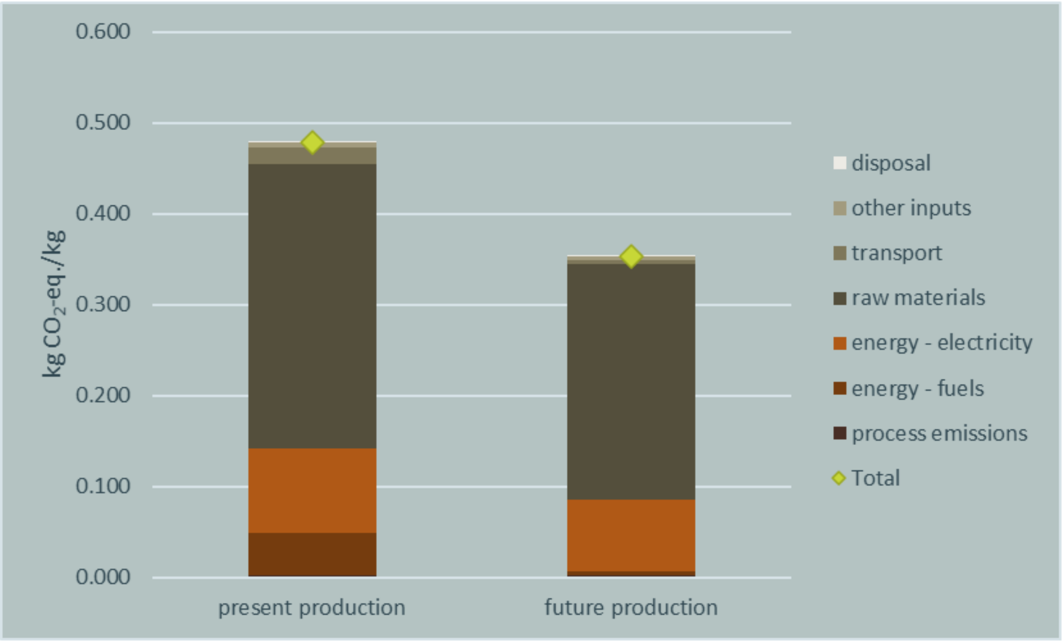

Fig. 3.14: Greenhouse gas emissions of 1 kg present and future particleboard production by contributing processes

Future fibreboard production reduces the CED non renewable and the greenhouse gas emissions by 81 % and 76 %, respectively, compared to the present production of fibreboards (Tab. 3.30). The overall environmental impacts are reduced by 39 %. CED renewable increases by 25 %.

Tab. 3.30: Environmental impacts of 1 kg present and future fibreboard production

		Present production	Future production	Improvement achieved
CED - non renewable	kWh oil-eq.	2.9	0.55	-81%
CED - renewable	kWh oil-eq.	6.6	8.2	25%
Greenhouse gas emissions	kg CO2-eq.	0.43	0.10	-76%
Overall environmental impacts	UBP	630	380	-39%

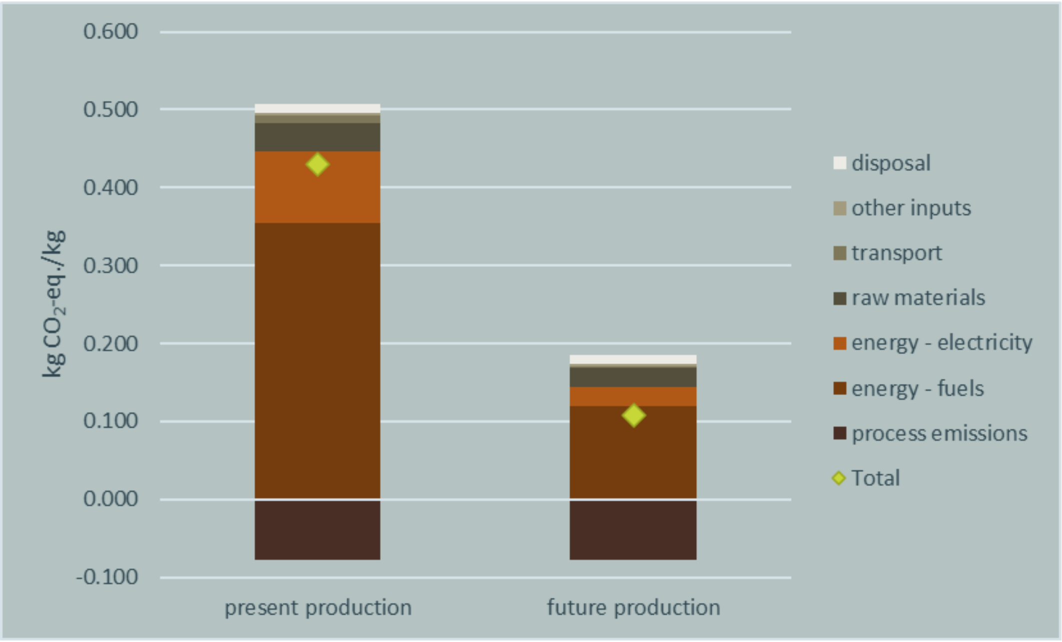

Fig. 3.15: Greenhouse gas emissions of 1 kg present and future fibreboard production by contributing processes

The replacement of fossil fuels with biogenic fuels is mainly responsible for the large reduction of greenhouse gas emissions in the production processes (Fig. 3.15). Other large contributors are reduced emissions from electricity. In the dataset of present fibreboard production, the use of animal fat for heating is modelled as the use of heat from light fuel oil. The negative process emissions stem from the correction of fossil CO_2 emissions (from the burning of light fuel oil) to biogenic CO_2 emissions (from the burning of animal fat). This modelling approach was not changed in the modelling of the future production of fibreboards.

3.11.3 Data quality considerations

Unfortunately, in desktop research we could not find a report for the Swiss forestry sector which shows how the development towards sustainable harvesting and environmentally sound utilization of Swiss timber should be implemented in concrete terms. A FOEN report on Swiss timber resource policy (BAFU et al. 2017) mentions the goal of sustainable harvesting and efficient and environmentally sound utilization of energy wood. However, no further reference is made to the environmentally friendly production of wood construction materials or a concept towards a fossil-free Swiss forestry sector. We therefore have no indication as to whether the developments modelled here will actually take place in Switzerland.

3.11.4 Time horizon for implementation of mitigation measures

The time horizon of the most important mitigation measures in the future manufacture of wood materials is summarised in Tab. 3.31. The replacement of fossil energy sources by biogenic sources in forest machinery and industrial processes can generally be done in the short term. However, the availability of sustainably produced biogas and ethanol may not be guaranteed as the demand is expected to increase significantly (see subchapter 8.1).

The use of production residues for the provision of heat used during the manufacturing process can be implemented in the short term.

Tab. 3.31: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of wood materials (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Substitution of natural gas by biogas	Short term (subject to availability)
Use of heat produced from production residues	Short term

3.12 Manufacture of glass wool

3.12.1 Life cycle inventory

The life cycle inventory for future glass wool production is based on the background report on the calculation of indicator values for the KBOB list for ISOVER glass wool (Werner 2019), which refers to glass wool production in the year 2018. A 100 % natural binder based on modified corn starch is used as a binding agent[14]. Already today, the melting of the raw materials is done using electricity as energy source. As ISOVER already uses 100 % hydropower today, also for future production the use of 100 % hydropower was assumed. In order to achieve more climate friendly production, the curing oven is operated with biogas instead of natural gas. Diesel burned in machines was replaced by biogas. Since the production process of glass wool is already highly optimized, no further increase in energy efficiency was considered.

The resulting inventories for glass wool production are shown in Appendix A.9.

3.12.2 Environmental impacts

The switch from natural gas to biogas in the curing oven translates in a reduction of the non-renewable energy demand by 72 % and a corresponding increase in the renewable energy demand by 47 % (Tab. 3.32). The reduction in greenhouse gas emissions is with 41 % somewhat smaller than the reduction in the non-renewable energy demand. This is due to the fact that there are also greenhouse gas emissions during biogas supply, mainly caused by methane leakage. The overall environmental impacts decrease by 17 %.

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[14] Currently, natural binders are mainly used for interior applications (e.g. facade insulation panels), for exterior applications products bound with phenolic resin are used.

Tab. 3.32: Environmental impacts of 1 kg present and future glass wool production

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	3.4	1.8	-47%
CED - renewable	*kWh oil-eq.*	2.6	3.5	35%
Greenhouse gas emissions	*kg CO_2-eq.*	0.71	0.42	-41%
Overall environmental impacts	*UBP*	1200	980	-17%

The greenhouse gas emissions for present glass wool production are dominated by fuel demand and raw material use, followed by other inputs (mainly packaging materials and infrastructure). For future glass wool production, the main contributors to the greenhouse gas emissions are the raw materials (31 %), followed by the fuel demand (25 %) and other inputs (18 %, see Fig. 3.16). Electricity demand contributes 14 % to total greenhouse gas emissions of future glass wool production.

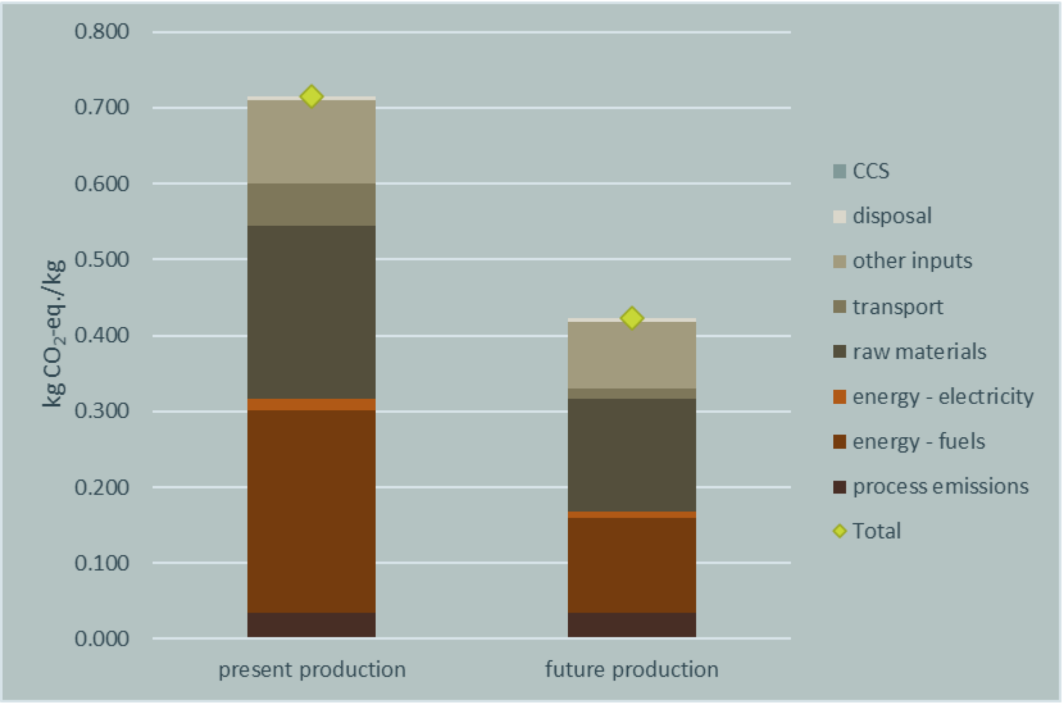

Fig. 3.16: Greenhouse gas emissions of 1 kg present and future glass wool production by contributing processes

3.12.3 Data quality considerations

In the inventory modelled, the curing oven is fuelled with biogas instead of natural gas. A more climate-friendly production could also be reached by operating the curing oven with electricity generated from renewable energy sources instead of natural gas. Technically, both options are feasible. Process efficiency has to be taken into account. In this respect, the heating of the curing air at high temperature with an electrical source should be further investigated. Biogas was chosen because it was considered the more likely option[15]. A critical assessment of the availability of biogas can be found in subchapter 8.1.

3.12.4 Time horizon for implementation of mitigation measures

Curing ovens are already operated by natural gas today, the switch to biogas could be implemented in short term, if the availability of biogas is guaranteed (see subchapter 8.1). ISOVER also replaced the diesel used in machines (forklifts) by natural gas already in 2019, so this measure was also considered to be feasible in short term.

Tab. 3.33: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of glass wool (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Curing oven heated with biogas	Short term (subject to availability)
Diesel for machines replaced by biogas	Short term (subject to availability)

3.13 Manufacture of rock wool

3.13.1 Life cycle inventory

For the manufacture of future rock wool, no detailed information was available. Therefore, the same procedure as for glass wool was applied: fossil fuels (hard coal coke and biogas) were replaced by biogas and the future Swiss grid mix was used for the electricity demand. Machines were assumed to be driven by ethanol.

The resulting inventories for rock wool production are shown in Appendix A.10.

3.13.2 Environmental impacts

The switch from fossil fuels to biogas reduces the greenhouse gas emissions by 59 % (Tab. 3.34). The non-renewable energy demand is reduced by the same percentage, whereas the renewable energy demand increases by 136 %. The overall environmental impact is reduced by 44 %.

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[15] Personal information M. Bohnenblust, ISOVER (18.11.2019)

Tab. 3.34: Environmental impacts of 1 kg present and future rock wool production

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	3.9	1.6	-60%
CED - renewable	*kWh oil-eq.*	0.32	0.76	136%
Greenhouse gas emissions	*kg CO_2-eq.*	1.0	0.43	-59%
Overall environmental impacts	*UBP*	1000	560	-44%

For present rock wool production, fuel use is the main contributor to the greenhouse gas emissions (Fig. 3.17). With the switch to biogas, those emissions can be reduced by 70 %. The second biggest contribution to the greenhouse gas emissions stems from the raw materials used (mainly briquettes). Future briquette production was not adapted, but the changes in the background inventories (electricity and cement use, transport services) lead to a reduction of 46 % for the greenhouse gas emissions caused by the raw materials.

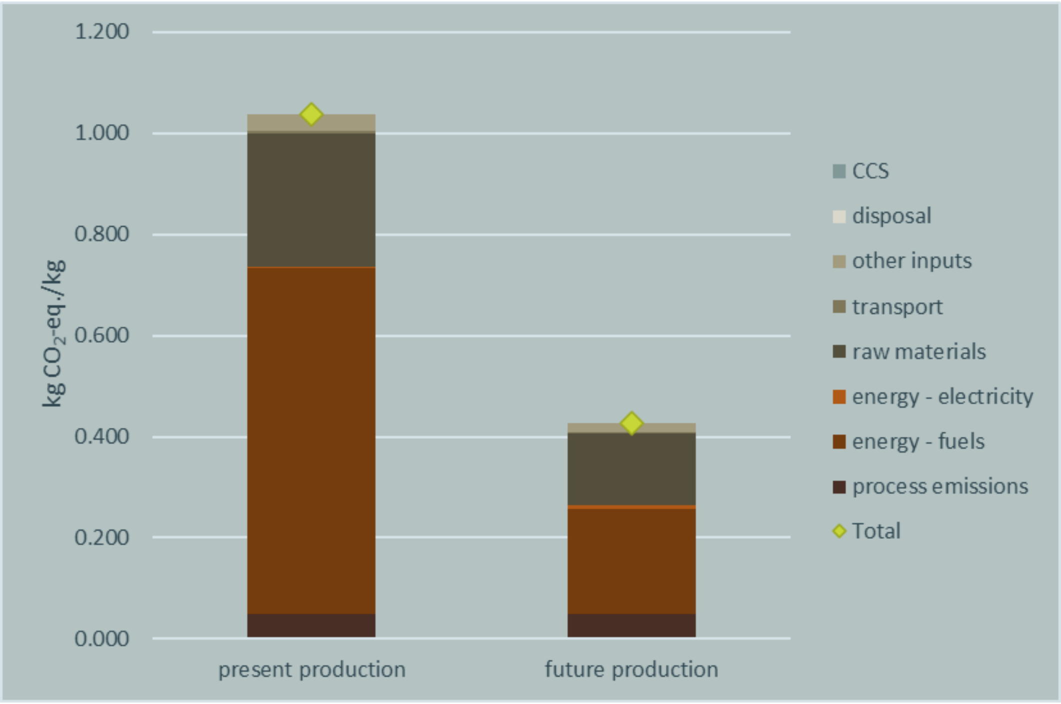

Fig. 3.17: Greenhouse gas emissions of 1 kg present and future rock wool production by contributing processes

3.13.3 Data quality considerations

No specific data were available for the future production of rock wool. Therefore the calculated reduction potentials are based on the assumption of a switch from fossil fuels to biogas. Another strategy is the electrification of the production process. Depending on the variant implemented and the framework conditions (e.g. the electricity mix used), the reduction potentials achieved may differ.

3.13.4 Time horizon for implementation of mitigation measures

The substitution of hard coal coke and natural gas by biogas is technically feasible today, if of enough sustainably produced biogas is available (see subchapter 8.1). According to the Swiss Energy Perspectives 2050 (Prognos 2012), the Swiss electricity mix will only be fully based on renewable energy carriers in the year 2050. However, electricity mixes from renewable sources are available and can already be deliberately purchased today. Ethanol-powered machines were estimated to be available in medium term.

Tab. 3.35: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of glass wool (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Substitution of fossil fuels by biogas	Short term (subject to availability)
Future electricity mix	Long-term (short-term if an electricity product based on renewable energy is purchased)
Ethanol-powered machines	Medium term

3.14 Manufacture of linoleum

3.14.1 Life cycle inventory

The life cycle inventory for the future linoleum production is based on the linoleum production of Forbo at Assendelft (NL), which claims to be climate-neutral[16]. The manufacturing process uses 100 % renewable electrical energy. Biogas is used to heat the drying chambers. Production data was taken from the background report on the EPD of the product “Marmoleum Striato & Walton” (Zeitler 2018). The resulting inventory for future linoleum production is show in Appendix A.10.

An important raw material for linoleum is linseed oil. For future linseed production, only the irrigation and harvesting processes were adapted (irrigation by future electricity mix, harvester running with biofuels). Fertilising has not been changed.

3.14.2 Environmental impacts

Future linoleum production reduces the greenhouse gas emissions per kg linoleum by 41 %. The non-renewable energy demand is reduced by 54 %, whereas the renewable energy demand increases by 54 %. The overall environmental impacts also increase by 21 %. This is because, according to the data provided, more linseed oil is used in future

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[16] https://www.forbo.com/flooring/de-de/umwelt/unser-einsatz/pczkuc, last visited 05.12.2019

linoleum production than at present. At over 90 %, linseed oil accounts for the largest share of the total environmental impacts.

Tab. 3.36: Environmental impacts of 1 kg present and future linoleum production

		Future production	**Present production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	11	4.9	-54%
CED - renewable	*kWh oil-eq.*	8.2	13	54%
Greenhouse gas emissions	*kg CO_2-eq.*	2.5	1.5	-41%
Overall environmental impacts	*UBP*	20’000	24’000	21%

For linoleum production the reduction in greenhouse gas emissions is smaller than for most of the other building materials assessed. 22 % of the greenhouse gas emissions of present linoleum production are caused by the linseed oil used resp. the growing of the linseed at farm. 45 % of those greenhouse gas emissions are direct emissions during cultivation (carbon dioxide emissions from urea and lime as well as dinitrogen monoxide emissions) which remain stable in future production.

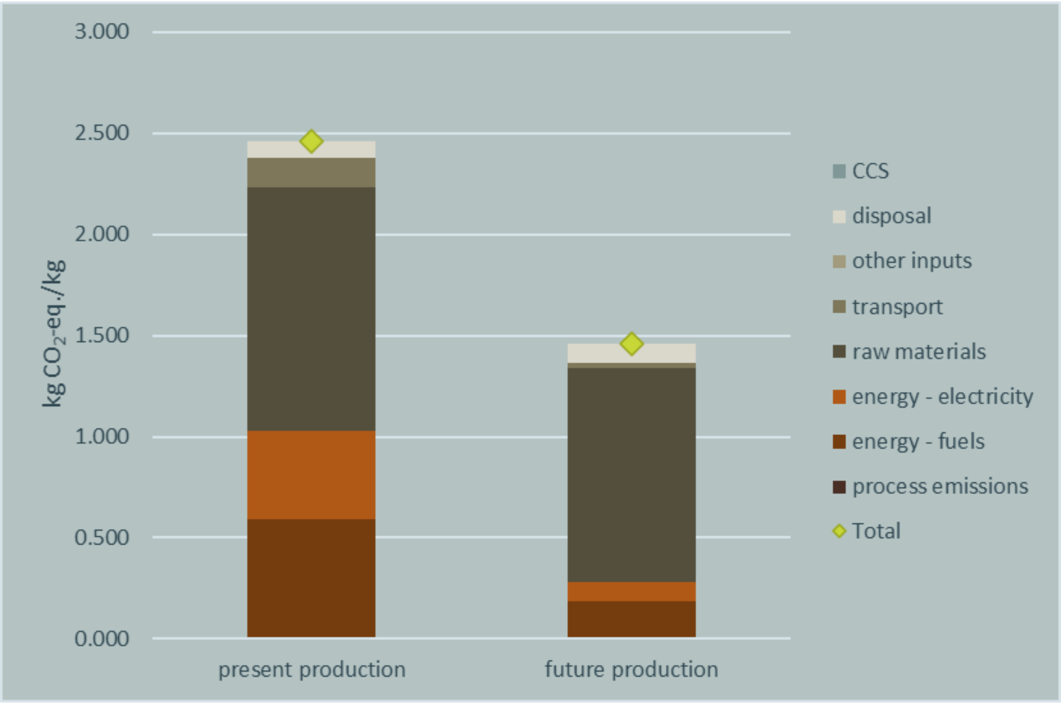

Fig. 3.18: Greenhouse gas emissions of 1 kg present and future linoleum production by contributing processes

Fig. 3.18 shows the greenhouse gas emissions of present and future linoleum production by contributing processes. Raw materials contribute most to the greenhouse gas emissions of linoleum. Future production reduces those greenhouse gas emissions by only 13 %. For higher reduction rates also the fertilizsation, an important contributor to the greenhouse gas emissions from linseed cultivation, would have to be changed. Greenhouse gas emissions from the use of fuels and electricity, the other two major contributors, can be reduced by 68 % and 79 %, respectively.

3.14.3 Data quality considerations

The data for future standard linoleum production reflect today's, albeit very advanced, technology. Further technical progress is not taken into account.

Due to the unknown origin of the agricultural raw material linseed oil, global inventories were used. As land use and water resources dominate the overall environmental impacts of linseed oil, the use of country-specific inventories could substantially change the results.

3.14.4 Time horizon for implementation of mitigation measures

The future production of linoleum is based on an existing production process of Forbo at Assendelft (NL). Therefore, all measures were considered to be feasible in short term. Only if electricity procurement is not explicitly switched to a product made from renewable energy sources will it take until 2050 for production to be switched to 100 % renewable energy sources even with Swiss grid electricity.

Tab. 3.37: Classification of the time horizon for the introduction of the mitigation measures considered in the future manufacture of linoleum (short-term: until 2025, medium-term: until 2035; long-term: until 2050)

Measure	Time horizon
Renewable electricity mix	Long-term (short-term if an electricity product based on renewable energy is purchased)
Biogas for drying chambers	Short term

3.15 Manufacture of plastic materials

3.15.1 Life cycle inventory

The most commonly used plastic materials in the construction industry are polystyrene (XPS/EPS), polyurethane (PUR) and polyvinylchloride (PVC). No quantitative information is available about the future production of those plastic materials. The plastic industry is mainly working towards increased circularity (PlasticsEurope 2019). According to Guy Castelan from PlasticsEurope the industry is also committed to foster the use of renewable and recycled feedstock at the level of production[17]. Due to the lack

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[17] Guy Castelan, PlasticsEurope. Personal communication 7.2.2020.

of data on specific reduction measures, the CO_2 emissions of the production of expandable polystyrene, polyurethane and polyvinylchloride have been abated via a carbon capture and storage system. A CCS system is also considered for the CO_2 emissions from the disposal (incineration) of those materials.

For extruded polystyrene, different blowing agents are available (e.g. HFCs CFCs, HCFCs). In the present inventory data, a mixture of HFCs and CO_2 is used. To replace CFCs, HCFCs and HFCs, a variety of climate-friendly blowing agents have been or are being developed (EPA 2011). To reflect this development, the future production of extruded polystyrene was modelled with 100 % CO_2 as blowing agent.

Additionally, the production of polylactic acid (PLA) granulate as an example for a biobased plastic material has been examined. PLA is made from corn starch. In future PLA production, biogas is used instead of natural gas and light fuel oil. Corn drying is done with agricultural biogas instead of light fuel oil. All other inputs and production processes remain the same.

The life cycle inventories for the present and future production of plastic materials are shown in Appendix A.12.

3.15.2 Environmental impacts

Tab. 3.38 to Tab. 3.41 show the environmental impacts of present and future production of plastic materials. The implementation of CCS-systems reduces the greenhouse gas emissions of the plastic materials production between 55 % (polystyrene foam slab) and 85 % (polystyrene, extruded). Extruded polystyrene has the highest reduction rate because for this material, also the blowing agents have been adapted.

The adaptation of electricity supply and transport in the supply chains leads together with the implementation of the CCS-systems to a change in non-renewable energy demand of +1% (polyvinylchloride) to -8 % (polystyrene extruded); the renewable energy demand increases by 109 % (polyurethane) to 218 % (polystyrenen foam slab). The overall environmental impacts are reduced by 22 % (polyvinylchloride) to 77 % (polystyrene extruded).

Future PLA production reduces the greenhouse gas emissions by 56 % and the overall environmental impacts by 22 %. Non-renewable energy demand decreases by 68 %, on the other hand renewable energy demand increases by 24 % (Tab. 3.42).

Tab. 3.38: Environmental impacts of 1 kg present and future polystyrene foam slab (EPS) production

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	29	28	-3%
CED - renewable	*kWh oil-eq.*	0.35	1.1	218%
Greenhouse gas emissions	*kg CO_2-eq.*	4.3	1.9	-55%
Overall environmental impacts	*UBP*	3500	2300	-33%

Tab. 3.39: Environmental impacts of 1 kg present and future polystyrene, extruded (XPS) production

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	27	25	-8%
CED - renewable	*kWh oil-eq.*	0.47	1.3	175%
Greenhouse gas emissions	*kg CO_2-eq.*	11	1.7	-85%
Overall environmental impacts	*UBP*	8700	2000	-77%

Tab. 3.40: Environmental impacts of 1 kg present and future polyurethane production

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	28	27	-2%
CED - renewable	*kWh oil-eq.*	0.75	1.6	109%
Greenhouse gas emissions	*kg CO_2-eq.*	4.4	1.8	-60%
Overall environmental impacts	*UBP*	4700	3400	-27%

Tab. 3.41: Environmental impacts of 1 kg present and future polyvinylchloride production

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	17	17	1%
CED - renewable	*kWh oil-eq.*	0.26	0.57	119%
Greenhouse gas emissions	*kg CO_2-eq.*	2.0	0.55	-73%
Overall environmental impacts	*UBP*	2900	2200	-22%

Tab. 3.42: Environmental impacts of 1 kg present and future PLA production

		Present production	**Future production**	**Improvement achieved**
CED - non renewable	*kWh oil-eq.*	13	4.3	-68%
CED - renewable	*kWh oil-eq.*	7.5	9.3	24%
Greenhouse gas emissions	*kg CO_2-eq.*	3.0	1.3	-56%
Overall environmental impacts	*UBP*	5000	3900	-22%

Fig. 3.19 shows as an example the greenhouse gas emissions of present and future polyurethane production by contributing processes. It clearly shows that the raw materials (diisocyanate and polyols), dominate the greenhouse gas emissions of plastic production. This is the case for all plastic materials analysed. As the CCS system is used in the production of those raw materials, the reduction in greenhouse gas emissions occurs there.

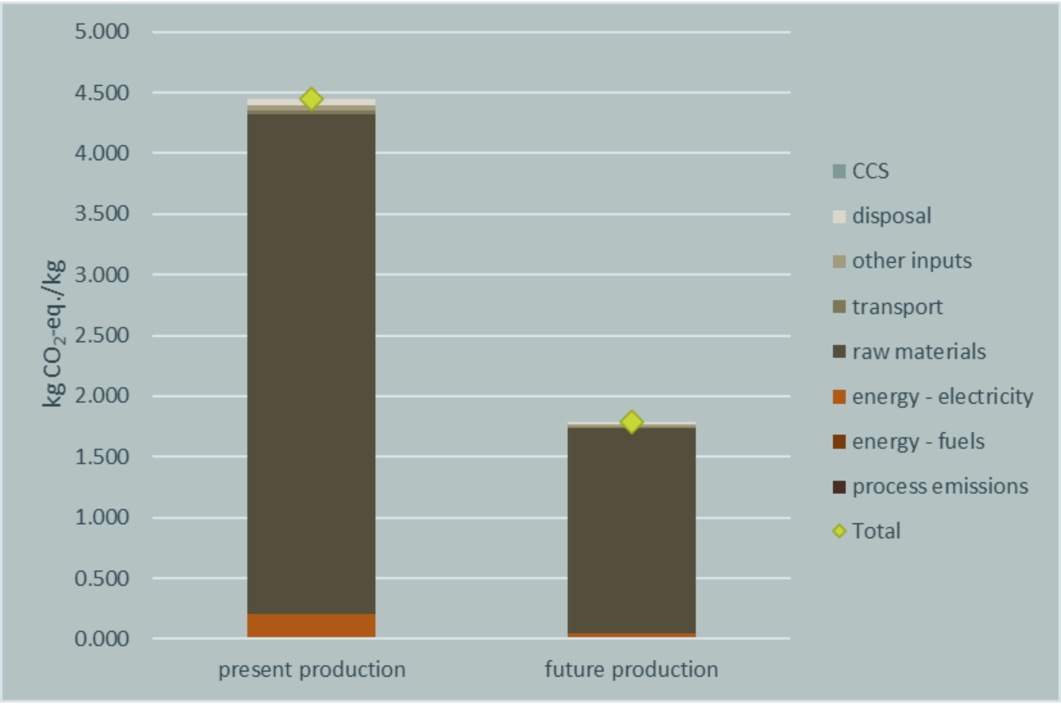

Fig. 3.19: Greenhouse gas emissions of 1 kg present and future polyurethane production by contributing processes.

The environmental impacts of present and future PLA production is in the same order of magnitude as the impacts of fossil based plastic materials. The greenhouse gas emissions of present PLA production are dominated by the energy demand (fuels and electricity, Fig. 3.20). Greenhouse gas emissions through electricity demand can be reduced by 77 %, emissions through fuel demand by 53 %. For future PLA production, fuel demand is the most important contributor to the total greenhouse gas emissions, followed by the raw materials (corn). It has to be noted that for corn production, only corn drying has been adapted to renewable energy suppy. Fertilising and direct emissions of corn production itself has not been changed.

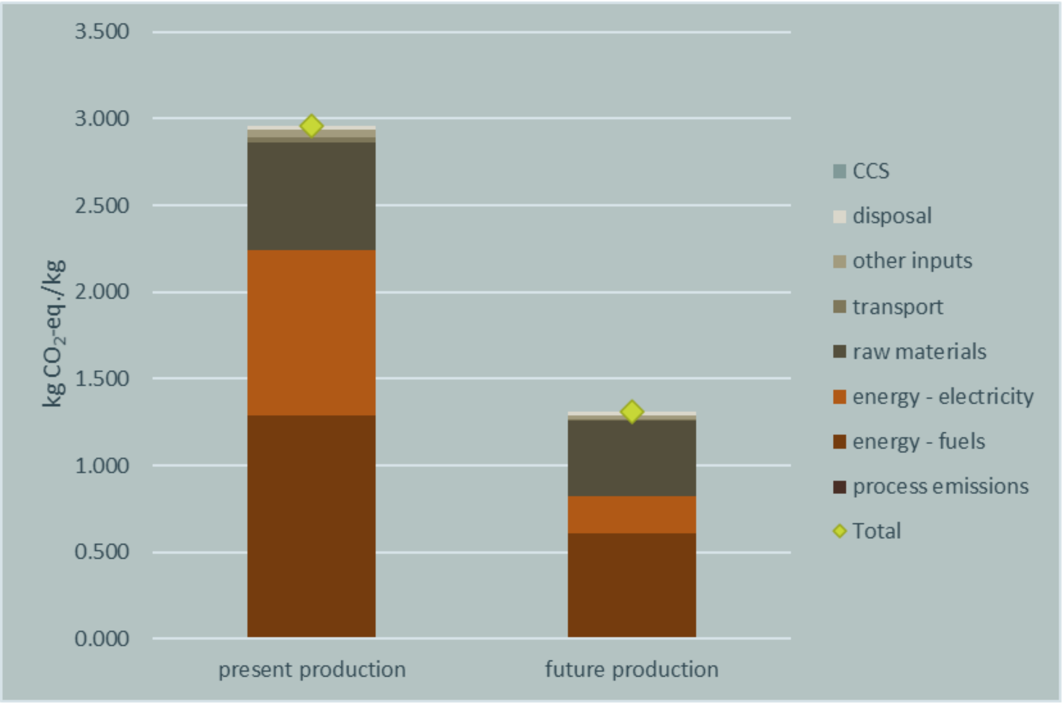

Fig. 3.20: Greenhouse gas emissions of 1 kg present and future PLA production by contributing processes

3.15.3 Data quality considerations

The foaming agent CO_2 exhibits a lower insulation value compared to HCFCs and therefore requires 30-50 % increase in foam thickness. In the inventory data described above, the environmental impacts are expressed per kg material. The increase in material demand due to the change in the blowing agent used is not captured in these figures. However, a increase in foam thickness by 30-50 % would results in an increase in environmental impacts by the same percentage.

3.15.4 Time horizon for implementation of mitigation measures

No specific information on mitigation measures in the plastics industry were available. Therefore, the time horizon for the implementation cannot be assessed.

4 Carbon capture and storage

4.1 Life cycle inventory

Carbon capture and storage (CCS) systems are used to absorb process-related (geogenic) CO_2 emissions which cannot be abated by other means. They are taken into account for brick, cement, copper, glass and nickel production as well as for the disposal of plastic materials.

The CCS systems considered are based on the inventories developed within the NEEDS project (NEEDS 2008). For carbon capture and compression, a separate inventory was built based on the inventory for a hard coal power plant equipped with CO_2 capture. Only post-combustion technology was considered. Technology key figures were taken from the very optimistic (VO) scenario for the year 2050. The capture efficiency is 90 % with an electricity use of 0.06 kWh per kilogram CO_2 captured (NEEDS 2008). The inventory for post-combustion carbon capture is shown in Appendix B.

After capture and compression, the compressed CO_2 is transported over 400 km via a pipeline. After 200 km, one recompression is taken into account. Afterwards the CO_2 is stored in a saline aquifer at a depth of 800 m. The inventories for transport and storage of CO_2 were taken directly from the NEEDs project (NEEDS 2008). CO_2-leakage during transport is 0.26g CO_2/tkm. Electricity use and transports were adapted to the future European electricity mix and future average lorry fleets.

4.2 Environmental impacts

The future capture of 1 kg CO_2 for storage has an energy demand of totally 2.9 kWh oil-eq. A bit more than half of the energy demand is generated by non-renewable energy carriers, a little less than half by renewable energy carriers (Tab. 4.1). 785 g CO2 are finally stored. This leads to a reduction in the overall environmental impacts of 339 UBP.

Tab. 4.1: Environmental impacts of 1 kg CO_2 storage, post combustion

CED - non renewable	*kWh oil-eq.*	1.58
CED - renewable	*kWh oil-eq.*	1.38
Greenhouse gas emissions	*kg CO_2-eq.*	-0.785
Overall environmental impacts	*UBP*	-339

CCS systems have been considered for those building materials, where considerable amounts of geogenic greenhouse gas emissions arise during the production process. These are clinker, bricks, float glass, copper and nickel. As the waste gas streams are usually not separated, all greenhouse gas emissions from the production process are fed into the CCS system – irrelevant of their origin (i.e. from geogenic, fossil or biogenic sources). Thereby the use of biogenic energy carriers leads to negative emissions (i.e. CO_2 is extracted from the atmosphere). Tab. 4.2 shows an overview of the geogenic/fossil CO_2 emissions and the biogenic CO_2 emissions of the building materials where a CCS system is considered. It shows that for clinker and bricks, the CCS system is mainly abating the geogenic emissions from the production process. In the case of copper and nickel, most CO_2 emissions captured by the CCS system come from biogenic sources. This shows an existing potential for negative greenhouse gas emissions and therefore for compensating the greenhouse gas emissions generated in the production chain. For float glass, the share of geogenic/fossil and biogenic emissions is about equal.

Tab. 4.2: Greenhouse gas emissions in g/kg for the building materials where a CCS system has been considered in future production

	Clinker	**Bricks**	**Float glass**	**Copper**	**Nickel**
Total	753	139	394	564	4021
Geogenic / fossil	716	119	200	110	206
Biogenic	38	20	194	454	3814
Share biogenic emissions	5%	14%	49%	80%	95%

4.3 Data quality considerations

At present, most CCS projects in Europe are planned as hubs and clusters (Page et al. 2019). This lowers the unit costs per kg CO_2 stored. However, the building materials equipped with CCS systems in this study are at least partially produced in relatively small units with limited production of CO_2. It is unclear whether CO_2 capture and storage will be available at a reasonable price for such smaller units. A possiblity might be the direct re-usage of the captured CO_2 on site, which avoids transport costs. However, this requires a demand for CO_2 on site or nearby.

Another open question is the location of the storage facilites. Existing and developing European projects rely on offshore CO_2 storage, avoiding public opposition to onshore storage (Page et al. 2019). Present storage facilities already operating are located in Norway, futher facilites are planned in Northern Europe (UK, the Netherlands, Norway and Ireland). This implicates large transport distances for Swiss companies. In order to minimize transport costs, new storage facilites in Switzerland or neigbouring countries would have to be installed.

5 Future energy supply

5.1 Overview

In the following subchapters, the life cycle inventories of future electricity mixes (subchapter 5.2) and future fuel supply (subchapter 5.3) are described. The first paragraph describes the data basis for the production inventories, the second paragraph describes the resulting environmental impacts and the third paragraph critically assesses the quality of the data used.

5.2 Electricity mixes

5.2.1 Life cycle inventories

The future Swiss electricity mix was compiled according to the Energy Perspectives 2050, scenario new energy policies (NEP), variant E (Prognos 2012). The European, the South American (used for copper production), the global (used for ferronickel production) and the Chinese production mixes were modelled according to the World Energy Outlook 2018, Sustainable Development-scenario (IEA 2018), which refers to the year 2040. Tab. 5.1 shows the composition of the future Swiss electricity mix. The composition of the future production mixes of Europe, South America and China as well as the future global production mix are shown in Tab. 5.2.

Tab. 5.1: Composition of future Swiss electricity mix

Domestic	**Electricity Mix**	**Share in electricity mix**
Unit	**TWh**	**%**
TOTAL MIX CONSUMED	**74.38**	**100.0%**
Renewables	**66.74**	**89.7%**
Hydropower	**44.15**	**59.4%**
Run-of-river power plants	13.51	18.2%
Reservoir power plants	19.93	26.8%
Small hydropower plants	4.68	6.3%
Pumped Storage	6.03	8.1%
Other renewables	**22.59**	**30.4%**
Solar	11.12	15.0%
Wind	4.26	5.7%
Wood	1.24	1.7%
Agricultural Biogas	0.87	1.2%
Biogas	0.71	1.0%
Geothermal	4.39	5.9%
Non-renewables	**2.12**	**2.9%**
Nuclear power	**0.00**	**0.0%**
Pressure water reactors (PWR)	0.00	0.0%
Boiling water reactors (BWR)	0.00	0.0%
Fossil fuels	**2.12**	**2.9%**
Fuel oil	0.24	0.3%
Natural gas	**1.88**	**2.5%**
Gas combined cycle plants (GCC)	0.00	0.0%
Combined heat and power plant	1.88	2.5%
Waste	**2.96**	**4.0%**
Imports (future European mix)	**2.56**	**3.4%**

Tab. 5.2: Future electricity production mixes of Europe, South America and China

	Europe		**South America**		**China**		**Global**	
Unit	**TWh**	**%**	**TWh**	**%**	**TWh**	**%**	**TWh**	**%**
TOTAL	**5'032**	**100%**	**1'988**	**100%**	**9'971**	**100%**	**37'082**	**100%**
Renewables	**3'403**	**68%**	**1'773**	**89%**	**6'640**	**67%**	**24'585**	**66%**
Hydropower	**820**	**16%**	**1'200**	**60%**	**1'738**	**17%**	**6'990**	**19%**
Run-of-river power plants	*689*	*14%*	*1'008*	*51%*	*1'460*	*15%*	*5'872*	*16%*
Reservoir power plants	*131*	*3%*	*192*	*10%*	*278*	*3%*	*1'118*	*3%*
Small hydropower plants	*0*	*0%*	*0*	*0%*	*0*	*0%*	*0*	*0%*
Other renewables	**2'583**	**51%**	**573**	**29%**	**4'902**	**49%**	**17'595**	**47%**
Solar	*468*	*9%*	*124*	*6%*	*2'134*	*21%*	*6'409*	*17%*
Wind	*1'558*	*31%*	*266*	*13%*	*2'070*	*21%*	*7'730*	*21%*
Biomass	429	9%	134	7%	501	5%	1'968	5%
Wood	*83*	*2%*	*26*	*1%*	*96*	*1%*	*379*	*1%*
Agricultural Biogas	*27*	*1%*	*8*	*0%*	*31*	*0%*	*123*	*0%*
Biogas	*61*	*1%*	*19*	*1%*	*71*	*1%*	*278*	*1%*
Biomass from waste incineration	*259*	*5%*	*81*	*4%*	*302*	*3%*	*1'188*	*3%*
Geothermal	*47*	*1%*	*30*	*2%*	*20*	*0%*	*555*	*1%*
CSP	*45*	*1%*	*18*	*1%*	*174*	*2%*	*855*	*2%*
Tide	*36*	*1%*	*1*	*0%*	*3*	*0%*	*78*	*0%*
Non-renewables	**1'629**	**32%**	**215**	**11%**	**3'331**	**33%**	**12'497**	**34%**
Nuclear power	**986**	**20%**	**76**	**4%**	**1'485**	**15%**	**4'960**	**13%**
Pressure water reactors (PWR)	*986*	*20%*	*76*	*4%*	*1'485*	*15%*	*4'960*	*13%*
Boiling water reactors (BWR)	*0*	*0%*	*0*	*0%*	*0*	*0%*	*0*	*0%*
Fossil fuels	**643**	**13%**	**139**	**7%**	**1'846**	**19%**	**7'537**	**20%**
Fuel oil	*10*	*0%*	*12*	*1%*	*2*	*0%*	*197*	*1%*
Natural gas	*566*	*11%*	*121*	*6%*	*701*	*7%*	*5'358*	*14%*
Coal	*67*	*1%*	*6*	*0%*	*1'143*	*11%*	*1'982*	*5%*
Hard Coal	*67*	*1%*	*6*	*0%*	*1'143*	*11%*	*1'982*	*5%*
Lignite	*0*	*0%*	*0*	*0%*	*0*	*0%*	*0*	*0%*
Waste	**0**	**0%**	**0**	**0%**	**0**	**0%**	**0**	**0%**

The resulting inventories for the future electricity mixes are shown in Appendix C.

5.2.2 Environmental impacts

The greenhouse gas emissions of the future electricity mixes are between 69 % (Switzerland) and 83 % (China) lower than the greenhouse gas emissions of the corresponding present mixes (Tab. 5.3). The lower reduction rate of the Swiss electricity mix compared to the Chinese mix is due to the fact that the Swiss mix already has a higher share of renewable energy carriers, therefore the reduction potential is smaller than in the current Chinese mix with its high share of fossil energy carriers. In absolute figures the Swiss mix exhibits the lowest greenhouse gas emissions both for present and future production.

Corresponding to the greenhouse gas emissions also the overall environmental impacts are reduced for all electricity mixes analysed.

Tab. 5.3: Environmental impacts of 1 kWh of present and future electricity supply (low voltage) in Switzerland, Europe, South America and China. For South America, no present supply mix is available.

		Switzer-land	**Europe**	**South America**	**China**	**Global**
Present production						
CED - non renewable	*kWh oil-eq.*	1.89	2.9	-	3.0	3.2
CED - renewable	*kWh oil-eq.*	0.65	0.30	-	0.248	0.249
Greenhouse gas emissions	*kg CO_2-eq.*	0.150	0.522	-	1.26	0.832
Overall environmental impacts	*UBP*	299	543	-	1173	858
Future production						
CED - non renewable	*kWh oil-eq.*	0.199	1.29	0.49	1.34	1.34
CED - renewable	*kWh oil-eq.*	1.15	0.79	1.18	0.82	0.83
Greenhouse gas emissions	*kg CO_2-eq.*	0.046	0.118	0.076	0.214	0.197
Overall environmental impacts	*UBP*	68.4	223	106	252	238
Improvement achieved						
CED - non renewable		-89%	-55%	-	-55%	-59%
CED - renewable		77%	167%	-	230%	231%
Greenhouse gas emissions		-69%	-77%	-	-83%	-76%
Overall environmental impacts		-77%	-59%	-	-79%	-72%

5.3 Fuel supply

5.3.1 Life cycle inventories

Conventional fuel production was not updated, as a shift to renewable energy sources was assumed instead of an optimised oil and gas supply. Biogas is used instead of natural gas; ethanol instead of diesel and in ship transports, methanol instead of heavy fuel oil. A critical assessment of the availability of biogas can be found in subchapter 8.1.

5.3.2 Environmental impacts

The use of biogas reduces the greenhouse gas emitted per kWh gas used by 48 % (Tab. 5.4). There is a clear shift from the non-renewable energy demand (wich is reduced by

85 %) to the renewable energy demand (which is increased by 1600 %). The substitution of natural gas by biogas also reduces the overall environmental impacts. The environmental impacts of replacing diesel by ethanol and heavy fuel oil by methanol is shown in subchapters 6.2 (lorry transports) and 6.4 (ship transports), respectively.

Tab. 5.4: Environmental impacts of 1 kWh present and future fuel used in Switzerland.

Conventional fuel		**Natural gas**
CED - non renewable	*kWh oil-eq.*	1.18
CED - renewable	*kWh oil-eq.*	0.005
Greenhouse gas emissions	*kg CO_2-eq.*	0.254
Overall environmental impacts	*UBP*	154.0
Renewable energy carriers		**Biogas**
CED - non renewable	*kWh oil-eq.*	0.179
CED - renewable	*kWh oil-eq.*	0.093
Greenhouse gas emissions	*kg CO_2-eq.*	0.132
Overall environmental impacts	*UBP*	98.5
Improvement achieved		
CED - non renewable		-85%
CED - renewable		1620%
Greenhouse gas emissions		-48%
Overall environmental impacts		-36%

5.3.3 Data quality considerations

Biogas production was modelled according to current production methods. Possible future improvements in biogas production (e.g. reduction of methane slip) or changes in the composition of raw material input (biowaste, sewage sludge, fats and oils, slurry) were not taken into account. However, it can be assumed that new raw material sources will have to be exploited as future biogas demand increases. The availability of biogas is discussed in Subchapter 8.1.

6 Future transport services

6.1 Overview

The following subchapters describe the life cycle inventories of future freight transports. Subchapter 6.2 present lorry transports, subchapter 6.3 cargo train transports and subchapter 6.4 ship transports. The first paragraph describes the data basis for the production inventories, the second paragraph describes the resulting environmental impacts and the third paragraph critically assesses the quality of the data used.

6.2 Lorry transport

6.2.1 Life cycle inventories

For future truck transports, both electric trucks and trucks powered by biodiesel were considered. The biodiesel-powered trucks were modelled on the basis of the present EURO 6 lorries. All existing weight classes (3.5-7.5t; 7.5-16t; 16-32t; 32-40t) have been adapted by replacing diesel fuel with 100 % biofuels. In the timeframe considered, first generation biofuels will most probably no longer be used, as they compete with food production. Second generation biofuels (generated from non-food residues or lignocellulosic biomass as well as energy crops) and third generation biofuels (produced from algae, sewage sludge, and municipal solid wastes) are considered more sustainable. Therefore, this study uses a biofuel that is not based on food crops, namely ethanol from wood[18]. Already today, ethanol is the biofuel with the largest production capacity (Iverfeldt et al. 2015). Besides the possibility to produce ethanol directly from biomass, ethanol is sulphur-free, which ensures compliance with the European Commission Sulphur Directive. The required quantity was determined according to the net caloric value of the respective fuels; 1 kg of diesel corresponds to 1.52 kg ethanol.

With biofuel engines, the emissions occuring during the use of the vehicles change (see Damyanov & Hofmann 2019 and Iverfeldt et al. 2015). Tab. 6.1 shows the correction factors which have been applied to determine the emissions from fuel combustion in an ethanol-powered lorry based on the emissions from a diesel-powered lorry. Sulphur and heavy metal emissions from diesel combustion in the original inventories were set to zero because ethanol contains neither sulphur nor heavy metals.

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[18] According to AEE SUISSE (2015), the majority of the energy wood used in Switzerland comes directly from the forest. The use of wood chips has increased most in recent years. For this reason it is assumed that ethanol is produced from wood chips from the forest.

Tab. 6.1: Correction factors for pollutants released during fuel combustion in an ethanol-powered lorry compared to a diesel-powered lorry (Damyanov & Hofmann 2019 and Iverfeldt et al. 2015)

Pollutant	**Correction factor**
Carbon monoxide (CO)	0.9
Heavy metals	0
Hydrocarbons (HC)	1.2
Nitrogen oxides (NO_x)	0.9
Particulates (PM)	0.01
Sulphur dioxide (SO_2)	0

The life cycle inventories for electric trucks are based on data obtained from companies distributing electric trucks in Switzerland[19]. Tab. 6.2 shows the key figures used for compiling the inventories. The average load factor and the vehicles lifetime have been transferred from the original, diesel-powered lorry inventories of the respective size class (EURO 6). No data was available for the lorry class 3.5-7.5 t. The key figures for this size class were therefore scaled using the ratio of diesel consumption from the next higher size class. In addition to the battery and power consumption, an electric motor of 280 kg was taken into account. The weight of the original diesel engine (1.27 t) was deducted from the total weight of the truck. No combustion emissions were considered. Lorry material need, road infrastructure, refrigerant use as well as brake, road and tyre wear emissions and disposal were adopted unchanged from the original, diesel-powered lorry inventories. Swiss electric trucks are operated with electricity from the Swiss grid, European electric trucks with European grid electricity.

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[19] Confidential data

Tab. 6.2: Key figures for the electric trucks by size class

Vehicle class	Battery type	Maximum range (km)	Average load factor (t)	Electricity needs (kWh/tkm)	Battery weight (kg)	Vehicle lifetime (km)
Lorry 3.5-7.5t	lithium-ion battery	300	0.98	0.565	1126	540'000
Lorry 7.5-16t	lithium-ion battery	400	3.29	0.243	2171	540'000
Lorry 16-32t	lithium-ion battery	500	5.79	0.212	4155	540'000
Lorry 32-40t	lithium-ion battery	600	11.6	0.129	6106	540'000

The share of electric trucks in the whole truck fleet was determined based on Heid et al. (2017). For light duty vehicles, a share of 30 % electric trucks was assumed, for medium duty vehicles a share of 25 % and for heavy duty vehicles a share of 3 %.

The resulting inventories for lorry transports are shown in Appendix D.1.

6.2.2 Environmental impacts

The greenhouse gas emissions of average future lorry transports are reduced by nearly 75 % (Tab. 6.3). The overall environmental impacts are about 25 % smaller than for the present average lorry transports.

Tab. 6.3: Environmental impacts of 1 tkm present and future lorry transports in Switzerland and Europe. Values refer to the average lorry fleet operated (all payloads).

		Freight transport, lorry, fleet average Switzerland	**Freight transport, lorry, fleet average Europe**
Present production			
CED - non renewable	*kWh oil-eq.*	0.62	0.57
CED - renewable	*kWh oil-eq.*	0.01	0.01
Greenhouse gas emissions	*kg CO_2-eq.*	0.135	0.124
Overall environmental impacts	*UBP*	188	170
Future production			
CED - non renewable	*kWh oil-eq.*	0.209	0.206
CED - renewable	*kWh oil-eq.*	1.129	1.021
Greenhouse gas emissions	*kg CO_2-eq.*	0.035	0.032
Overall environmental impacts	*UBP*	138	126
Improvement achieved			
CED - non renewable		-66%	-64%
CED - renewable		11677%	11412%
Greenhouse gas emissions		-74%	-74%
Overall environmental impacts		-27%	-25%

6.2.3 Data quality considerations

Due to the very high octane number of ethanol, engine adaptations are necessary to make it possible to use ethanol in a compression ignited engine. In today's compression engines powered by ethanol, an ignition improver (polyethylene glycol) is used in order to adress the low cetane rating of the fuel (Iverfeldt et al. 2015). This has not been taken into account in the data used for this study.

For the electric lorries, data have been obtained from three different companies. Battery weight was similar in all data obtained. The electricity need is difficult to assess, as it very much depends on speed, auxiliary consumers, topology and payload. The data used is based on measurements according to the New European Driving Cycle (NEDC) with 50 % payload.

Another unknown factor is the composition of the powertrain systems in the future truck fleet. According to various studies, large proportion of regional and urban delivery is assumed to be electric in future (IEA 2018; Transport and Mobility Leuven & IRU 2017).

However, the predictions for the composition of the future truck fleet is different depending on the source. Furthermore, other powertrain technologies (such as hydrogen, external electric power systems) could also play a role.

A critical assessment of the availability of biogas can be found in subchapter 8.1.

6.3 Cargo train transport

6.3.1 Life cycle inventories

The current SBB-mix used for the Swiss cargo trains is already mainly based on renewable energy (primarily hydropower). Yet 3 % of the energy used is still based on nuclear power. Since nuclear power plants mainly supply base load energy, this share was replaced by electricity from run-of-river power plants, which also produce base load energy. Shunting by diesel locomotives was replaced by fully electric operation.

The current electricity mix of the German railways (Deutsche Bahn, DB) still contains a considerable amount of fossil energy carriers, above all electricity from coal (37 %), nuclear energy (16 %) and natural gas (6 %). However, the German railways want to increase the share of renewable energies in the total electricity consumed by the trains to 100 % by 2038[20]. The fossil energy carriers were therefore replaced by electricity from hydropower, as this is the most important source of green electricity purchased by DB[21]. For both German and European rail transports, fully electric operation was assumed.

For the whole cargo train transport, infrastructure was used without adaptations. The resulting inventories are shown in Appendix D.2.

6.3.2 Environmental impacts

The German railway transports exhibit with minus 89 % the highest reduction in greenhouse gas emissions (Tab. 6.4). The greenhouse gas emissions of the average European railway transport are reduced by 79 %, the greenhouse gas emissions of the Swiss railway transport by 52 %. The different reduction rates are due to the different shares of renewable energy carriers in the electricity mixes of the present railway services, which is highest for the current Swiss railway transports.

The overall environmental impacts are reduced between 16 % (Swiss railway transports) and 44 % (German railway transports).

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[20] https://www.deutschebahn.com/de/nachhaltigkeit/ueberblick/SDG-1181534; last visited 23.1.2020

[21] https://inside.bahn.de/bahn-umwelt-gruen/; last visited 23.1.2020

Tab. 6.4: Environmental impacts of 1 tkm present and future rail transports in Switzerland, Germany and Europe.

		Freight transport, railways Switzerland	**Freight transport, railways Germany**	**Freight transport, railways Europe**
Present transports				
CED - non renewable	*kWh oil-eq.*	0.06	0.11	0.14
CED - renewable	*kWh oil-eq.*	0.06	0.01	0.01
Greenhouse gas emissions	*kg CO_2-eq.*	0.011	0.025	0.027
Overall environmental impacts	*UBP*	34.1	42.8	48.7
Future transports				
CED - non renewable	*kWh oil-eq.*	0.023	0.011	0.055
CED - renewable	*kWh oil-eq.*	0.080	0.047	0.044
Greenhouse gas emissions	*kg CO_2-eq.*	0.005	0.003	0.006
Overall environmental impacts	*UBP*	28.7	23.9	30.3
Improvement achieved				
CED - non renewable		-59%	-89%	-61%
CED - renewable		30%	293%	231%
Greenhouse gas emissions		-52%	-89%	-79%
Overall environmental impacts		-16%	-44%	-38%

6.3.3 Data quality considerations

The exact technologies for generating the additional electricity from renewable sources are not known. As the majority of SBB's electricity comes from hydropower, it was assumed that the additional renewable electricity used to replace nuclear power will also come from this source. However, other technologies could also be envisaged. However, this uncertainty affects only a small proportion of the electricity used (4%).

In the electricity mix of the German railways, the share of fossil electricity replaced by renewable energies is higher (59 %). Again, the exact technologies used to generate the additional electricity from renewable sources are not known. Hydropower was used because it is the current source of electricity from renewable energy sources. However, in the electricity mix currently used for German railway transports in the KBOB database, most of the renewable energy used comes from wind power (13 %) and biogas (12 %). If the additional renewable electricity needed comes from sources other than hydropower, this could significantly change the environmental impact of the German railways' electricity mix.

6.4 Ship transport

6.4.1 Life cycle inventories

Different possibilities exist for eliminating greenhouse gas emissions from ship transports: electrification, the use of hydrogen or ammonia in either direct combustion or fuels cells, and the use of biofuels. According to Lloyd’s Register and UMAS (2017), advanced biofuels appear to be the most attractive low greenhouse gas emission vessels solution currently available. They consistently outperform other technologies economically due to their low capital cost implications for machinery and storage, and low fuel and travel costs (Lloyd's Register Group Limited & UMAS 2017). Baker et al. (2017) see a combination of regular diesel / fuel oil with biofuels as the main credible option for the future fuel mix. As the use of fossil diesel and fuel oil is not compatible with the Paris Agreement, 100 % biofuels were chosen as the future propulsion system for ship transport.

The biofuel used is methanol produced from wood. Methanol has been identified as promising marine fuel (Ellis & Tanneberger 2015) and already today methanol fuelled ships are in use[22]. As ethanol, also methanol is sulphur-free, which ensures compliance with the European Commission Sulphur Directive. The specific methanol consumption per km was determined according to the net caloric value of the respective fuels; 1 kg of heavy fuel oil corresponds to 2.06 kg methanol. Emissions from methanol combustion in ship enginges were adopted from Ellis & Tanneberger (2015) using the emission factors shown in Tab. 6.5.

Tab. 6.5: Emission factors for main air pollutants released during fuel combustion in an methanol-powered ship (Ellis & Tanneberger 2015). * = Relative to current emission factor.

Pollutant	**Emission factor**
Carbon dioxide, biogenic (CO_2)	69.1 g/MJ fuel
Nitrogen oxides (NO_x)	1.11 g/MJ fuel
Sulphur dioxide (SO_2)	1%*
Particulates (PM)	5%*
Methane (CH_4)	0%*

The resulting inventories for ship transports are shown in Appendix D.3.

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[22] See https://shipinsight.com/articles/methanol-fuel-what-you-need-to-know, last visited 12.12.2019

6.4.2 Environmental impacts

The greenhouse gas emissions of future ship transports are reduced between 87 % and 90 % (Tab. 6.6). The reduction in the non-renewable energy demand is with 81 % to 87 % only slightly lower. The overall environmental impacts are reduced between 28 % and 56 %.

Tab. 6.6: Environmental impacts of 1 tkm present and future ship transports.

		Trans-oceanic freight ship	**Trans-oceanic tanker**	**Trans-oceanic container ship**	**Barge**	**Barge tanker**
Present production						
CED - non renewable	*kWh oil-eq.*	0.029	0.025	0.064	0.16	0.19
CED - renewable	*kWh oil-eq.*	0.00066	0.00039	0.00075	0.0039	0.0041
Greenhouse gas emissions	*kg CO_2-eq.*	0.0069	0.0060	0.015	0.038	0.045
Overall environmental impacts	*UBP*	16.1	19.0	35.4	47.0	55.9
Future production						
CED - non renewable	*kWh oil-eq.*	0.0037	0.0084	0.030	0.034	0.0037
CED - renewable	*kWh oil-eq.*	0.059	0.16	0.35	0.42	0.059
Greenhouse gas emissions	*kg CO_2-eq.*	0.00066	0.0016	0.0048	0.0057	0.00066
Overall environmental impacts	*UBP*	11.5	15.6	33.5	40.3	11.5
Improvement achieved						
CED - non renewable		-85%	-87%	-81%	-82%	-85%
CED - renewable		14726%	20844%	8741%	10224%	14726%
Greenhouse gas emissions		-89%	-90%	-87%	-87%	-89%
Overall environmental impacts		-39%	-56%	-29%	-28%	-39%

6.4.3 Data quality considerations

Emission reduction for SO_2 and particulates were also adopted for previously diesel-fuelled barge ships, although comparison in literature was based on other fuel types.

A critical assessment of the availability of biogas can be found in subchapter 8.1.

7 Building case studies

7.1 Overview

This chapter describes and discusses the effects of future production of building materials on the environmental impacts of construction, operation and and end of life management of entire buildings. For this purpose, two buildings were selected which differ in terms of materialization and use:

- Office building ARE, Ittigen (subchapter 7.2)
- Residential building Rautistrasse, Zurich (subchapter 7.3)

The buildings whose environmental characteristics are shown here were modelled in previous studies (Tschümperlin et al. 2016; Wyss et al. 2014). The bill of materials and the energy performance of the buildings were not changed and thus corresponds to the modelling as documented in the studies mentioned above. Only the background database (KBOB Life Cycle Inventory data DQRv2:2016, KBOB et al. 2016) was changed to represent the future production of construction materials as described in Chapter 3.

Construction, operation and end of life management of the buildings are considered in the analyses. Building-induced mobility is not included. In addition to the actual construction phase, the building construction also includes replacements of building elements (amortisation period of building elements according to SIA 2032 technical bulletin, SIA 2010). Operation includes energy consumption during the use of the building (heating, hot water supply, ventilation, lighting, building equipment and auxiliaries). The buildings were structured according to the elementary cost classification (ECG) (SN 508502 1995) and include the following ECG items:

- D0: excavation building pit
- D1: backfilling, construction
- D2: bottom plate: construction
- E0: ceiling: construction
- E1: roof: construcion
- E2: pillar: construction
- E3: exterior wall basement: reinforced: construction
- E4: exterior wall upper floor: construction
- E5: window: construction
- E6: inner wall: brick built: construction
- M1: stud wall: construction
- M3: cement cast plaster floor: construction
- M4: wall cover: construction

- M5: roof cover: construction
- I: building equipment: construction
- B: operation of the building

The amortisation period of the buildings was derived from the specifications of the SIA 2032 technical bulletin (SIA 2010) and is 60 years for all buildings examined. The materials and components required for construction are assessed in relation to the energy reference area and the amortisation period. This means that the values are amortised per square metre of energy reference area and year.

7.2 Office building ARE, Ittigen

7.2.1 Description

The office building for the ARE (Federal Office for Spatial Development) meets the strict requirements of the federal government in terms of efficiency and sustainability.

The office building with 96 workplaces is certified according to Minergie-P-ECO (label BE-038-P-ECO), constructed in a 2000-Watt-society compatible manner and meets the requirements of GI Healthy Indoor Climate. This is made possible by a very compact structure with reduced facade surface and a modern timber construction with the minimum of necessary concrete structure.

Fig. 7.1: Exterior view of the office building ARE, Ittigen

The structure of the building including its building services is partly flexible, the office area is divided with non-load-bearing lightweight walls, which allow a variable use. The building is heated by an electric heat pump. The materialisation of the building is shown in Appendix E.1

7.2.2 Environmental impacts

The non-renewable primary energy demand of the office building ARE as built (including operation) amounts to 92 kWh oil-eq/m^{2}a, the non-renewable primary energy demand of the same office building under the future scenario is 22 kWh oil-eq/m^{2}a (Fig. 7.2). This is a reduction of 76 %. The target value according to SIA technical bulletin 2040 (SIA 2017) is 120 kWh oil-eq/m^{2}a.

The operation of the building (B) is with nearly 70 % the main contributor to the non-renewable energy demand. With the future building, the non-renewable energy demand for building operation can be reduced by 92 %. Its share in the non-renewable energy demand of the whole building reduces to 23 %. The non renewable primary energy demand of construction and end of life of the building (D0 - I)is reduced from 28 kWh oil-eq/m^{2}a to 17 kWh oil-eq/m^{2}a (minus 39 %). The most important contribution to the total energy demand in the future scenario building stems from the construction of the building equipment (I) with 28 %.

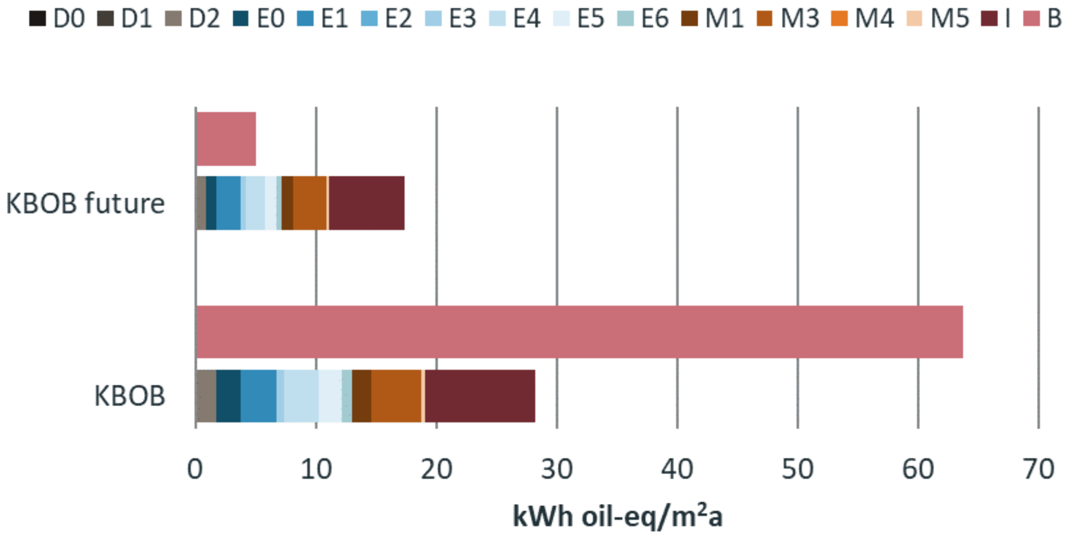

Fig. 7.2: Non-renewable primary energy demand in kWh oil-eq per m^{2}a of the present (KBOB) and future (KBOB future) office building ARE, Ittigen. Target values SIA 2040: 40 and 80 kWh oil-eq/m^{2}a (construction and operation, respectively).

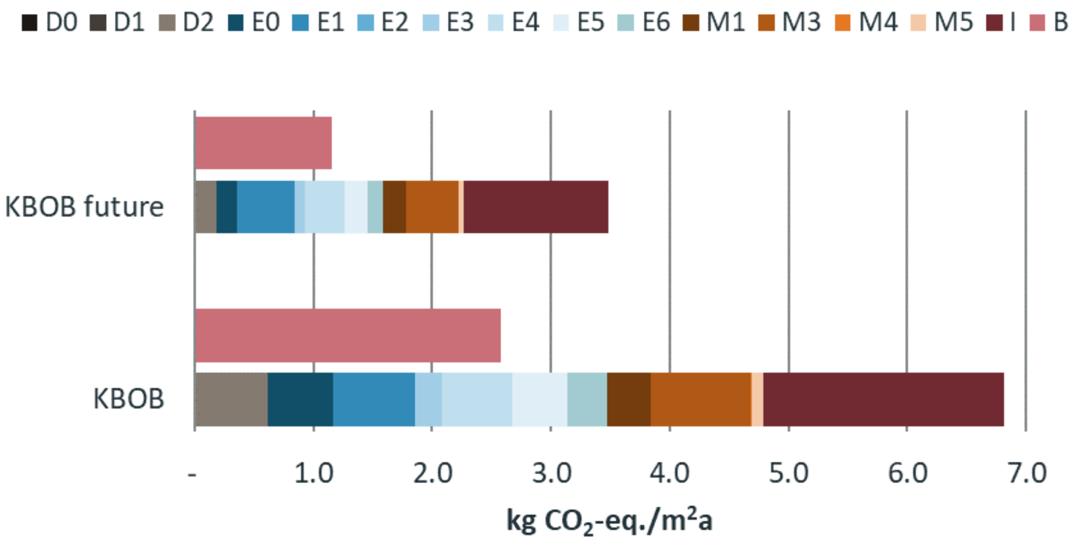

Fig. 7.3: Greenhouse gas emissions in kg CO_2-eq. per m^2a of the present (KBOB) and future (KBOB future) office building ARE, Ittigen. Target values SIA 2040: 9 and 4 kg CO_2-eq./m^2a (construction and operation, respectively).

The greenhouse gas emissions of the present office building ARE as built (including operation) amount to 9.4 kg CO_2-eq./m^2a; the future scenario building exhibits greenhouse gas emissions of 4.6 kg CO_2-eq./m^2a (Fig. 7.3). This is a reduction of 51 %. The target values according to the SIA technical bulletin 2040 (SIA 2017) are 9 and 4 kg CO_2-eq./m^2a (construction and operation, respectively).

The operation of the building (B) contributes most to the total greenhouse gas emissions of the present building (27 %), followed by the construction of the building equipment (I; 22 %). These contributions can be reduced by 55 % and 40 % respectively. For the future building, the construction of the building equipment (I) contributes with 26 % most to the total greenhouse gas emissions, closely followed by the operation of the building (B) with 25 %. The greenhouse gas emissions of construction and end of life of the building (D0 - I) amount to 6.8 kg CO_2-eq./m^2a and 3.5 kg CO_2-eq./m^2a for the present office building as built and the future scenario building, respectively. This is a reduction of 49 %.

The overall environmental impact of the present office building ARE (including operation) is 22’576 UBP/m^2a, for the future scenario building it amounts to 10’611 UBP/m^2a (

Fig. 7.4). This is a reduction of 53 %. The construction and end of life related environmental impacts (D0 - I)are reduced from 13’721 to 8’820 UBP/m^2a (minus 36 %).

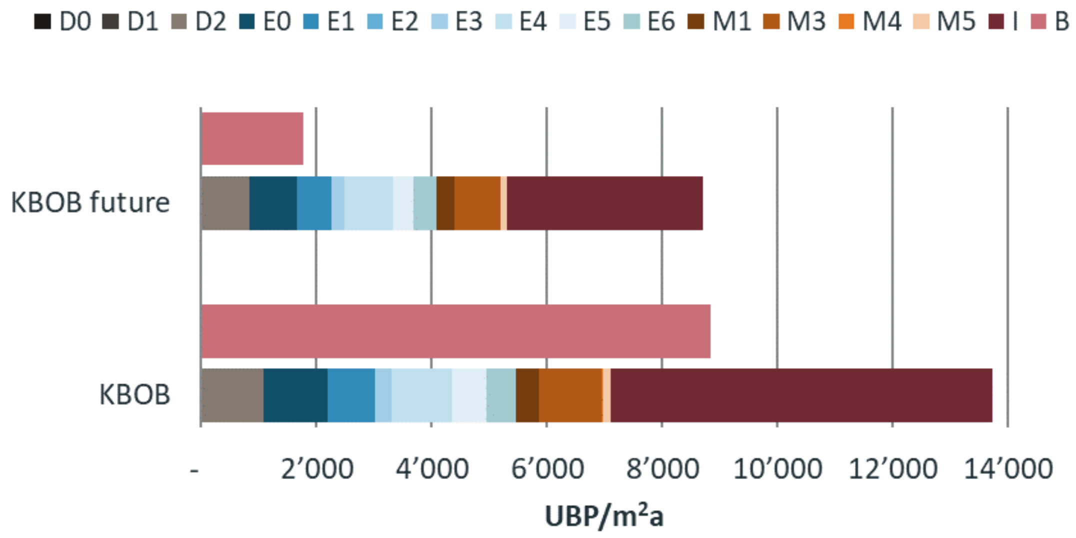

Fig. 7.4: Overall environmental impacts in UBP per m^{2}a of the present (KBOB) and future scenario (KBOB future) office building ARE, Ittigen.

The overall environmental impact follows the same pattern as the environmental impacts analysed above: For the current building, the operation of the building (B) and the construction of the building equipment (I) dominate the total environmental impact with shares of 39 % and 29 % respectively; for the future building, the construction of the building equipment is most important (32 %), followed by the operation of the building (17 %). The reduction of the overall environmental impact is highest for the operation of the building (minus 80 %), the impact of the building equipment construction is reduced by 48 %.

7.3 Residential building Rautistrasse, Zurich

7.3.1 Description

The residential building Rautistrasse in Zurich-Altstetten offers living space with 104 apartments. In order to construct the seven new buildings, four existing buildings were demolished (demolition is not part of the assessment). The new property replaces the wooden residential settlement built in 1948 and has been built according to the Minergie-Eco standard. All apartments have comfort ventilation and are equipped with underfloor heating, which is supplied with heat from geothermal probes and electric heat pumps. The materialisation of the building is shown in Appendix E.2.

Fig. 7.5: Exterior view of the residential building Rautistrasse, Zurich

7.3.2 Environmental impacts

The non-renewable primary energy demand of the residential building Rautistrasse as built (including operation) amounts to 94 kWh oil-eq/m^{2}a (Fig. 7.6). With future production, this is reduced to 26 kWh oil-eq/m^{2}a, which corresponds to a reduction of 72 %. The target values according to the SIA standard 2040 are 30 and 60 kWh oil-eq/m^{2}a (construction and operation, respectively).

As with the office building ARE, the energy demand for the operation of the building (B) contributes with 63 % most to the total non-renewable primary energy demand. The second most important contribution stems from the construction of the building equipment (13 %, I). With the future scenario building, the non-renewable primary energy demand for the operation of the building and for the construction of the building equipment are reduced by 92 % and 32 % respectively. Thus, in the future building, the construction of the building infrastructure (I) contributes the most to the energy demand (31 %), the operation of the building follows in the second place (18 %).

The non-renewable primary energy demand of construction and end of life of the building (D0 - I) is reduced from 35 kWh oil-eq/m^{2}a to 22 kWh oil-eq./m^{2}a (minus 38 %).

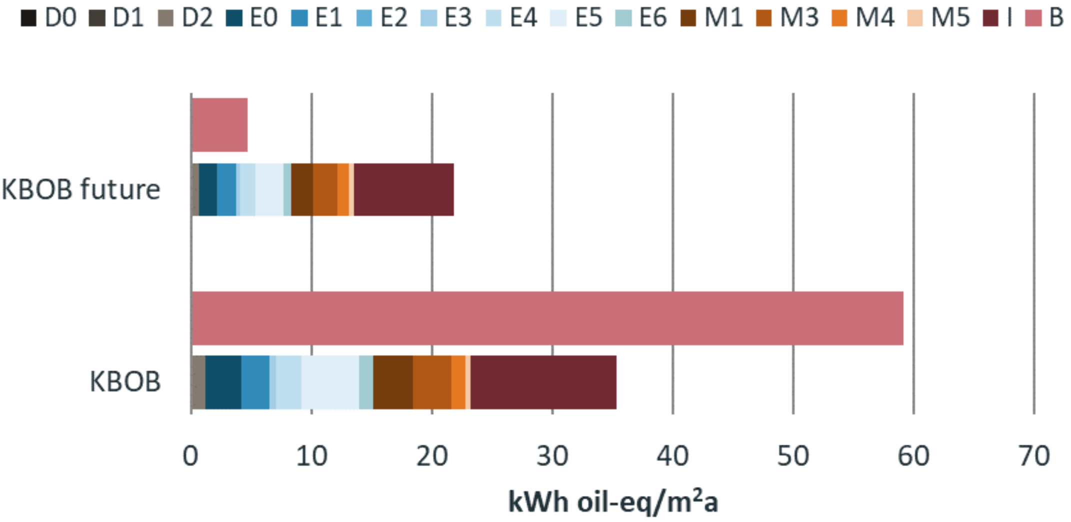

Fig. 7.6: Non-renewable energy primary demand in kWh oil-eq per m^2a of the present (KBOB) and future (KBOB future) residential building Rautistrasse, Zurich. Target values SIA 2040:30 and 60 kWh oil-eq/m^2a (construction and operation, respectively).

The greenhouse gas emissions of the residential building Rautistrasse as built (including operation) are 11.8 kg CO_2-eq./m^2a; for the future scenario building they amount to 5.1 kg CO_2-eq./m^2a (Fig. 7.7). This is a reduction of 57 %. The target values according to the SIA standard 2040 are 9 and 3 kg CO_2-eq./m^2a for construction and operation, respectively.

The most important contribution stems from the construction of the building equipment (I) for both the present and the future scenario building (23 % and 29 % respectively), followed by the operation of the building (I, 20 % and 21 % respectively). With the future scenario building, the former is reduced by 45 %, the latter by 55 %.

The greenhouse gas emissions for the construction and end of life of the building (D0 - I) are reduced from 9.4 to 4.1 kg CO_2-eq/m^2a, which is also a reduction by 57 %.

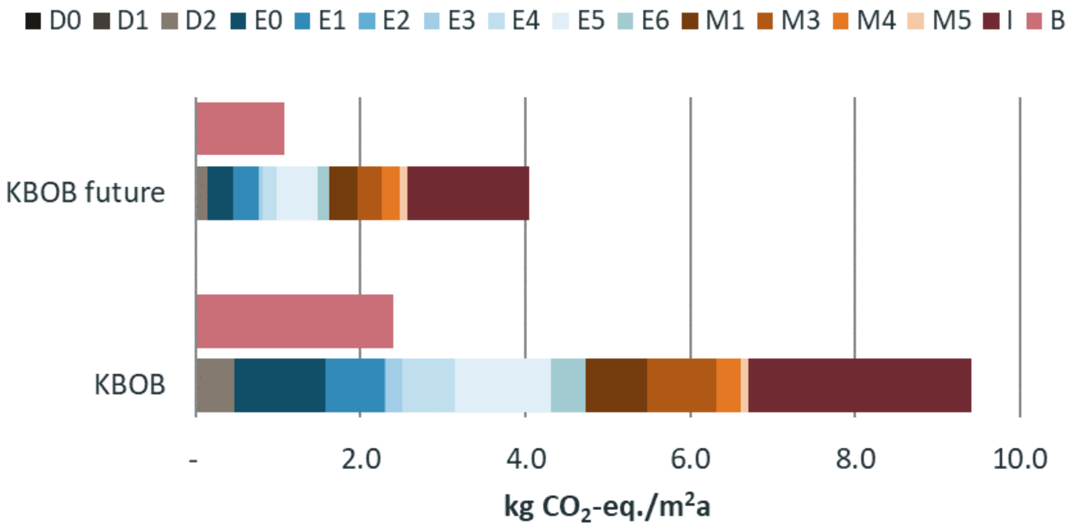

Fig. 7.7: Greenhouse gas emissions in kg CO_2-eq. per m^2a of the present (KBOB) and future scenario (KBOB future) residential building Rautistrasse, Zurich. Target values SIA 2040: 9 and 3 kg CO_2-eq./m^2a (construction and operation, respectively).

The overall environmental impact of the residential building Rautistrasse as built (including operation) is 22’665 UPB/m^2a, the impact of the future scenario building amounts to 11’476 UBP/m^2a (Fig. 7.8). This is a reduction of 49 %.

As for the other environmental impacts analysed, for the present building the operation contributes with 36 % most to the overall environmental impact, for the future building it is the construction of the building equipment with 28 %. With the future building, the overall environmental impact of the building operation is reduced by 80 %, the impact of the construction of the building equipment by 38 %.

The overall environmental impacts of the construction and end of life of the building (D0 - I) are reduced from 14’430 to 9’795 UBP/m^2a (minus 32 %).

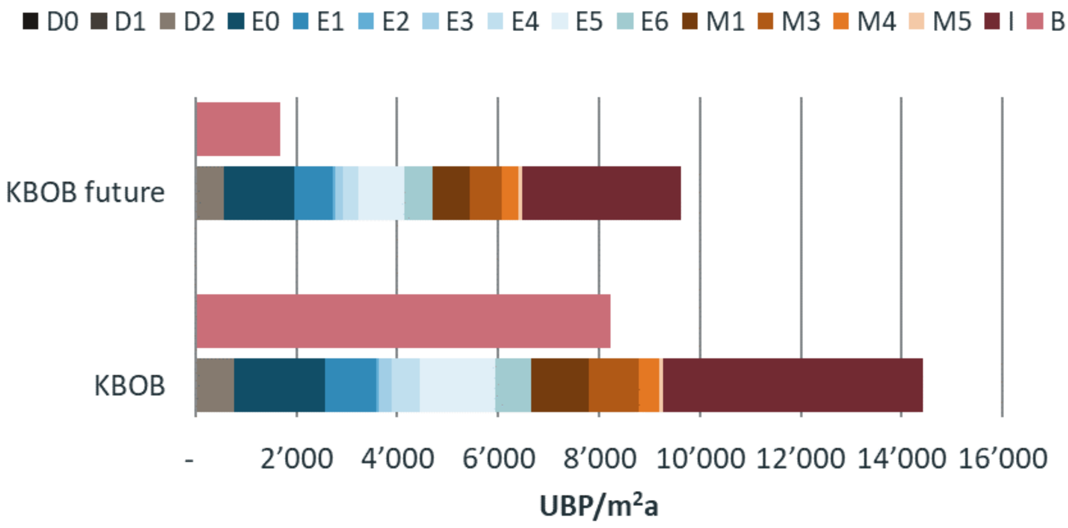

Fig. 7.8: Overall environmental impact in UBP per m^2a of the present (KBOB) and future scenario (KBOB future) residential building Rautistrasse, Zurich

7.3.3 Impact of carbonation on greenhouse gas emissions

The effect of carbonation can be observed during the use phase of cement, bricks and lime-based construction products e.g. in buildings. It binds CO_2 from the atmosphere. Therefore, it can compensate some of the greenhouse gas emissions emitted during the construction of the building. To estimate the magnitude of this effect, the carbonation of the concrete used in the residential building Rautistrasse was quantified and put in relation to the total greenhouse gas emissions of the building.

The estimation of the carbonation is based on Leemann et al. (2018b). The floor slabs of the foundation of the residential building Rautistrasse were constructed with a concrete of strength class C 25/30, all other structural elements with a concrete of strength class C 30/37. The characteristic values required to determine the carbonation were taken from the KBOB Life Cycle Inventories on Concretes (Tschümperlin & Frischknecht 2016b) and Leemann et al. (2018b).

Only the floor slabs in the foundations and the concrete ceiling of the underground car park are in direct contact with the ambient air on one side. All other building elements containing concrete are either covered with one or more layers of insulating material or plaster or, like the exterior walls in the basement, are in direct contact with the ground on one side. In a conservative estimate of the reabsorption of geogenic CO_2 emissions (minimum variant), it is assumed that only free-standing concrete surfaces carbonate. In a maximum variant it is assumed that the coated and covered concrete parts also carbonate (the parts covered with soil but in neither of the two variants). The minimum amount of CO_2 that can be absorbed over a service life of 60 years is 10 g per m^2 and year, and the maximum amount absorbed is 100 g per m^2 and year (see Tab. 7.1). The carbonation effect therefore reduces the greenhouse gas emissions of the future Rautistrasse residential building by around 2.5 % in the maximum case. The realistic extent of CO_2 binding is well below 1 %.

Tab. 7.1: Estimation of the absorption of geogenic CO_2 emissions by carbonation of exposed or coated and covered concrete components of the residential building Rautistrasse (based on Leemann et al. 2018a)

ECG Nr.	**Concrete elements in the residential building Rautistrasse**	**Volume [m^3 concrete]**	**kg CO_2/m^3 concrete C 25/30**	**kg CO_2/m^3 concrete C 30/37**	**Min. carbonation [kg CO_2 / m^2a]**	**Max. carbonation [kg CO_2 / m^2a]**
D2	Foundation base plates 35 cm	183	4.60		6.50E-03	6.50E-03
E1	Concrete ceiling underground car park 40 cm	107		4.45	3.68E-03	3.68E-03
E3	External walls basement 25 cm	51.8		7.13		2.85E-03
E1	Roof 22 cm	56.1		16.2		7.02E-03
E2	Concrete pillars 63*16 cm	4.10		22.3		7.05E-04
E2	Concrete pillars 40*16 cm	1.30		22.3		2.24E-04
E0	Concrete roofs 22 cm	454		16.2		5.68E-02
E4	External concrete walls all floors 18 cm	32.1		19.8		4.91E-03
E6	Interior concrete walls 35 cm	14.4		10.2		1.13E-03
E6	Interior concrete walls 25 cm	33.0		14.3		3.64E-03
E6	Interior concrete walls 20 cm	91.6		17.8		1.26E-02
	Total carbonation				**1.02E-02**	**1.00E-01**
	Greenhouse gas emissions construction				**4.1**	**4.1**
	Share of carbonation				**0.25%**	**2.47%**

In the EPD “SwissModul” (p + f Sursee 2017) with a reference life time of 150 years, the CO_2-absorption of bricks is estimated at 2 g CO_2-eq./kg brick.

7.4 Share of materials with future production life cycle inventories

In the case of the office building ARE Ittigen, around 70 % of the building is covered by future building materials in terms of mass, and 84 % in terms of volume. Not covered materials are mainly sand and gravel as well as the anhydrite floor. In the case of the residential building Rautistrasse, it is 96 % in terms of mass and 94 % in terms of volume. If all the building materials used were taken into account, the greenhouse gas emission reductions achieved could reach about 70 % for the office building ARE Ittigen and about 59 % for the residential building Rautistrasse.

7.5 Synthesis

With future building material production, the environmental impacts of the future buildings analysed can be substantially reduced. The reduction rates (including construction and end of life) are similar for both buildings and highest for the the greenhouse gas emissions (-49 % and -57 % for the office building ARE and the residential building Rautistrasse respectively), followed by the non-renewable primary energy demand (-39 % and -38 % for the office building ARE and the residential building Rautistrasse respectively). The overall environmental impact exhibits the lowest reduction rates for both buildings (-36 % and -32 % respectively), but still can be reduced by about a third.

For concrete and ceramic products, CCS systems during clinker production contribute orders of magnitude more to the reduction of greenhouse gas emissions than carbonation during the service life of the products.

It has to be noted that future production has not been modelled for all of the building materials used. For the office building ARE Ittigen, around 70 % of the building is covered by future building materials, for the residential building Rautistrasse 96 %. If all the building materials used were taken into account, the greenhouse gas emission reductions achieved could reach about 70 % for the office building ARE Ittigen and about 59 % for the residential building Rautistrasse.

The environmental impacts of the future office building ARE are 42 % (non-renewable energy demand) and 61 % (greenhouse gas emissions) lower than the current target values according to SIA 2040 for office building construction. For the future scenario residential building Rautistrasse the environmental impacts are 45 % (non-renewable energy demand) and 55 % (greenhouse gas emissions) lower than the current SIA-target values for residential building construction.

The current SIA 2040 target values represent an intermediate goal of the 2000-Watt-society as defined in 2014. With a consequent conversion to building material production with as little greenhouse gas as possible (and the corresponding adjustments in the energy and transport sectors), these goals can be well achieved in the year 2050. However, this is not sufficient. With the new goal of the 2000-Watt-society launched in 2020 (net zero greenhouse gas emissions by 2050), construction material industries need to reduce the greenhouse gas emissions in their supply chains to close to zero. Recommendations and tips for involvement in supply chain management to reduce the environmental footprints can be found in the Environmental Atlas “Supply chains Switzerland” (Alig et al. 2019).

8 Discussion

8.1 Availability of biogas

The future production of many of the building materials assessed in chapter 3 as well as the fuel supply for future transport services (chapter 6) rely on biogas as substitution for fossil fuels such as natural gas or light fuel oil. However, the availability of biogas is limited. Today Switzerland's natural gas consumption amounts to roughly 32'000 GWh/a (BFE 2020). One third of the natural gas is consumed in industry, mostly for process heat. Biogas contributes about 2 % to Switzerland's total natural gas consumption. About half of this amount is produced domestically, half is imported (Grosse Ruse 2018). Based on Thees et al. (2017), Grosse Ruse (2018) estimates the maximum additional potential of domestic, sustainably produceable biogas at 4'000 GWh/a. Together with the current production, this results in a maximum available biogas quantity of somewhat less than 4'500 GWh/a. This is just one ninth of the current Swiss natural gas consumption and covers only one third of the current natural gas needs of the Swiss industry.

The current production volumes of bricks, concrete and glasswool would require 470 GWh biogas, which is about 10 to 15 % of the maximum potential of domestically produced biogas.

In order to be able to cover the future biogas demands of Swiss industry, the gas demand in industry and in other sectors (especially in buildings) would have to be substantially reduced.

Another problem with biogas is the fact that present biogas production is not climate-neutral. In order to be a viable option for a climate-neutral future, the diffuse methane emissions in pre-storage, in the fermenter and the fermentation residue storage are to be reduced substantially. Additionally, there is optimizing potential with regard to energy need and CO_2 emissions during transport, storage, fermentation and post-fermentation of the substrates, as well as during the processing of biogas (Grosse Ruse 2018).

According to Agora Verkehrswende and Agora Energiewende (2018) synthetic fuels will play an important role in decarbonising the industrial sector by using synthetic fuel production technologies to produce high-temperature process heat. Also Terlouw et al. (2019) conclude that in the EU, industrial low temperature heat will be mostly based on direct electricity, high temperature industrial heat mainly on “green” hydrogen (either produced at industrial sites or close to large-scale renewable power plants (hydroelectric power or (offshore) wind farms) and transported to demand hubs using existing natural gas infrastructure).

In the present report, hydrogen was only considered in steel production. For the other building materials there was no evidence on the future use of synthetic gases, including hydrogen.

8.2 Availability of wood

According to BAFU (2019), the wood reserves of all living trees in Switzerland are 419 Mio. m^3. The average annual increase is 10.4 Mio. m^3; the average annual quantity of trees removed and died amounts to 8.9 Mio. m^3. In total, the withdrawals are about 14 % below the growth - with significant differences between different regions and tree species. The amount of wood harvested in 2019 amounted to 5.2 Mio. m^3, which is about half of the annual growth. In 2018, 37 % of the wood harvested was used as energy wood (2019), mostly for heat production. This generated around 9’800 GWh of usable energy.

Vans and lorries used for freight transport in Switzerland required nearly 12’000 GWh of final energy in 2018 (Kemmler et al. 2019). Assuming that the energy consumption for the future transport fleet is the same and half of it is covered by biofuels (ethanol from wood), 1.7 Mio. m^3 of wood will be needed for this, which represents 16 % of the annual increase.

9 Conclusions and outlook

9.1 Main findings

With future construction materials manufacture, substantial reductions are possible both for non-renewable primary energy demand and greenhouse gas emissions. On average, greenhouse gas emissions are reduced by 65 %, with a minimum of 27 % (particleboard and gypsum plaster board) and a maxium of 98 % (ferronickel). The average reduction of the non-renewable primary energy demand is 48 %, with a range from -12 % to -84 %[23].

In line with the reduction of greenhouse gas emissions, the overall environmental impact of most building materials is also decreasing. On average, it is reduced by 38 %. The maximum reduction is 92 % (copper). For some materials (gypsum plaster board, linoleum and steel), the overall environmental impact increases (up to + 41 %). This is due to changes in the production processes which have a negative impact on areas other than greenhouse gas emissions (e.g. nuclear wastes caused by the future European electricity mix used in hydrogen steel making).

At building level, greenhouse gas emissions of construction (including building technology) and end of life can be reduced by around 50-60 % - even though not all building materials used in the buildings examined have been modelled in terms of their potential future production. However, already with the current modelling, the greenhouse gas emissions are approximately equal to the SIA target value for the residential building Rautistrasse and for the office building ARE 24 % below the SIA target value.

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[23] In the case of plastic materials, there is hardly any change in non-renewable energy demand. Here, no information was available on future production, which is why a CCS system was introduced to reduce greenhouse gas emissions. Therefore, plastic materials are not included in the figures on the range of the non-renewable primary energy demand.

In terms of building operation, the Swiss energy transition, already anchored in law, will lead to a 55% reduction in greenhouse gas emissions.

9.2 Limitations of the study

Detailed and quantified target paths towards a climate-friendly or even net zero greenhouse gas emission manufacturing of construction materials were only available for a few of the industries considered. Most of the targets were of a more general nature and mainly involved a switch to renewable energy sources or an increase in the share of recycled feedstock material. Thus, the switch to renewable energy sources is also the measure considered in the future production of most of the building materials. Substantial changes in the production process itself were only considered for a few materials (e.g. steel, bricks). An increase in energy efficiency is not expected for many materials, since according to the information received, this measure is fairly exhausted. Only the inclusion of CCS systems represents a major novelty compared to current production systems.

The present analysis refers exclusively to the primary production of building materials and current material losses in construction and manufacturing of building elements. The environmental impact of building materials may also be reduced by increasing the proportion of recycled feedstock materials or increasing the material efficiency (less waste produced on the construction site or in pre-manufacturing building elements such as windows).

If we look at the construction of entire buildings, there are even more possibilities to reduce the environmental and greenhouse gas footprints: optimisation of the building design, use of low-impact building materials and completely different construction methods (e.g. wood construction, clay, straw bales, alternative insulation materials) or re-use of entire building components. The reuse of building components can substantially reduce grey energy and greenhouse gas emissions (Pfäffli 2020). The topic of circular economy should also be mentioned here, as the reuse or recycling of building materials can be facilitated by an appropriately designed construction method. The energy supply of a building can also contribute to low footprint buildings: keywords are, for example, PV systems, solar façades or seasonal storage heating. It is already possible today for a building to produce all the energy required for its operation. All these technical possibilities are not considered in this report.

9.3 Outlook

The development of reduction measures and reduction paths is in full progress in many economic sectors and construction material industries. It can be expected that more concrete and comprehensive figures will be available in a few years. This would allow the results shown here to be updated and made more accurate.

The inclusion of alternative building materials or construction methods would also be informative. It can be expected that this will make even more comprehensive greenhouse gas reductions possible.

Yet even with today's expected and assumed changes in production processes, substantial greenhouse gas reductions are within reach. However, in view of the new goal of the 2000-Watt-society launched in 2020 (net zero greenhouse gas emissions by 2050), this is not sufficient. Construction material industries need to reduce their own and the greenhouse gas emissions in their supply chains to close to zero. Such emission reductions require binding commitments to the 1.5°C target and substantial changes in the production processes of construction material industries and their supply chains. Construction material industries that decide to engage in supply chain management to lower their environmental footprints may get inspired by the recommendations and tips in the Environmental Atlas "Supply chains Switzerland" (Alig et al. 2019).

The availability of alternative energy sources, especially biogas and biofuels, needs to be clarified in more detail. It is likely that the domestic potential would not be able to cover the demand of Swiss construction material industries and the road transport sector. There are also still open questions regarding the feasibility and cost-effectiveness of CCS systems. Since such changes in production processes often involve major investments, clear signals from the Swiss Federal Council and a reliable legal framework issued by the Swiss Federal Parliament and the Cantons are needed. Paris-compatible national and cantonal policies facilitate the needed transition to net zero greenhouse gas emission buildings and construction material production within the next two to three decades.

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A Life cycle inventories of materials manufacture

A.1 Manufacture of cement and concrete

Tab. A.1.1: Life cycle inventory of future production of 1 kg clinker, at plant

	Name	Location	Unit	clinker (data from ecoinvent v3.2), at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CH			
	InfrastructureProcess			0			
	Unit			kg			
product	clinker (data from ecoinvent v3.2), at plant	CH	kg	1.00E+0			
technosphere	ammonia, liquid, at regional storehouse	CH	kg	1.88E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	bauxite, at mine	GLO	kg	2.70E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	calcareous marl, at plant	CH	kg	3.86E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	diesel, burned in building machine, average	CH	MJ	1.34E-2	1	2.00	(1,1,1,1,1,3,BU:2); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	electricity, medium voltage, at grid	CH	kWh	9.47E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: total energy use reduced to 3MJ/kg clinker by keeping the present fuel mix.
	hard coal supply mix	DE	kg	2.90E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: total energy use reduced to 3MJ/kg clinker by keeping the present fuel mix.
	heavy fuel oil, at regional storage	CH	kg	5.93E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: total energy use reduced to 3MJ/kg clinker by keeping the present fuel mix.
	industrial machine, heavy, unspecified, at plant	RER	kg	3.76E-5	1	3.00	(1,1,1,1,1,3,BU:3); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	light fuel oil, at regional storage	CH	kg	1.57E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: total energy use reduced to 3MJ/kg clinker by keeping the present fuel mix.
	limestone, crushed, for mill	CH	kg	1.16E+0	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	lubricating oil, at plant	RER	kg	4.71E-5	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	natural gas, high pressure, at consumer	CH	MJ	3.06E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: total energy use reduced to 3MJ/kg clinker by keeping the present fuel mix.
	petroleum coke, at refinery	RER	kg	6.97E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: total energy use reduced to 3MJ/kg clinker by keeping the present fuel mix.
	pulverised lignite, at plant	DE	MJ	1.22E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: total energy use reduced to 3MJ/kg clinker by keeping the present fuel mix.
	refractory, basic, packed, at plant	DE	kg	1.90E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	refractory, fireclay, packed, at plant	DE	kg	8.21E-5	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	refractory, high aluminium oxide, packed, at plant	DE	kg	1.37E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	chromium steel 18/8, at plant	RER	kg	5.86E-5	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	tap water, at user	CH	kg	3.40E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	urea, as N, at regional storehouse	RER	kg	1.40E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"

Tab. A.1.1: Life cycle inventory of future production of 1 kg clinker, at plant (continuation)

	Name	Location	Unit	clinker (data from ecoinvent v3.2), at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CH			
	InfrastructureProcess			0			
	Unit			kg			
product	clinker (data from ecoinvent v3.2), at plant	CH	kg	1.00E+0			
emission air, unspecified	Ammonia	-	kg	2.21E-5	1	1.21	(1,1,1,1,1,3,BU:1.2); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Antimony	-	kg	2.41E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Arsenic	-	kg	4.33E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Cadmium	-	kg	2.13E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Carbon dioxide, fossil	-	kg	7.16E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: total energy use reduced to 3MJ/kg clinker by keeping the present fuel mix.
	Carbon dioxide, biogenic	-	kg	3.75E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: total energy use reduced to 3MJ/kg clinker by keeping the present fuel mix.
	Carbon monoxide, fossil	-	kg	1.63E-3	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Chromium	-	kg	5.91E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Cobalt	-	kg	2.25E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Copper	-	kg	4.18E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	kg	2.78E-14	1	3.00	(1,1,1,1,1,3,BU:3); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Hydrogen chloride	-	kg	2.94E-6	1	1.50	(1,1,1,1,1,3,BU:1.5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Lead	-	kg	2.97E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Mercury	-	kg	1.18E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	kg	6.05E-5	1	1.50	(1,1,1,1,1,3,BU:1.5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Nickel	-	kg	9.16E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Nitrogen oxides	-	kg	8.90E-4	1	1.50	(1,1,1,1,1,3,BU:1.5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Particulates, < 2.5 um	-	kg	3.96E-6	1	3.00	(1,1,1,1,1,3,BU:3); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Particulates, > 10 um	-	kg	9.29E-7	1	1.50	(1,1,1,1,1,3,BU:1.5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Particulates, > 2.5 um, and < 10um	-	kg	1.30E-6	1	2.00	(1,1,1,1,1,3,BU:2); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Sulfur dioxide	-	kg	4.10E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Thallium	-	kg	1.46E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Tin	-	kg	1.34E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Vanadium	-	kg	1.84E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Zinc	-	kg	6.11E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Heat, waste	-	MJ	7.41E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
emission resource, in water	Water, unspecified natural origin, CH	-	m3	1.62E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	transport, freight, lorry 16-32 metric ton, fleet average	CH	tkm	3.14E-2	1	2.00	(1,1,1,1,1,3,BU:2); hinzugefügt, da in ecoinvent v3.2 nicht berücksichtigt
	transport, freight, rail	RER	tkm	6.11E-3	1	2.00	(1,1,1,1,1,3,BU:2); hinzugefügt, da in ecoinvent v3.2 nicht berücksichtigt
	CCS, aquifer, 400 km pipeline	RER	kg	7.53E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Future production by 2050: Carbon capture post-combustion

Tab. A.1.2: Life cycle inventory of present production of 1 kg clinker, at plant

	Name	Location	Unit	clinker (data from ecoinvent v3.2), at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CH			
	InfrastructureProcess			0			
	Unit			kg			
product	clinker (data from ecoinvent v3.2), at plant	CH	kg	1.00E+0			
technosphere	ammonia, liquid, at regional storehouse	CH	kg	1.88E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	bauxite, at mine	GLO	kg	2.70E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	calcareous marl, at plant	CH	kg	3.86E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	diesel, burned in building machine	GLO	MJ	1.34E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	electricity, medium voltage, at grid	CH	kWh	1.21E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	hard coal supply mix	DE	kg	3.70E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	heavy fuel oil, at regional storage	CH	kg	7.58E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	industrial machine, heavy, unspecified, at plant	RER	kg	3.76E-5	1	3.00	(1,1,1,1,1,3,BU:3); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	light fuel oil, at regional storage	CH	kg	2.00E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	limestone, crushed, for mill	CH	kg	1.16E+0	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	lubricating oil, at plant	RER	kg	4.71E-5	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	natural gas, high pressure, at consumer	CH	MJ	3.91E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	petroleum coke, at refinery	RER	kg	8.91E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	pulverised lignite, at plant	DE	MJ	1.56E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	refractory, basic, packed, at plant	DE	kg	1.90E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	refractory, fireclay, packed, at plant	DE	kg	8.21E-5	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	refractory, high aluminium oxide, packed, at plant	DE	kg	1.37E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	chromium steel 18/8, at plant	RER	kg	5.86E-5	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	tap water, at user	CH	kg	3.40E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	urea, as N, at regional storehouse	RER	kg	1.40E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"

Tab. A.1.2: Life cycle inventory of present production of 1 kg clinker, at plant (continuation)

	Name	Location	Unit	clinker (data from ecoinvent v3.2), at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CH			
	InfrastructureProcess			0			
	Unit			kg			
product	clinker (data from ecoinvent v3.2), at plant	CH	kg	1.00E+0			
emission air, unspecified	Ammonia	-	kg	2.21E-5	1	1.21	(1,1,1,1,1,3,BU:1.2); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Antimony	-	kg	2.41E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Arsenic	-	kg	4.33E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Cadmium	-	kg	2.13E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Carbon dioxide, fossil	-	kg	7.69E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Carbon dioxide, biogenic	-	kg	4.81E-2	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Carbon monoxide, fossil	-	kg	1.63E-3	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Chromium	-	kg	5.91E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Cobalt	-	kg	2.25E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Copper	-	kg	4.18E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	kg	2.78E-14	1	3.00	(1,1,1,1,1,3,BU:3); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Hydrogen chloride	-	kg	2.94E-6	1	1.50	(1,1,1,1,1,3,BU:1.5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Lead	-	kg	2.97E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Mercury	-	kg	1.18E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	kg	6.05E-5	1	1.50	(1,1,1,1,1,3,BU:1.5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Nickel	-	kg	9.16E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Nitrogen oxides	-	kg	8.90E-4	1	1.50	(1,1,1,1,1,3,BU:1.5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Particulates, < 2.5 um	-	kg	3.96E-6	1	3.00	(1,1,1,1,1,3,BU:3); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Particulates, > 10 um	-	kg	9.29E-7	1	1.50	(1,1,1,1,1,3,BU:1.5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Particulates, > 2.5 um, and < 10um	-	kg	1.30E-6	1	2.00	(1,1,1,1,1,3,BU:2); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Sulfur dioxide	-	kg	4.10E-4	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Thallium	-	kg	1.46E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Tin	-	kg	1.34E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Vanadium	-	kg	1.84E-9	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Zinc	-	kg	6.11E-8	1	5.00	(1,1,1,1,1,3,BU:5); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	Heat, waste	-	MJ	9.47E-1	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
emission resource, in water	Water, unspecified natural origin, CH	-	m3	1.62E-3	1	1.07	(1,1,1,1,1,3,BU:1.05); Basiert auf cemsuisse Daten; entspricht ecoinvent 3.2 Dataset "clinker production, CH"
	transport, lorry 20-28t, fleet average	CH	tkm	3.15E-2	1	2.00	(1,1,1,1,1,3,BU:2); hinzugefügt, da in ecoinvent v3.2 nicht berücksichtigt
	transport, freight, rail	RER	tkm	7.27E-3	1	2.00	(1,1,1,1,1,3,BU:2); hinzugefügt, da in ecoinvent v3.2 nicht berücksichtigt

Tab. A.1.3: Life cycle inventory for future production of 1 m^3 of four unspecific concrete types, at plant

Explanations	Name	Location	Category	Sub-Category	Infrastructure-Process	Unit	lean concrete, unspecific, at plant, with resource correction	concrete for building construction, unspecific, at plant, with resource correction	concrete for civil engineering, unspecific, at plant, with resource correction	concrete for drilled piles, unspecific, at plant, with resource correction	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location						CH	CH	CH	CH			
	InfrastructureProcess						0	0	0	0			
	Unit						m3	m3	m3	m3			
Technosphere	electricity, medium voltage, at grid	CH			0	kWh	5.40E+0	4.30E+0	4.90E+0	5.00E+0	1	1.16	(3,3,3,2,1,1,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	diesel, burned in building machine, average	CH			0	MJ	2.00E-1	4.00E-1	5.00E-1	5.00E-1	1	1.31	(1,3,3,3,1,1,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	tap water, at user	CH			0	kg	7.50E+1	1.45E+2	1.60E+2	1.78E+2	1	1.31	(4,2,2,1,1,5,BU:1.05); ; w/z Wert = 0.5 (Zementgehalt*0.5=Wassergehalt), gemäss Herrn Pöll, AHB, Persönliche Mitteilung vom 27.06.2016
	biogas, burned in boiler condensing modulating <100kW	RER			0	MJ	2.40E+0	8.20E+0	9.50E+0	8.80E+0	1	1.58	(5,1,3,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz, future production by 2050: Use of biogas instead of fossil fuels
	gravel, round, at mine	CH			0	kg	6.23E+2	1.07E+3	1.16E+3	1.03E+3	1	1.22	(2,1,2,2,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	sand, at mine	CH			0	kg	3.39E+2	6.05E+2	7.09E+2	5.80E+2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	synthetic rubber, at plant	RER			0	kg	1.20E-1	1.20E-1	1.20E-1	1.20E-1	1	1.22	(2,1,1,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	biogas, burned in industrial furnace low-NOx >100kW	RER			0	MJ	2.60E+0	5.70E+0	8.80E+0	8.80E+0	1	1.22	(2,1,1,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz, future production by 2050: Use of biogas instead of fossil fuels
	transport, freight, lorry 32-40 metric ton, fleet average	CH			0	tkm	4.15E+1	4.31E+1	4.39E+1	4.30E+1	1	2.05	(2,1,2,2,1,5,BU:2); 43.0545; hinzugefügt, da in ecoinvent v3.2 nicht berücksichtigt
	transport, freight, rail, electricity with shunting	CH			0	tkm	1.50E+1	2.93E+1	3.47E+1	3.67E+1	1	2.05	(2,1,1,1,1,5,BU:2); 36.006; hinzugefügt, da in ecoinvent v3.2 nicht berücksichtigt
	lubricating oil, at plant	RER			0	kg	2.00E-2	2.00E-2	2.00E-2	2.00E-2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	cEM II/B cement, at plant	CH			0	kg	7.50E+1	1.30E+2	1.45E+2	1.60E+2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	cEM II/A cement, at plant	CH			0	kg	7.50E+1	1.30E+2	1.45E+2	1.60E+2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	cEM I cement, at plant	CH			0	kg	0	3.00E+1	3.00E+1	3.50E+1	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	recycling aggregate from mixed demolition, dry, at plant	CH			0	kg	9.63E+2	9.32E+1	0	0	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	recycling aggregate from concrete demolition, dry, at plant	CH			0	kg	0	9.32E+1	0	1.79E+2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	polycarboxylates, 40% active substance, at plant	RER			0	kg	0	2.00E-1	1.80E+0	8.00E-1	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	concrete mixing plant	CH			1	p	4.17E-7	4.17E-7	4.17E-7	4.17E-7	1	3.05	(2,1,2,1,1,5,BU:3); Menge auf aktive Substanz angepasst; basiert auf ecoinvent 3.2 Datensatz
	disposal, concrete, 5% water, to inert material landfill	CH			0	kg	5.29E+0	5.38E+0	5.40E+0	5.39E+0	1	1.22	(2,1,2,1,1,5,BU:1.05); Menge abhängig von Rohdichte über v3.2 Datensätze leicht angepasst; basiert auf ecoinvent 3.2 Datensatz
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH			0	kg	5.00E-2	5.00E-2	5.00E-2	5.00E-2	1	1.22	(2,1,2,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
resource, in ground	Gravel, resource correction		resource	in ground		kg	-5.61E+2	-9.66E+2	-1.04E+3	-9.28E+2	1	1.30	(4,2,2,1,1,5,BU:1.05); ; Ressourcenkorrektur
	Sand, resource correction		resource	in ground		kg	-3.05E+2	-5.45E+2	-6.38E+2	-5.22E+2	1	1.58	(5,1,3,1,1,5,BU:1.05); ; Ressourcenkorrektur
Outputs	lean concrete, unspecific, at plant, with resource correction	CH			0	m3	1.00E+0	0	0	0			
	concrete for building construction, unspecific, at plant, with resource correction	CH			0	m3	0	1.00E+0	0	0			
	concrete for civil engineering, unspecific, at plant, with resource correction	CH			0	m3	0	0	1.00E+0	0			
	concrete for drilled piles, unspecific, at plant, with resource correction	CH			0	m3	0	0	0	1.00E+0			

Tab. A.1.4: Life cycle inventory for present production of 1 m^3 of four unspecific concrete types, at plant

Explanations	Name	Location	Category	Sub-Category	Infrastructure-Process	Unit	lean concrete, unspecific, at plant, with resource correction	concrete for building construction, unspecific, at plant, with resource correction	concrete for civil engineering, unspecific, at plant, with resource correction	concrete for drilled piles, unspecific, at plant, with resource correction	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location						CH	CH	CH	CH			
	InfrastructureProcess						0	0	0	0			
	Unit						m3	m3	m3	m3			
Technosphere	electricity, medium voltage, at grid	CH			0	kWh	5.40E+0	4.30E+0	4.90E+0	5.00E+0	1	1.16	(3,3,3,2,1,1,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	diesel, burned in building machine, average	CH			0	MJ	2.00E-1	4.00E-1	5.00E-1	5.00E-1	1	1.31	(1,3,3,3,1,1,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	tap water, at user	CH			0	kg	7.50E+1	1.45E+2	1.60E+2	1.78E+2	1	1.31	(4,2,2,1,1,5,BU:1.05); ; w/z Wert = 0.5 (Zementgehalt*0.5=Wassergehalt), gemäss Herrn Pöll, AHB, Persönliche Mitteilung vom 27.06.2016
	light fuel oil, burned in boiler 10kW condensing, non-modulating	CH			0	MJ	2.40E+0	8.20E+0	9.50E+0	8.80E+0	1	1.58	(5,1,3,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	gravel, round, at mine	CH			0	kg	6.23E+2	1.07E+3	1.16E+3	1.03E+3	1	1.22	(2,1,2,2,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	sand, at mine	CH			0	kg	3.39E+2	6.05E+2	7.09E+2	5.80E+2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	synthetic rubber, at plant	RER			0	kg	1.20E-1	1.20E-1	1.20E-1	1.20E-1	1	1.22	(2,1,1,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	natural gas, burned in industrial furnace low-NOx >100kW	RER			0	MJ	2.60E+0	5.70E+0	8.80E+0	8.80E+0	1	1.22	(2,1,1,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	transport, freight, lorry 32-40 metric ton, fleet average	CH			0	tkm	4.15E+1	4.31E+1	4.39E+1	4.30E+1	1	2.05	(2,1,2,2,1,5,BU:2); 43.0545; hinzugefügt, da in ecoinvent v3.2 nicht berücksichtigt
	transport, freight, rail, electricity with shunting	CH			0	tkm	1.50E+1	2.93E+1	3.47E+1	3.67E+1	1	2.05	(2,1,1,1,1,5,BU:2); 36.006; hinzugefügt, da in ecoinvent v3.2 nicht berücksichtigt
	lubricating oil, at plant	RER			0	kg	2.00E-2	2.00E-2	2.00E-2	2.00E-2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
	cEM II/B cement, at plant	CH			0	kg	7.50E+1	1.30E+2	1.45E+2	1.60E+2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	cEM II/A cement, at plant	CH			0	kg	7.50E+1	1.30E+2	1.45E+2	1.60E+2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	cEM I cement, at plant	CH			0	kg	0	3.00E+1	3.00E+1	3.50E+1	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	recycling aggregate from mixed demolition, dry, at plant	CH			0	kg	9.63E+2	9.32E+1	0	0	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	recycling aggregate from concrete demolition, dry, at plant	CH			0	kg	0	9.32E+1	0	1.79E+2	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	polycarboxylates, 40% active substance, at plant	RER			0	kg	0	2.00E-1	1.80E+0	8.00E-1	1	1.22	(2,1,1,1,1,5,BU:1.05); ; Betonzusammensetzung gemäss persönlicher Mitteilung, Philipp Hubler, 16. Juni 2016
	concrete mixing plant	CH			1	p	4.17E-7	4.17E-7	4.17E-7	4.17E-7	1	3.05	(2,1,2,1,1,5,BU:3); Menge auf aktive Substanz angepasst; basiert auf ecoinvent 3.2 Datensatz
	disposal, concrete, 5% water, to inert material landfill	CH			0	kg	5.29E+0	5.38E+0	5.40E+0	5.39E+0	1	1.22	(2,1,2,1,1,5,BU:1.05); Menge abhängig von Rohdichte über v3.2 Datensätze leicht angepasst; basiert auf ecoinvent 3.2 Datensatz
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH			0	kg	5.00E-2	5.00E-2	5.00E-2	5.00E-2	1	1.22	(2,1,2,1,1,5,BU:1.05); ; basiert auf ecoinvent 3.2 Datensatz
resource, in ground	Gravel, resource correction		resource	in ground		kg	-5.61E+2	-9.66E+2	-1.04E+3	-9.28E+2	1	1.30	(4,2,2,1,1,5,BU:1.05); ; Ressourcenkorrektur
	Sand, resource correction		resource	in ground		kg	-3.05E+2	-5.45E+2	-6.38E+2	-5.22E+2	1	1.58	(5,1,3,1,1,5,BU:1.05); ; Ressourcenkorrektur
Outputs	lean concrete, unspecific, at plant, with resource correction	CH			0	m3	1.00E+0	0	0	0			
	concrete for building construction, unspecific, at plant, with resource correction	CH			0	m3	0	1.00E+0	0	0			
	concrete for civil engineering, unspecific, at plant, with resource correction	CH			0	m3	0	0	1.00E+0	0			
	concrete for drilled piles, unspecific, at plant, with resource correction	CH			0	m3	0	0	0	1.00E+0			

Tab. A.1.5: Life cycle inventory of future production of 1 m^3 precast concrete, high performance concrete, at plant

Explanations	Name	Location	Infrastructure-Process	Unit	precast concrete, high performance concrete, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Technosphere	electricity, medium voltage, at grid	CH	0	kWh	4.53E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	diesel, burned in building machine, average	CH	0	MJ	7.10E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	tap water, at user	CH	0	kg	3.43E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	biogas, burned in boiler condensing modulating <100kW	RER	0	MJ	2.31E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern, future production by 2050: Use of biogas instead of fossil fuels
	gravel, round, at mine	CH	0	kg	8.50E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	sand, at mine	CH	0	kg	7.50E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	reinforcing steel, secondary production, (100% Rec.)	CH	0	kg	8.00E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	5.14E+1	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, freight, rail, electricity with shunting	CH	0	tkm	2.62E+2	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, barge	RER	0	tkm	3.68E+1	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	lubricating oil, at plant	RER	0	kg	1.06E-1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	cEM I cement, at plant	CH	0	kg	5.75E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	polycarboxylates, 40% active substance, at plant	RER	0	kg	3.00E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern; mit 0.4 multipliziert, da 40% aktive Substanz gemäss polycarboxylate Datensatz
	concrete mixing plant	CH	1	p	4.80E-7	1	3.03	(3,3,1,3,1,4,BU:3); ; Durchschnitt aus Daten von Schweizer Herstellern
	solvents, organic, unspecified, at plant	GLO	0	kg	8.11E-3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	3.39E-2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, concrete, 5% water, to inert material landfill	CH	0	kg	4.35E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.81E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
resource, in ground	Gravel, resource correction			kg	-7.65E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Ressourcenkorrektur
	Sand, resource correction			kg	-6.75E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Ressourcenkorrektur
Outputs	precast concrete, high performance concrete, at plant	CH	0	m3	1.00E+0			

Tab. A.1.6: Life cycle inventory of present production of 1 m^3 precast concrete, high performance concrete, at plant

Explanations	Name	Location	Infrastructure-Process	Unit	precast concrete, high performance concrete, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Technosphere	electricity, medium voltage, at grid	CH	0	kWh	4.53E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	diesel, burned in building machine, average	CH	0	MJ	7.10E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	tap water, at user	CH	0	kg	3.43E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	light fuel oil, burned in boiler 10kW condensing, non-modulating	CH	0	MJ	2.31E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	gravel, round, at mine	CH	0	kg	8.50E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	sand, at mine	CH	0	kg	7.50E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	reinforcing steel, secondary production, (100% Rec.)	CH	0	kg	8.00E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	5.14E+1	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, freight, rail, electricity with shunting	CH	0	tkm	2.62E+2	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, barge	RER	0	tkm	3.68E+1	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	lubricating oil, at plant	RER	0	kg	1.06E-1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	cEM I cement, at plant	CH	0	kg	5.75E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	polycarboxylates, 40% active substance, at plant	RER	0	kg	3.00E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern; mit 0.4 multipliziert, da 40% aktive Substanz gemäss polycarboxylate Datensatz
	concrete mixing plant	CH	1	p	4.80E-7	1	3.03	(3,3,1,3,1,4,BU:3); ; Durchschnitt aus Daten von Schweizer Herstellern
	solvents, organic, unspecified, at plant	GLO	0	kg	8.11E-3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	3.39E-2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, concrete, 5% water, to inert material landfill	CH	0	kg	4.35E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.81E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
resource, in ground	Gravel, resource correction			kg	-7.65E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Ressourcenkorrektur
	Sand, resource correction			kg	-6.75E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Ressourcenkorrektur
Outputs	precast concrete, high performance concrete, at plant	CH	0	m3	1.00E+0			

Tab. A.1.7: Life cycle inventory of future production of 1 m^3 precast concrete, standard concrete, at plant

Explanations	Name	Location	Infrastructure-Process	Unit	precast concrete, standard concrete, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Technosphere	electricity, medium voltage, at grid	CH	0	kWh	4.53E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	diesel, burned in building machine, average	CH	0	MJ	7.10E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	tap water, at user	CH	0	kg	2.33E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	biogas, burned in boiler condensing modulating <100kW	RER	0	MJ	2.31E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern, future production by 2050: Use of biogas instead of fossil fuels
	gravel, round, at mine	CH	0	kg	1.14E+3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	sand, at mine	CH	0	kg	6.30E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	reinforcing steel, secondary production, (100% Rec.)	CH	0	kg	8.00E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	3.97E+1	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, freight, rail, electricity with shunting	CH	0	tkm	1.32E+2	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, barge	RER	0	tkm	3.68E+1	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	lubricating oil, at plant	RER	0	kg	5.00E-1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	glued laminated timber, indoor use, at plant	RER	0	m3	3.41E-2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	xxx Sawn timber, softwood, raw, air dried, u=20%, at plant	RER	0	m3	1.35E-3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	cEM I cement, at plant	CH	0	kg	3.55E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	polycarboxylates, 40% active substance, at plant	RER	0	kg	1.80E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern; mit 0.4 multipliziert, da 40% aktive Substanz gemäss polycarboxylate Datensatz
	limestone, milled, packed, at plant	CH	0	kg	2.56E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	chemicals organic, at plant	GLO	0	kg	2.62E-1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	concrete mixing plant	CH	1	p	4.80E-7	1	3.03	(3,3,1,3,1,4,BU:3); ; Durchschnitt aus Daten von Schweizer Herstellern
	stone meal, at regional storehouse	CH	0	kg	9.20E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	titanium dioxide, production mix, at plant	RER	0	kg	1.74E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	gravel, crushed, at mine	CH	0	kg	7.43E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	solvents, organic, unspecified, at plant	GLO	0	kg	8.11E-3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	3.39E-2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, glue-laminated timber	CH	0	kg	3.55E-2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, concrete, 5% water, to inert material landfill	CH	0	kg	4.35E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.81E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
resource, in ground	Gravel, resource correction			kg	-1.09E+3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Ressourcenkorrektur
	Sand, resource correction			kg	-5.67E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Ressourcenkorrektur
Outputs	precast concrete, standard concrete, at plant	CH	0	m3	1.00E+0			

Tab. A.1.8: Life cycle inventory of present production of 1 m^3 precast concrete, standard concrete, at plant

Explanations	Name	Location	Infrastructure-Process	Unit	precast concrete, standard concrete, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Technosphere	electricity, medium voltage, at grid	CH	0	kWh	4.53E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	diesel, burned in building machine, average	CH	0	MJ	7.10E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	tap water, at user	CH	0	kg	2.33E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	light fuel oil, burned in boiler 10kW condensing, non-modulating	CH	0	MJ	2.31E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	gravel, round, at mine	CH	0	kg	1.14E+3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	sand, at mine	CH	0	kg	6.30E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	reinforcing steel, secondary production, (100% Rec.)	CH	0	kg	8.00E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	3.97E+1	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, freight, rail, electricity with shunting	CH	0	tkm	1.32E+2	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	transport, barge	RER	0	tkm	3.68E+1	1	2.01	(3,1,1,3,1,na,BU:2); ; Durchschnitt aus Daten von Schweizer Herstellern
	lubricating oil, at plant	RER	0	kg	5.00E-1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	glued laminated timber, indoor use, at plant	RER	0	m3	3.41E-2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	xxx Sawn timber, softwood, raw, air dried, u=20%, at plant	RER	0	m3	1.35E-3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	cEM I cement, at plant	CH	0	kg	3.55E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	polycarboxylates, 40% active substance, at plant	RER	0	kg	1.80E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern; mit 0.4 multipliziert, da 40% aktive Substanz gemäss polycarboxylate Datensatz
	limestone, milled, packed, at plant	CH	0	kg	2.56E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	chemicals organic, at plant	GLO	0	kg	2.62E-1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	concrete mixing plant	CH	1	p	4.80E-7	1	3.03	(3,3,1,3,1,4,BU:3); ; Durchschnitt aus Daten von Schweizer Herstellern
	stone meal, at regional storehouse	CH	0	kg	9.20E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	titanium dioxide, production mix, at plant	RER	0	kg	1.74E+0	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	gravel, crushed, at mine	CH	0	kg	7.43E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	solvents, organic, unspecified, at plant	GLO	0	kg	8.11E-3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	3.39E-2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, glue-laminated timber	CH	0	kg	3.55E-2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, concrete, 5% water, to inert material landfill	CH	0	kg	4.35E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.81E+1	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Durchschnitt aus Daten von Schweizer Herstellern
resource, in ground	Gravel, resource correction			kg	-1.09E+3	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Ressourcenkorrektur
	Sand, resource correction			kg	-5.67E+2	1	1.17	(3,3,1,3,1,4,BU:1.05); ; Ressourcenkorrektur
Outputs	precast concrete, standard concrete, at plant	CH	0	m3	1.00E+0			

A.2 Manufacture of bricks

Tab. A.2.1: Life cycle inventory of future production of 1 kg bricks

Explanations	Name	Location	Infrastructure-Process	Unit	brick, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	electricity, medium voltage, at grid	CH	0	kWh	3.70E-2	1	1.64	(5,5,3,3,1,5);
	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	1.40E-2	1	2.34	(5,5,3,3,1,5);
	transport, freight, rail	RER	0	tkm	9.00E-5	1	2.34	(5,5,3,3,1,5);
	biogas, burned in boiler condensing modulating <100kW (Proj. 210)	RER	0	MJ	3.49E-1	1	1.64	(5,5,3,3,1,5);
	heat, at industrial microwave	CH	0	MJ	2.74E-1	1	1.64	(5,5,3,3,1,5);
	limestone, milled, packed, at plant	CH	0	kg	0	1	1.64	(5,5,3,3,1,5);
	diesel, burned in building machine, average	CH	0	MJ	7.55E-3	1	1.64	(5,5,3,3,1,5);
	lubricating oil, at plant	RER	0	kg	1.32E-5	1	1.64	(5,5,3,3,1,5);
	steel, low-alloyed, at plant	RER	0	kg	3.06E-5	1	1.64	(5,5,3,3,1,5);
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	4.68E-3	1	2.34	(5,5,3,3,1,5);
	tap water, at user	RER	0	kg	3.74E-2	1	1.64	(5,5,3,3,1,5);
	clay, at mine	CH	0	kg	6.99E-1	1	1.64	(5,5,3,3,1,5);
	mine, clay	CH	1	p	2.00E-10	1	3.38	(3,5,5,1,3,5);
	sand, at mine	CH	0	kg	4.31E-1	1	1.64	(5,5,3,3,1,5);
	limestone, crushed, for mill	CH	0	kg	0	1	1.64	(5,5,3,3,1,5);
	pulverised lignite, at plant	DE	0	MJ	0	1	1.64	(5,5,3,3,1,5);
	sheet rolling, chromium steel	RER	0	kg	1.57E-7	1	1.64	(5,5,3,3,1,5);
	sheet rolling, steel	RER	0	kg	1.57E-5	1	1.64	(5,5,3,3,1,5);
	heavy fuel oil, at regional storage	RER	0	kg	0	1	1.64	(5,5,3,3,1,5);
	light fuel oil, at regional storage	RER	0	kg	0	1	1.64	(5,5,3,3,1,5);
	polyethylene, HDPE, granulate, at plant	RER	0	kg	8.58E-7	1	1.64	(5,5,3,3,1,5);
	polystyrene, expandable, at plant	RER	0	kg	3.52E-4	1	1.64	(5,5,3,3,1,5);
	packaging film, LDPE, at plant	RER	0	kg	5.70E-4	1	1.64	(5,5,3,3,1,5);
	transport, passenger car, fleet average	RER	0	personkm	1.66E-2	1	1.64	(5,5,3,3,1,5);
	transport, freight, lorry 16-32 metric ton, EURO 6	RER	0	tkm	2.23E-3	1	1.64	(5,5,3,3,1,5);
	wood chips, hardwood, wet, measured as dry mass, at sawmill	RER	0	kg	0	0		(5,5,3,3,1,5)
	wood chips, softwood, wet, measured as dry mass, at sawmill	RER	0	kg	0	0		(5,5,3,3,1,5)
	eUR-flat pallet	RER	0	p	1.61E-5	1	1.64	(5,5,3,3,1,5);
	CCS, aquifer, 400 km pipeline	RER	0	kg	1.39E-1	1	3.38	(4,5,5,3,3,4,BU:3)
resource, in water	Water, well			m3	7.36E-5	1	1.64	(5,5,3,3,1,5);
air, unspecified	Heat, waste			MJ	1.42E-1	1	1.64	(5,5,3,3,1,5);
	Carbon dioxide, fossil			kg	1.19E-1	1	1.89	(5,5,3,3,1,5);
	Hydrogen chloride			kg	0	1	1.89	(5,5,3,3,1,5);
	Hydrogen fluoride			kg	5.00E-8	1	1.89	(5,5,3,3,1,5);
	Particulates, > 10 um			kg	1.00E-6	1	1.89	(5,5,3,3,1,5);
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	7.00E-6	1	2.34	(5,5,3,3,1,5);
	Phenol			kg	0	1	2.34	(5,5,3,3,1,5);
Outputs	brick, at plant	CH	0	kg	1.00E+0			

Tab. A.2.2: Life cycle inventory of present production of 1 kg bricks

Explanations	Name	Location	Infrastructure-Process	Unit	brick, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	3.94E-2	1	1.64	(5,5,3,3,1,5);
	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	1.40E-2	1	2.34	(5,5,3,3,1,5);
	transport, freight, rail	RER	0	tkm	9.00E-5	1	2.34	(5,5,3,3,1,5);
	natural gas, high pressure, at consumer	RER	0	MJ	1.24E+0	1	1.64	(5,5,3,3,1,5);
	limestone, milled, packed, at plant	CH	0	kg	2.39E-2	1	1.64	(5,5,3,3,1,5);
	diesel, burned in building machine, average	CH	0	MJ	2.97E-2	1	1.64	(5,5,3,3,1,5);
	lubricating oil, at plant	RER	0	kg	1.32E-5	1	1.64	(5,5,3,3,1,5);
	steel, low-alloyed, at plant	RER	0	kg	3.06E-5	1	1.64	(5,5,3,3,1,5);
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	4.68E-3	1	2.34	(5,5,3,3,1,5);
	tap water, at user	RER	0	kg	2.72E-2	1	1.64	(5,5,3,3,1,5);
	clay, at mine	CH	0	kg	1.35E+0	1	1.64	(5,5,3,3,1,5);
	mine, clay	CH	1	p	2.00E-10	1	3.38	(3,5,5,1,3,5);
	sand, at mine	CH	0	kg	1.47E-2	1	1.64	(5,5,3,3,1,5);
	limestone, crushed, for mill	CH	0	kg	3.96E-4	1	1.64	(5,5,3,3,1,5);
	pulverised lignite, at plant	DE	0	MJ	2.45E-2	1	1.64	(5,5,3,3,1,5);
	sheet rolling, chromium steel	RER	0	kg	1.57E-7	1	1.64	(5,5,3,3,1,5);
	sheet rolling, steel	RER	0	kg	1.57E-5	1	1.64	(5,5,3,3,1,5);
	heavy fuel oil, at regional storage	RER	0	kg	3.81E-4	1	1.64	(5,5,3,3,1,5);
	light fuel oil, at regional storage	RER	0	kg	5.41E-3	1	1.64	(5,5,3,3,1,5);
	polyethylene, HDPE, granulate, at plant	RER	0	kg	8.58E-7	1	1.64	(5,5,3,3,1,5);
	polystyrene, expandable, at plant	RER	0	kg	3.52E-4	1	1.64	(5,5,3,3,1,5);
	packaging film, LDPE, at plant	RER	0	kg	5.42E-4	1	1.64	(5,5,3,3,1,5);
	transport, passenger car, fleet average	RER	0	personkm	1.66E-2	1	1.64	(5,5,3,3,1,5);
	wood chips, hardwood, wet, measured as dry mass, at sawmill	RER	0	kg	3.55E-3	0		(5,5,3,3,1,5); species
	wood chips, softwood, wet, measured as dry mass, at sawmill	RER	0	kg	6.45E-3	0		(5,5,3,3,1,5); species
	eUR-flat pallet	RER	0	p	1.61E-5	1	1.64	(5,5,3,3,1,5);
resource, in water	Water, well			m3	7.36E-5	1	1.64	(5,5,3,3,1,5);
air, unspecified	Carbon dioxide, fossil			kg	1.80E-1	1	1.64	(5,5,3,3,1,5);
	Carbon monoxide, fossil			kg	3.91E-4	1	1.64	(5,5,3,3,1,5);
	Heat, waste			MJ	1.42E-1	1	1.64	
	Hydrogen chloride			kg	1.22E-5	1	1.89	(5,5,3,3,1,5);
	Hydrogen fluoride			kg	1.06E-5	1	1.89	(5,5,3,3,1,5);
	Nitrogen oxides			kg	2.60E-4	1	1.89	(5,5,3,3,1,5);
	Particulates, < 2.5 um			kg	1.40E-5	1	3.33	(5,5,3,3,1,5);
	Sulfur dioxide			kg	9.98E-5	1	2.34	(5,5,3,3,1,5);
	Particulates, > 10 um			kg	4.68E-6	1	1.89	(5,5,3,3,1,5);
	Benzene			kg	2.96E-6	1	2.34	(5,5,3,3,1,5);
	Formaldehyde			kg	1.64E-5	1	2.34	(5,5,3,3,1,5);
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	7.63E-5	1	2.34	(5,5,3,3,1,5);
	Phenol			kg	1.30E-7	1	2.34	(5,5,3,3,1,5);
Outputs	brick, at plant	RER	0	kg	1.00E+0			

A.3 Manufacture of float glass

Tab. A.3.1: Life cycle inventory of future production of 1 kg float glass

Explanations	Name	Location	Infrastructure-Process	Unit	float glass, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	silica sand, at plant	DE	0	kg	6.50E-1	1	1.13	(1;2;2;2;1)
	soda, powder, at plant	RER	0	kg	2.00E-1	1	1.13	(1;2;2;2;1)
	limestone, milled, packed, at plant	CH	0	kg	4.00E-2	1	1.13	(1;2;2;2;1)
	glass cullets, sorted, at sorting plant	RER	0	kg	4.00E-2	1	1.13	(1;2;2;2;1)
	dolomite, at plant	RER	0	kg	1.70E-1	1	1.13	(1;2;2;2;1)
	sodium sulphate, powder, production mix, at plant	RER	0	kg	1.00E-2	1	1.13	(1;2;2;2;1)
	feldspar, at plant	RER	0	kg	4.38E-3	1	1.13	(1;2;2;2;1)
	nitrogen, liquid, at plant	RER	0	kg	9.00E-2	1	1.13	(1;2;2;2;1)
	sodium chloride, powder, at plant	RER	0	kg	5.40E-5	1	1.13	(1;2;2;2;1)
	oxygen, liquid, at plant	RER	0	kg	1.00E-2	1	1.13	(1;2;2;2;1)
	biogas, burned in boiler condensing modulating <100kW (Proj. 210)	RER	0	MJ	3.46E+0	1	1.13	(1;2;2;2;1)
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	9.53E-1	1	1.13	(1;2;2;2;1)
	hydrogen, liquid, at plant	RER	0	kg	3.67E-4	1	1.13	(1;2;2;2;1)
	hard coal, at regional storage	WEU	0	kg	7.53E-5	1	1.13	(1;2;2;2;1)
	heavy fuel oil, at regional storage	RER	0	kg	0	1	1.13	(1;2;2;2;1)
	flat glass plant	RER	1	p	2.41E-10	1	9.45	(3;3;3;3;3)
	transport, freight, lorry 16-32 metric ton, fleet average	RER	0	tkm	6.13E-2	1	4.02	(2;2;2;2;1)
	transport, freight, rail	RER	0	tkm	1.61E-2	1	4.02	(2;2;2;2;1)
	treatment, sewage, to wastewater treatment, class 2	CH	0	m3	7.70E-4	1	1.13	(1;2;2;2;1)
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	3.70E-3	1	1.13	(1;2;2;2;1)
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	1.11E-3	1	1.13	(1;2;2;2;1)
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	9.67E-3	1	1.13	(1;2;2;2;1)
	CCS, aquifer, 400 km pipeline	RER	0	kg	3.94E-1	1	3.38	(4,5,5,3,3,4,BU:3)
resource, in water	Water, cooling, unspecified natural origin/m3			m3	1.44E+0	1	1.13	(1;2;2;2;1)
air, unspecified	Nitrogen dioxide			kg	2.22E-4	1	2.27	(2;2;2;2;1)
	Sulfur dioxide			kg	1.11E-3	1	2.27	(2;2;2;2;1)
	Nitrogen oxides			kg	0	1	2.27	(2;2;2;2;1)
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	0	1	2.27	(2;2;2;2;1)
	Chromium			kg	1.00E-7	1	2.27	(2;2;2;2;1)
	Hydrogen chloride			kg	7.53E-5	1	2.27	(2;2;2;2;1)
	Particulates, unspecified			kg	3.00E-4	1	2.27	(2;2;2;2;1)
	Hydrogen fluoride			kg	1.15E-5	1	2.27	(2;2;2;2;1)
	Lead			kg	3.00E-7	1	2.27	(2;2;2;2;1)
	Nickel			kg	4.00E-7	1	2.27	(2;2;2;2;1)
	Carbon dioxide, fossil			kg	2.00E-1	1	1.13	(2;2;2;2;1)
	Carbon monoxide, fossil			kg	0	1	1.13	(2;2;2;2;1)
water, unspecified	Suspended solids, unspecified			kg	3.48E-5	1	2.27	(2;2;2;2;1)
	Nitrogen			kg	5.20E-6	1	2.27	(2;2;2;2;1)
	Phosphorus			kg	7.00E-7	1	2.27	(2;2;2;2;1)
	BOD5, Biological Oxygen Demand			kg	1.63E-5	1	2.27	(2;2;2;2;1)
	COD, Chemical Oxygen Demand			kg	8.70E-5	1	2.27	(2;2;2;2;1)
	Chloride			kg	2.93E-5	1	2.27	(2;2;2;2;1)
	Nickel			kg	1.00E-7	1	2.27	(2;2;2;2;1)
	Oils, unspecified			kg	3.00E-7	1	2.27	(2;2;2;2;1)
	Zinc			kg	5.00E-7	1	2.27	(2;2;2;2;1)
Outputs	float glass, at plant	RER	0	kg	1.00E+0			

Tab. A.3.2: Life cycle inventory of present production of 1 kg float glass

Explanations	Name	Location	Infrastructure-Process	Unit	float glass, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	silica sand, at plant	DE	0	kg	6.50E-1	1	1.13	(1;2;2;2;1)
	soda, powder, at plant	RER	0	kg	2.00E-1	1	1.13	(1;2;2;2;1)
	limestone, milled, packed, at plant	CH	0	kg	4.00E-2	1	1.13	(1;2;2;2;1)
	glass cullets, sorted, at sorting plant	RER	0	kg	4.00E-2	1	1.13	(1;2;2;2;1)
	dolomite, at plant	RER	0	kg	1.70E-1	1	1.13	(1;2;2;2;1)
	sodium sulphate, powder, production mix, at plant	RER	0	kg	1.00E-2	1	1.13	(1;2;2;2;1)
	feldspar, at plant	RER	0	kg	4.38E-3	1	1.13	(1;2;2;2;1)
	nitrogen, liquid, at plant	RER	0	kg	9.00E-2	1	1.13	(1;2;2;2;1)
	sodium chloride, powder, at plant	RER	0	kg	5.40E-5	1	1.13	(1;2;2;2;1)
	oxygen, liquid, at plant	RER	0	kg	1.00E-2	1	1.13	(1;2;2;2;1)
	natural gas, high pressure, at consumer	RER	0	MJ	6.10E+0	1	1.13	(1;2;2;2;1)
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	2.22E-1	1	1.13	(1;2;2;2;1)
	hydrogen, liquid, at plant	RER	0	kg	3.67E-4	1	1.13	(1;2;2;2;1)
	hard coal, at regional storage	WEU	0	kg	7.53E-5	1	1.13	(1;2;2;2;1)
	heavy fuel oil, at regional storage	RER	0	kg	4.96E-2	1	1.13	(1;2;2;2;1)
	flat glass plant	RER	1	p	2.41E-10	1	9.45	(3;3;3;3;3)
	transport, lorry >16t, fleet average	RER	0	tkm	6.13E-2	1	4.02	(2;2;2;2;1)
	transport, freight, rail	RER	0	tkm	1.61E-2	1	4.02	(2;2;2;2;1)
	treatment, sewage, to wastewater treatment, class 2	CH	0	m3	7.70E-4	1	1.13	(1;2;2;2;1)
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	3.70E-3	1	1.13	(1;2;2;2;1)
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	1.11E-3	1	1.13	(1;2;2;2;1)
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	9.67E-3	1	1.13	(1;2;2;2;1)
resource, in water	Water, cooling, unspecified natural origin/m3			m3	1.44E+0	1	1.13	(1;2;2;2;1)
air, unspecified	Nitrogen dioxide			kg	2.22E-4	1	25.06	(2;2;2;2;1)
	Sulfur dioxide			kg	2.60E-3	1	25.06	(2;2;2;2;1)
	Nitrogen oxides			kg	4.21E-3	1	25.06	(2;2;2;2;1)
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	2.80E-6	1	25.06	(2;2;2;2;1)
	Chromium			kg	1.00E-7	1	25.06	(2;2;2;2;1)
	Hydrogen chloride			kg	7.53E-5	1	25.06	(2;2;2;2;1)
	Particulates, unspecified			kg	3.00E-4	1	25.06	(2;2;2;2;1)
	Hydrogen fluoride			kg	1.15E-5	1	25.06	(2;2;2;2;1)
	Lead			kg	3.00E-7	1	25.06	(2;2;2;2;1)
	Nickel			kg	4.00E-7	1	25.06	(2;2;2;2;1)
	Carbon dioxide, fossil			kg	7.00E-1	1	1.13	(2;2;2;2;1)
	Carbon monoxide, fossil			kg	3.60E-4	1	1.13	(2;2;2;2;1)
water, unspecified	Suspended solids, unspecified			kg	3.48E-5	1	2.27	(2;2;2;2;1)
	Nitrogen			kg	5.20E-6	1	2.27	(2;2;2;2;1)
	Phosphorus			kg	7.00E-7	1	2.27	(2;2;2;2;1)
	BOD5, Biological Oxygen Demand			kg	1.63E-5	1	2.27	(2;2;2;2;1)
	COD, Chemical Oxygen Demand			kg	8.70E-5	1	2.27	(2;2;2;2;1)
	Chloride			kg	2.93E-5	1	2.27	(2;2;2;2;1)
	Nickel			kg	1.00E-7	1	2.27	(2;2;2;2;1)
	Oils, unspecified			kg	3.00E-7	1	2.27	(2;2;2;2;1)
	Zinc			kg	5.00E-7	1	2.27	(2;2;2;2;1)
Outputs	float glass, at plant	RER	0	kg	1.00E+0			

A.4 Manufacture of copper

Tab. A.4.1.: Life cycle inventory of future European copper mix, values are given per kg copper supplied to the European market

Explanations	Name	Location	Infrastructure-Process	Unit	copper, at regional storage	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	iron scrap, at plant	RER	0	kg	2.20E-1	1	1.07	(2,1,1,3,1,1,4)
	transport, barge tanker	RER	0	tkm	1.10E-1	1	2.00	composite
	transport, transoceanic freight ship	OCE	0	tkm	8.53E+0	1	2.00	composite
	transport, freight, rail	RER	0	tkm	7.17E-1	1	2.00	composite
	transport, freight, lorry, fleet average	RER	0	tkm	9.91E-2	1	2.00	composite
	copper concentrate, future production, at beneficiation	RLA	0	kg	4.41E-1	1	1.07	composite
	copper concentrate, at beneficiation	RER	0	kg	0	1	1.07	(2,1,1,3,1,1,4)
	copper concentrate, at beneficiation	ID	0	kg	0	1	1.07	(2,1,1,3,1,1,4)
	copper, from imported concentrates, at refinery	DE	0	kg	1.31E-1	1	1.07	(2,1,1,3,1,1,4)
	copper, primary, at refinery	ID	0	kg	0	1	1.07	(2,1,1,3,1,1,4)
	copper, primary, future production, at refinery	RLA	0	kg	4.30E-1	1	1.07	composite
	copper, primary, at refinery	RER	0	kg	0	1	1.07	(2,1,1,3,1,1,4)
	copper, secondary, future production, at refinery	RER	0	kg	2.20E-1	1	1.07	(2,1,1,3,1,1,4)
Outputs	copper, at regional storage	RER	0	kg	1.00E+0			

Tab. A.4.2.: Life cycle inventory of present European copper mix, values are given per kg copper supplied to the European market

Explanations	Name	Location	Infrastructure-Process	Unit	copper, at regional storage	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	iron scrap, at plant	RER	0	kg	2.20E-1	1	1.07	(2,1,1,3,1,1,4)
	transport, barge tanker	RER	0	tkm	1.10E-1	1	2.00	composite
	transport, transoceanic freight ship	OCE	0	tkm	8.53E+0	1	2.00	composite
	transport, freight, rail	RER	0	tkm	7.17E-1	1	2.00	composite
	transport, freight, lorry, fleet average	RER	0	tkm	9.91E-2	1	2.00	composite
	copper, primary, at refinery	ID	0	kg	2.20E-2	1	1.07	(2,1,1,3,1,1,4)
	copper, primary, at refinery	RLA	0	kg	1.69E-1	1	1.07	composite
	copper, primary, at refinery	RER	0	kg	2.39E-1	1	1.07	(2,1,1,3,1,1,4)
	copper concentrate, at beneficiation	RLA	0	kg	1.97E-1	1	1.07	composite
	copper concentrate, at beneficiation	RER	0	kg	1.34E-1	1	1.07	(2,1,1,3,1,1,4)
	copper, secondary, at refinery	RER	0	kg	2.20E-1	1	1.07	(2,1,1,3,1,1,4)
	copper concentrate, at beneficiation	ID	0	kg	1.11E-1	1	1.07	(2,1,1,3,1,1,4)
	copper, from imported concentrates, at refinery	DE	0	kg	1.31E-1	1	1.07	(2,1,1,3,1,1,4)
Outputs	copper, at regional storage	RER	0	kg	1.00E+0			

Tab. A.4.3.: Life cycle inventory of future production of 1 kg copper concentrate (copper content: 30 %) in Latin America

Explanations	Name	Location	Infrastructure-Process	Unit	copper concentrate, future production, at beneficiation	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RLA			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	electricity, medium voltage, production RLA, at grid	RLA	0	kWh	2.76E-1	1	1.14	(2,3,2,1,1,4,2)
	limestone, milled, packed, at plant	CH	0	kg	1.60E-2	1	1.04	reported values
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	0	1	1.14	(2,3,2,1,1,4,2)
	blasting	RER	0	kg	1.20E-2	1	1.13	(2,2,2,1,1,4,4)
	ethanol, burned in building machine	GLO	0	MJ	4.07E-4	1	1.13	(2,2,2,1,1,4,4)
	chromium steel 18/8, at plant	RER	0	kg	1.11E-2	1	1.20	reported values
	chemicals inorganic, at plant	GLO	0	kg	9.25E-3	1	2.00	reported values
	sodium cyanide, at plant	RER	0	kg	4.21E-4	1	2.00	reported values
	chemicals organic, at plant	GLO	0	kg	2.71E-3	1	2.00	reported values
	conveyor belt, at plant	RER	1	m	9.10E-7	1	3.36	(5,5,1,1,3,5,9)
	aluminium hydroxide, plant	RER	1	p	1.01E-10	1	3.07	(3,2,2,1,3,4,9)
	non-ferrous metal mine, surface	GLO	1	p	1.02E-10	1	3.36	(5,5,1,1,3,5,9)
	non-ferrous metal mine, underground	GLO	1	p	4.41E-11	1	3.36	(5,5,1,1,3,5,9)
	disposal, sulfidic tailings, off-site	GLO	0	kg	1.35E+1	1	1.13	(2,2,2,1,1,4,6)
resource, in water	Water, river			m3	8.73E-3	1	1.13	(2,2,1,1,1,4,12)
resource, land	Occupation, mineral extraction site			m2a	6.28E-4	1	1.51	(2,2,2,1,1,2,7)
	Transformation, to mineral extraction site			m2	2.09E-5	1	2.01	(2,2,2,1,1,2,8)
	Transformation, from unknown			m2	2.09E-5	1	2.01	(2,2,2,1,1,2,8)
resource, in ground	Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore			kg	5.02E-3	1	1.13	(2,2,2,1,1,4,12)
	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore			kg	2.70E-1	1	1.13	(2,2,2,1,1,4,12)
air, low population density	Antimony			kg	1.10E-9	1	1.59	(3,2,1,1,3,4,31)
	Arsenic			kg	8.30E-9	1	1.59	(3,2,1,1,3,4,31)
	Cadmium			kg	6.08E-10	1	1.59	(3,2,1,1,3,4,31)
	Carbon dioxide, fossil			kg	7.06E-3	1	2.30	(5,3,3,6,5,5,24)
	Chromium			kg	5.53E-7	1	1.59	(3,2,1,1,3,4,31)
	Copper			kg	2.76E-7	1	1.59	(3,2,1,1,3,4,31)
	Heat, waste			MJ	1.10E+0	1	1.14	(2,3,2,1,1,4,13)
	Lead			kg	7.74E-8	1	1.59	(3,2,1,1,3,4,31)
	Manganese			kg	5.25E-6	1	1.59	(3,2,1,1,3,4,31)
	Mercury			kg	2.76E-10	1	1.59	(3,2,1,1,3,4,31)
	Nickel			kg	4.42E-7	1	1.59	(3,2,1,1,3,4,31)
	Particulates, < 2.5 um			kg	2.81E-3	1	2.69	(3,2,1,1,5,4,23)
	Particulates, > 10 um			kg	2.72E-4	1	2.69	(3,2,1,1,5,4,19)
	Particulates, > 2.5 um, and < 10um			kg	2.45E-3	1	3.69	(3,2,1,1,5,4,20)
	Selenium			kg	2.76E-10	1	1.59	(3,2,1,1,3,4,31)
	Zinc			kg	1.05E-6	1	1.59	(3,2,1,1,3,4,31)
	Beryllium			kg	1.43E-8	1	1.59	(3,2,1,1,3,4,31)
	Boron			kg	5.53E-8	1	1.59	(3,2,1,1,3,4,31)
	Carbon disulfide			kg	1.20E-3	1	2.31	(4,2,2,5,4,4,23)
	Cobalt			kg	1.10E-7	1	1.59	(3,2,1,1,3,4,31)
	Fluorine			kg	5.25E-6	1	1.59	(3,2,1,1,3,4,31)
water, river	Arsenic			kg	2.58E-8	1	10.00	reported values
	Cadmium			kg	2.75E-9	1	10.00	reported values
	Chromium			kg	4.77E-9	1	10.00	reported values
	Copper			kg	6.90E-8	1	10.00	reported values
	Lead			kg	2.44E-8	1	10.00	reported values
	Mercury			kg	3.29E-10	1	10.00	reported values
	Nickel			kg	2.13E-7	1	10.00	reported values
	Zinc			kg	6.62E-7	1	10.00	reported values
	Aluminium			kg	7.53E-7	1	10.00	reported values
	BOD5, Biological Oxygen Demand			kg	9.09E-5	1	10.00	reported values
	Calcium			kg	5.98E-3	1	10.00	reported values
	Cobalt			kg	6.81E-9	1	10.00	reported values
	COD, Chemical Oxygen Demand			kg	9.09E-5	1	10.00	reported values
	Cyanide			kg	4.67E-5	1	1.84	(4,2,2,3,4,4,33)
	DOC, Dissolved Organic Carbon			kg	3.55E-5	1	10.00	reported values
	Iron			kg	2.54E-6	1	10.00	reported values
	Manganese			kg	2.15E-7	1	10.00	reported values
	Nitrogen, organic bound			kg	1.98E-4	1	10.00	reported values
	Suspended solids, unspecified			kg	4.51E-5	1	10.00	reported values
	Sulfate			kg	2.06E-2	1	10.00	reported values
	TOC, Total Organic Carbon			kg	3.55E-5	1	10.00	reported values
Outputs	copper concentrate, future production, at beneficiation	RLA	0	kg	1.00E+0			

Tab. A.4.4.: Life cycle inventory of present production of 1 kg copper concentrate (copper content: 30 %) in Latin America

Explanations	Name	Location	Infrastructure-Process	Unit	copper concentrate, at beneficiation	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RLA			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	2.56E-1	1	1.14	(2,3,2,1,1,4,2)
	limestone, milled, packed, at plant	CH	0	kg	4.32E-2	1	1.04	reported values
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	3.84E-1	1	1.14	(2,3,2,1,1,4,2)
	blasting	RER	0	kg	3.25E-2	1	1.13	(2,2,2,1,1,4,4)
	diesel, burned in building machine, average	CH	0	MJ	2.81E-3	1	1.13	(2,2,2,1,1,4,4)
	chromium steel 18/8, at plant	RER	0	kg	2.24E-2	1	1.20	reported values
	chemicals inorganic, at plant	GLO	0	kg	2.50E-2	1	2.00	reported values
	sodium cyanide, at plant	RER	0	kg	1.14E-3	1	2.00	reported values
	chemicals organic, at plant	GLO	0	kg	7.35E-3	1	2.00	reported values
	conveyor belt, at plant	RER	1	m	2.46E-6	1	3.36	(5,5,1,1,3,5,9)
	aluminium hydroxide, plant	RER	1	p	2.73E-10	1	3.07	(3,2,2,1,3,4,9)
	non-ferrous metal mine, surface	GLO	1	p	3.56E-10	1	3.36	(5,5,1,1,3,5,9)
	non-ferrous metal mine, underground	GLO	1	p	1.55E-10	1	3.36	(5,5,1,1,3,5,9)
	disposal, sulfidic tailings, off-site	GLO	0	kg	9.67E+1	1	1.13	(2,2,2,1,1,4,6)
resource, in water	Water, river			m3	2.70E-2	1	1.13	(2,2,1,1,1,4,12)
resource, land	Occupation, mineral extraction site			m2a	1.70E-3	1	1.51	(2,2,2,1,1,2,7)
	Transformation, to mineral extraction site			m2	5.66E-5	1	2.01	(2,2,2,1,1,2,8)
	Transformation, from unknown			m2	5.66E-5	1	2.01	(2,2,2,1,1,2,8)
resource, in ground	Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore			kg	5.02E-3	1	1.13	(2,2,2,1,1,4,12)
	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore			kg	3.93E-1	1	1.13	(2,2,2,1,1,4,12)
air, low population density	Antimony			kg	3.00E-9	1	1.59	(3,2,1,1,3,4,31)
	Arsenic			kg	2.24E-8	1	1.59	(3,2,1,1,3,4,31)
	Cadmium			kg	1.65E-9	1	1.59	(3,2,1,1,3,4,31)
	Carbon dioxide, fossil			kg	1.90E-2	1	2.30	(5,3,3,6,5,5,24)
	Chromium			kg	1.49E-6	1	1.59	(3,2,1,1,3,4,31)
	Copper			kg	7.49E-7	1	1.59	(3,2,1,1,3,4,31)
	Heat, waste			MJ	2.30E+0	1	1.14	(2,3,2,1,1,4,13)
	Lead			kg	2.10E-7	1	1.59	(3,2,1,1,3,4,31)
	Manganese			kg	1.43E-5	1	1.59	(3,2,1,1,3,4,31)
	Mercury			kg	7.49E-10	1	1.59	(3,2,1,1,3,4,31)
	Nickel			kg	1.20E-6	1	1.59	(3,2,1,1,3,4,31)
	Particulates, < 2.5 um			kg	7.61E-3	1	2.69	(3,2,1,1,5,4,23)
	Particulates, > 10 um			kg	7.36E-4	1	2.69	(3,2,1,1,5,4,19)
	Particulates, > 2.5 um, and < 10um			kg	6.62E-3	1	3.69	(3,2,1,1,5,4,20)
	Selenium			kg	7.49E-10	1	1.59	(3,2,1,1,3,4,31)
	Zinc			kg	2.84E-6	1	1.59	(3,2,1,1,3,4,31)
	Beryllium			kg	3.89E-8	1	1.59	(3,2,1,1,3,4,31)
	Boron			kg	1.49E-7	1	1.59	(3,2,1,1,3,4,31)
	Carbon disulfide			kg	3.25E-3	1	2.31	(4,2,2,5,4,4,23)
	Cobalt			kg	3.00E-7	1	1.59	(3,2,1,1,3,4,31)
	Fluorine			kg	1.43E-5	1	1.59	(3,2,1,1,3,4,31)
water, river	Arsenic			kg	7.96E-8	1	10.00	reported values
	Cadmium			kg	8.53E-9	1	10.00	reported values
	Chromium			kg	1.47E-8	1	10.00	reported values
	Copper			kg	2.14E-7	1	10.00	reported values
	Lead			kg	7.55E-8	1	10.00	reported values
	Mercury			kg	1.02E-9	1	10.00	reported values
	Nickel			kg	6.58E-7	1	10.00	reported values
	Zinc			kg	2.05E-6	1	10.00	reported values
	Aluminium			kg	2.33E-6	1	10.00	reported values
	BOD5, Biological Oxygen Demand			kg	2.81E-4	1	10.00	reported values
	Calcium			kg	1.85E-2	1	10.00	reported values
	Cobalt			kg	2.11E-8	1	10.00	reported values
	COD, Chemical Oxygen Demand			kg	2.81E-4	1	10.00	reported values
	Cyanide			kg	1.26E-4	1	1.84	(4,2,2,3,4,4,33)
	DOC, Dissolved Organic Carbon			kg	1.10E-4	1	10.00	reported values
	Iron			kg	7.85E-6	1	10.00	reported values
	Manganese			kg	6.67E-7	1	10.00	reported values
	Nitrogen, organic bound			kg	6.15E-4	1	10.00	reported values
	Suspended solids, unspecified			kg	1.40E-4	1	10.00	reported values
	Sulfate			kg	6.36E-2	1	10.00	reported values
	TOC, Total Organic Carbon			kg	1.10E-4	1	10.00	reported values
Outputs	copper concentrate, at beneficiation	RLA	0	kg	1.00E+0			

Tab. A.4.5.: Life cycle inventory of future production of 1 kg primary copper in Latin America

Explanations	Name	Location	Infrastructure-Process	Unit	copper, primary, future production, at refinery	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RLA			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	8.10E+0	1	1.10	(2,2,2,3,1,3,1)
	oxygen, liquid, at plant	RER	0	kg	3.00E-1	1	1.10	(2,2,2,3,1,3,4)
	silica sand, at plant	DE	0	kg	7.50E-1	1	1.51	(5,2,2,3,1,3,4)
	limestone, milled, packed, at plant	CH	0	kg	2.50E-1	1	1.51	(5,2,2,3,1,3,4)
	electricity, high voltage, production RLA, at grid	RLA	0	kWh	4.92E-1	1	1.10	(2,2,2,3,1,3,2)
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	0	1	1.10	(2,2,2,3,1,3,2)
	anode, aluminium electrolysis	RER	0	kg	1.00E-3	1	2.07	(5,5,5,6,4,6,4)
	non-ferrous metal smelter	GLO	1	p	1.14E-11	1	3.07	(3,2,2,1,3,4,9)
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	0	1	1.10	(2,2,2,3,1,3,1)
	copper concentrate, at beneficiation	RER	0	kg	4.14E+0	1	1.10	(2,2,2,3,1,3,4)
	disposal, nickel smelter slag, 0% water, to residual material landfill	CH	0	kg	9.25E-1	1	1.10	(2,2,2,3,1,3,6)
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	5.80E-3	1	1.13	(2,2,1,1,1,4,13)
	CCS, aquifer, 400 km pipeline	RER	0	kg	5.64E-1	1	3.38	(4,5,5,3,3,4,BU:3)
resource, in water	Water, river			m3	5.80E-3	1	1.13	(2,2,1,1,1,4,12)
air, low population density	Antimony			kg	5.50E-6	1	5.08	(3,2,1,1,3,4,22)
	Arsenic			kg	3.25E-5	1	5.08	(3,2,1,1,3,4,22)
	Cadmium			kg	6.50E-6	1	5.08	(3,2,1,1,3,4,22)
	Carbon dioxide, fossil			kg	1.10E-1	1	1.89	(5,4,1,3,3,5,7)
	Carbon monoxide, fossil			kg	3.00E-5	1	5.08	(3,2,1,1,3,4,22)
	Chromium			kg	5.00E-8	1	5.08	(3,2,1,1,3,4,22)
	Copper			kg	2.50E-4	1	5.08	(3,2,1,1,3,4,22)
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	2.00E-12	1	3.07	(3,2,1,1,3,4,21)
	Heat, waste			MJ	1.97E+0	1	1.14	(2,3,2,1,1,4,13)
	Lead			kg	1.50E-4	1	5.08	(3,2,1,1,3,4,22)
	Manganese			kg	1.50E-5	1	5.08	(3,2,1,1,3,4,22)
	Mercury			kg	1.00E-7	1	5.08	(3,2,1,1,3,4,22)
	Nickel			kg	5.50E-5	1	5.08	(3,2,1,1,3,4,22)
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	1.50E-5	1	1.59	(3,2,1,1,3,4,16)
	Particulates, < 2.5 um			kg	5.08E-7	1	3.07	(3,2,1,1,3,4,27)
	Particulates, > 10 um			kg	1.02E-4	1	1.50	(3,2,1,1,3,4,29)
	Particulates, > 2.5 um, and < 10um			kg	3.04E-4	1	1.34	(3,2,1,1,3,4,28)
	Selenium			kg	5.50E-6	1	5.08	(3,2,1,1,3,4,22)
	Sulfur dioxide			kg	3.57E-2	1	1.64	(5,4,1,3,3,5,15)
	Tin			kg	6.25E-6	1	5.08	(3,2,1,1,3,4,22)
	Vanadium			kg	3.75E-7	1	5.08	(3,2,1,1,3,4,22)
	Zinc			kg	1.50E-4	1	5.08	(3,2,1,1,3,4,22)
water, river	Arsenic			kg	1.08E-7	1	10.00	reported values
	Cadmium			kg	1.58E-8	1	10.00	reported values
	Chromium			kg	1.66E-7	1	10.00	reported values
	Copper			kg	3.05E-7	1	10.00	reported values
	Lead			kg	9.26E-8	1	10.00	reported values
	Mercury			kg	1.66E-9	1	10.00	reported values
	Nickel			kg	1.23E-7	1	10.00	reported values
	Tin			kg	1.66E-7	1	10.00	reported values
	Zinc			kg	4.91E-7	1	10.00	reported values
Outputs	copper, primary, future production, at refinery	RLA	0	kg	1.00E+0			

Tab. A.4.6.: Life cycle inventory of present production of 1 kg primary copper in Latin America

Explanations	Name	Location	Infrastructure-Process	Unit	copper, primary, at refinery	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	natural gas, burned in industrial furnace >100kW	RER	0	MJ	3.74E+0	1	1.10	(2,2,2,3,1,3,1)
	oxygen, liquid, at plant	RER	0	kg	3.00E-1	1	1.10	(2,2,2,3,1,3,4)
	silica sand, at plant	DE	0	kg	7.50E-1	1	1.51	(5,2,2,3,1,3,4)
	limestone, milled, packed, at plant	CH	0	kg	2.50E-1	1	1.51	(5,2,2,3,1,3,4)
	electricity, high voltage, production ENTSO, at grid	ENTSO	0	kWh	2.19E-1	1	1.10	(2,2,2,3,1,3,2)
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	3.28E-1	1	1.10	(2,2,2,3,1,3,2)
	anode, aluminium electrolysis	RER	0	kg	1.00E-3	1	2.07	(5,5,5,6,4,6,4)
	non-ferrous metal smelter	GLO	1	p	1.14E-11	1	3.07	(3,2,2,1,3,4,9)
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	4.53E+0	1	1.10	(2,2,2,3,1,3,1)
	copper concentrate, at beneficiation	RER	0	kg	4.14E+0	1	1.10	(2,2,2,3,1,3,4)
	disposal, nickel smelter slag, 0% water, to residual material landfill	CH	0	kg	9.25E-1	1	1.10	(2,2,2,3,1,3,6)
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	5.80E-3	1	1.13	(2,2,1,1,1,4,13)
resource, in water	Water, river			m3	5.80E-3	1	1.13	(2,2,1,1,1,4,12)
air, low population density	Antimony			kg	5.50E-6	1	5.08	(3,2,1,1,3,4,22)
	Arsenic			kg	3.25E-5	1	5.08	(3,2,1,1,3,4,22)
	Cadmium			kg	6.50E-6	1	5.08	(3,2,1,1,3,4,22)
	Carbon dioxide, fossil			kg	1.10E-1	1	1.89	(5,4,1,3,3,5,7)
	Carbon monoxide, fossil			kg	3.00E-5	1	5.08	(3,2,1,1,3,4,22)
	Chromium			kg	5.00E-8	1	5.08	(3,2,1,1,3,4,22)
	Copper			kg	2.50E-4	1	5.08	(3,2,1,1,3,4,22)
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	2.00E-12	1	3.07	(3,2,1,1,3,4,21)
	Heat, waste			MJ	1.97E+0	1	1.14	(2,3,2,1,1,4,13)
	Lead			kg	1.50E-4	1	5.08	(3,2,1,1,3,4,22)
	Manganese			kg	1.50E-5	1	5.08	(3,2,1,1,3,4,22)
	Mercury			kg	1.00E-7	1	5.08	(3,2,1,1,3,4,22)
	Nickel			kg	5.50E-5	1	5.08	(3,2,1,1,3,4,22)
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	1.50E-5	1	1.59	(3,2,1,1,3,4,16)
	Particulates, < 2.5 um			kg	5.08E-7	1	3.07	(3,2,1,1,3,4,27)
	Particulates, > 10 um			kg	1.02E-4	1	1.50	(3,2,1,1,3,4,29)
	Particulates, > 2.5 um, and < 10um			kg	3.04E-4	1	1.34	(3,2,1,1,3,4,28)
	Selenium			kg	5.50E-6	1	5.08	(3,2,1,1,3,4,22)
	Sulfur dioxide			kg	3.57E-2	1	1.64	(5,4,1,3,3,5,15)
	Tin			kg	6.25E-6	1	5.08	(3,2,1,1,3,4,22)
	Vanadium			kg	3.75E-7	1	5.08	(3,2,1,1,3,4,22)
	Zinc			kg	1.50E-4	1	5.08	(3,2,1,1,3,4,22)
water, river	Arsenic			kg	1.08E-7	1	10.00	reported values
	Cadmium			kg	1.58E-8	1	10.00	reported values
	Chromium			kg	1.66E-7	1	10.00	reported values
	Copper			kg	3.05E-7	1	10.00	reported values
	Lead			kg	9.26E-8	1	10.00	reported values
	Mercury			kg	1.66E-9	1	10.00	reported values
	Nickel			kg	1.23E-7	1	10.00	reported values
	Tin			kg	1.66E-7	1	10.00	reported values
	Zinc			kg	4.91E-7	1	10.00	reported values
Outputs	copper, primary, at refinery	RER	0	kg	1.00E+0			

Tab. A.4.7.: Life cycle inventory of future production of 1 kg secondary copper in Europe

Explanations	Name	Location	Infrastructure-Process	Unit	copper, secondary, future production, at refinery	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	silica sand, at plant	DE	0	kg	6.25E-2	1	1.13	(2,4,2,3,1,nA,4)
	limestone, milled, packed, at plant	CH	0	kg	7.39E-2	1	1.13	(2,4,2,3,1,nA,4)
	electricity, high voltage, production ENTSO, at grid	ENTSO	0	kWh	9.57E-1	1	1.13	(2,4,2,3,1,nA,2)
	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	7.20E+0	1	1.13	(2,4,2,3,1,nA,1)
	non-ferrous metal smelter	GLO	1	p	9.57E-12	1	3.07	(3,2,2,1,3,4,9)
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	0	1	1.13	(2,4,2,3,1,nA,1)
	chemical plant, organics	RER	1	p	4.00E-10	1	3.07	(3,2,2,1,3,4,9)
	copper, blister-copper, at primary smelter	RER	0	kg	1.14E-1	1	1.13	(2,4,2,3,1,nA,4)
	iron scrap, at plant	RER	0	kg	1.31E+0	1	1.13	(2,4,2,3,1,nA,4)
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	1.00E-3	1	1.13	(2,4,2,3,1,nA,6)
air, low population density	Antimony			kg	3.00E-6	1	5.02	(2,4,2,3,1,nA,22)
	Arsenic			kg	2.00E-6	1	5.02	(2,4,2,3,1,nA,22)
	Cadmium			kg	3.00E-6	1	5.02	(2,4,2,3,1,nA,22)
	Carbon monoxide, fossil			kg	2.00E-3	1	5.02	(2,4,2,3,1,nA,17)
	Copper			kg	8.50E-5	1	5.02	(2,4,2,3,1,nA,22)
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	5.00E-11	1	10.00	(2,4,2,3,1,nA,21)
	Heat, waste			MJ	3.97E+0	1	1.14	(2,3,2,1,1,4,13)
	Lead			kg	9.00E-5	1	5.02	(2,4,2,3,1,nA,22)
	Nickel			kg	1.00E-6	1	5.02	(2,4,2,3,1,nA,22)
	Particulates, < 2.5 um			kg	2.82E-4	1	3.02	(2,4,2,3,1,nA,27)
	Particulates, > 10 um			kg	9.40E-5	1	1.52	(2,4,2,3,1,nA,25)
	Particulates, > 2.5 um, and < 10um			kg	9.40E-5	1	2.02	(2,4,2,3,1,nA,26)
	Sulfur dioxide			kg	3.00E-3	1	1.13	(2,4,2,3,1,nA,15)
	Zinc			kg	3.75E-4	1	5.02	(2,4,2,3,1,nA,22)
	Nitrogen oxides			kg	1.00E-3	1	1.13	(2,4,2,3,1,nA,15)
water, river	Arsenic			kg	1.00E-7	1	5.02	(2,4,2,3,1,nA,35)
	Cadmium			kg	1.00E-8	1	5.02	(2,4,2,3,1,nA,35)
	Copper			kg	1.00E-6	1	5.02	(2,4,2,3,1,nA,35)
	Lead			kg	5.00E-7	1	5.02	(2,4,2,3,1,nA,35)
	Nickel			kg	3.00E-7	1	5.02	(2,4,2,3,1,nA,35)
	Zinc			kg	2.00E-7	1	5.02	(2,4,2,3,1,nA,35)
Outputs	copper, secondary, future production, at refinery	RER	0	kg	1.00E+0			

Tab. A.4.8.: Life cycle inventory of present production of 1 kg secondary copper in Europe

Explanations	Name	Location	Infrastructure-Process	Unit	copper, secondary, at refinery	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	silica sand, at plant	DE	0	kg	6.25E-2	1	1.13	(2,4,2,3,1,nA,4)
	limestone, milled, packed, at plant	CH	0	kg	7.39E-2	1	1.13	(2,4,2,3,1,nA,4)
	electricity, high voltage, production ENTSO, at grid	ENTSO	0	kWh	1.10E+0	1	1.13	(2,4,2,3,1,nA,2)
	hard coal, burned in industrial furnace 1-10MW	RER	0	MJ	6.53E+0	1	1.13	(2,4,2,3,1,nA,1)
	non-ferrous metal smelter	GLO	1	p	9.57E-12	1	3.07	(3,2,2,1,3,4,9)
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	2.58E+0	1	1.13	(2,4,2,3,1,nA,1)
	chemical plant, organics	RER	1	p	4.00E-10	1	3.07	(3,2,2,1,3,4,9)
	copper, blister-copper, at primary smelter	RER	0	kg	1.14E-1	1	1.13	(2,4,2,3,1,nA,4)
	iron scrap, at plant	RER	0	kg	1.31E+0	1	1.13	(2,4,2,3,1,nA,4)
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	1.00E-3	1	1.13	(2,4,2,3,1,nA,6)
air, low population density	Antimony			kg	3.00E-6	1	5.02	(2,4,2,3,1,nA,22)
	Arsenic			kg	2.00E-6	1	5.02	(2,4,2,3,1,nA,22)
	Cadmium			kg	3.00E-6	1	5.02	(2,4,2,3,1,nA,22)
	Carbon monoxide, fossil			kg	2.00E-3	1	5.02	(2,4,2,3,1,nA,17)
	Copper			kg	8.50E-5	1	5.02	(2,4,2,3,1,nA,22)
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	5.00E-11	1	10.00	(2,4,2,3,1,nA,21)
	Heat, waste			MJ	3.97E+0	1	1.14	(2,3,2,1,1,4,13)
	Lead			kg	9.00E-5	1	5.02	(2,4,2,3,1,nA,22)
	Nickel			kg	1.00E-6	1	5.02	(2,4,2,3,1,nA,22)
	Particulates, < 2.5 um			kg	2.82E-4	1	3.02	(2,4,2,3,1,nA,27)
	Particulates, > 10 um			kg	9.40E-5	1	1.52	(2,4,2,3,1,nA,25)
	Particulates, > 2.5 um, and < 10um			kg	9.40E-5	1	2.02	(2,4,2,3,1,nA,26)
	Sulfur dioxide			kg	3.00E-3	1	1.13	(2,4,2,3,1,nA,15)
	Zinc			kg	3.75E-4	1	5.02	(2,4,2,3,1,nA,22)
	Nitrogen oxides			kg	1.00E-3	1	1.13	(2,4,2,3,1,nA,15)
water, river	Arsenic			kg	1.00E-7	1	5.02	(2,4,2,3,1,nA,35)
	Cadmium			kg	1.00E-8	1	5.02	(2,4,2,3,1,nA,35)
	Copper			kg	1.00E-6	1	5.02	(2,4,2,3,1,nA,35)
	Lead			kg	5.00E-7	1	5.02	(2,4,2,3,1,nA,35)
	Nickel			kg	3.00E-7	1	5.02	(2,4,2,3,1,nA,35)
	Zinc			kg	2.00E-7	1	5.02	(2,4,2,3,1,nA,35)
Outputs	copper, secondary, at refinery	RER	0	kg	1.00E+0			

Tab. A.4.9.: Life cycle inventory of future processing (sheet rolling) of 1 kg copper

Explanations	Name	Location	Infrastructure-Process	Unit	sheet rolling, copper	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	copper, at regional storage	RER	0	kg	3.96E-2	1	1.45	(4,5,2,1,3,5,3)
	sawnwood, production mix, softwood, raw, dried (u=20%), at sawmill	RER	0	m3	6.12E-7	1	1.45	(4,5,2,1,3,5,4)
	sheet rolling, steel	RER	0	kg	1.65E-3	1	1.45	(4,5,2,1,3,5,4)
	steel, converter, unalloyed, at plant	RER	0	kg	1.65E-3	1	1.45	(4,5,2,1,3,5,4)
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	1.74E-1	1	1.45	(4,5,2,1,3,5,2)
	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	7.20E-1	1	1.45	(4,5,2,1,3,5,1)
	lubricating oil, at plant	RER	0	kg	4.00E-3	1	1.45	(4,5,2,1,3,5,11)
	transport, freight, lorry, fleet average	RER	0	tkm	1.41E-2	1	2.10	(4,5,n.a.,n.a.,n.a.,n.a.,5)
	packaging film, LDPE, at plant	RER	0	kg	1.32E-3	1	1.45	(4,5,2,1,3,5,4)
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	0	1	1.45	(4,5,2,1,3,5,1)
	rolling mill	RER	1	p	1.43E-9	1	3.18	(4,5,2,1,3,5,9)
	packaging, corrugated board, mixed fibre, single wall, at plant	RER	0	kg	3.30E-4	1	1.45	(4,5,2,1,3,5,4)
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	1.55E-2	1	1.45	(4,5,2,1,3,5,6)
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	2.32E-2	1	1.45	(4,5,2,1,3,5,6)
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	2.40E-3	1	1.45	(4,5,2,1,3,5,6)
resource, in water	Water, cooling, unspecified natural origin/m3			m3	6.00E-3	1	1.45	(4,5,2,1,3,5,12)
air, unspecified	Heat, waste			MJ	8.04E-1	1	1.45	(4,5,2,1,3,5,13)
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.00E-4	1	2.19	(4,5,2,1,3,5,23)
water, unspecified	BOD5, Biological Oxygen Demand			kg	7.90E-5	1	2.79	(5,5,5,5,5,5,32)
	COD, Chemical Oxygen Demand			kg	7.90E-5	1	1.73	(4,5,2,1,3,5,32)
	DOC, Dissolved Organic Carbon			kg	2.06E-5	1	2.79	(5,5,5,5,5,5,32)
	TOC, Total Organic Carbon			kg	2.06E-5	1	2.79	(5,5,5,5,5,5,32)
Outputs	sheet rolling, copper	RER	0	kg	1.00E+0			

Tab. A.4.10.: Life cycle inventory of present processing (sheet rolling) of 1 kg copper

Explanations	Name	Location	Infrastructure-Process	Unit	sheet rolling, copper	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	copper, at regional storage	RER	0	kg	3.96E-2	1	1.45	(4,5,2,1,3,5,3)
	sawnwood, production mix, softwood, raw, dried (u=20%), at sawmill	RER	0	m3	6.12E-7	1	1.45	(4,5,2,1,3,5,4)
	sheet rolling, steel	RER	0	kg	1.65E-3	1	1.45	(4,5,2,1,3,5,4)
	steel, converter, unalloyed, at plant	RER	0	kg	1.65E-3	1	1.45	(4,5,2,1,3,5,4)
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	2.23E-1	1	1.45	(4,5,2,1,3,5,2)
	natural gas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	8.00E-1	1	1.45	(4,5,2,1,3,5,1)
	lubricating oil, at plant	RER	0	kg	4.00E-3	1	1.45	(4,5,2,1,3,5,11)
	transport, freight, lorry, fleet average	RER	0	tkm	1.41E-2	1	2.10	(4,5,n.a.,n.a.,n.a.,n.a.,5)
	packaging film, LDPE, at plant	RER	0	kg	1.32E-3	1	1.45	(4,5,2,1,3,5,4)
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	8.00E-1	1	1.45	(4,5,2,1,3,5,1)
	rolling mill	RER	1	p	1.43E-9	1	3.18	(4,5,2,1,3,5,9)
	packaging, corrugated board, mixed fibre, single wall, at plant	RER	0	kg	3.30E-4	1	1.45	(4,5,2,1,3,5,4)
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	1.55E-2	1	1.45	(4,5,2,1,3,5,6)
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	2.32E-2	1	1.45	(4,5,2,1,3,5,6)
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	2.40E-3	1	1.45	(4,5,2,1,3,5,6)
resource, in water	Water, cooling, unspecified natural origin/m3			m3	6.00E-3	1	1.45	(4,5,2,1,3,5,12)
air, unspecified	Heat, waste			MJ	8.04E-1	1	1.45	(4,5,2,1,3,5,13)
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.00E-4	1	2.19	(4,5,2,1,3,5,23)
water, unspecified	BOD5, Biological Oxygen Demand			kg	7.90E-5	1	2.79	(5,5,5,5,5,5,32)
	COD, Chemical Oxygen Demand			kg	7.90E-5	1	1.73	(4,5,2,1,3,5,32)
	DOC, Dissolved Organic Carbon			kg	2.06E-5	1	2.79	(5,5,5,5,5,5,32)
	TOC, Total Organic Carbon			kg	2.06E-5	1	2.79	(5,5,5,5,5,5,32)
Outputs	sheet rolling, copper	RER	0	kg	1.00E+0			

A.5 Manufacture of nickel

Tab. A.5.1 Life cycle inventory of future production of 1 kg ferronickel

Explanations	Name	Location	Infrastructure-Process	Unit	ferronickel, 25% Ni, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	ethanol, burned in building machine	GLO	0	MJ	1.91E+0	1	1.13	(2,2,2,1,1,4,4)
	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	3.29E+0	1	1.10	(2,2,2,3,1,3,1)
	electricity, high voltage, production GLO, at grid	GLO	0	kWh	3.71E+0	1	1.10	composite
	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	3.51E+1	1	1.10	(2,2,2,3,1,3,1)
	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	2.61E+1	1	1.10	composite
	blasting	RER	0	kg	1.20E-3	1	1.13	(2,2,2,1,1,4,4)
	conveyor belt, at plant	RER	1	m	8.00E-7	1	1.26	(3,2,2,1,3,4,4)
	limestone, milled, packed, at plant	CH	0	kg	4.69E-1	1	1.51	(5,2,2,3,1,3,4)
	non-ferrous metal smelter	GLO	1	p	6.48E-11	1	3.07	(3,2,2,1,3,4,9)
	non-ferrous metal mine, surface	GLO	1	p	2.00E-9	1	3.07	(3,2,2,1,3,4,9)
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	5.57E+0	1	1.10	composite
	disposal, nickel smelter slag, 0% water, to residual material landfill	CH	0	kg	1.27E+1	1	2.15	composite
	CCS, aquifer, 400 km pipeline	RER	0	kg	3.81E+0	1	3.38	(4,5,5,3,3,4,BU:3)
resource, land	Occupation, mineral extraction site			m2a	1.65E-3	1	1.59	(3,2,2,1,3,4,7)
	Transformation, from unknown			m2	5.49E-5	1	3.07	(3,2,2,1,3,4,9)
	Transformation, to mineral extraction site			m2	5.49E-5	1	2.08	(3,2,2,1,3,4,8)
resource, in ground	Nickel, 1.98% in silicates, 1.04% in crude ore			kg	4.35E-1	0		(2,2,2,1,1,4,12)
air, low population density	Antimony			kg	2.02E-9	1	1.59	(3,2,1,1,3,4,31)
	Arsenic			kg	1.44E-5	1	5.07	composite
	Beryllium			kg	2.63E-8	1	1.59	(3,2,1,1,3,4,31)
	Boron			kg	1.01E-7	1	1.59	(3,2,1,1,3,4,31)
	Cadmium			kg	1.11E-9	1	1.59	(3,2,1,1,3,4,31)
	Fluorine			kg	9.60E-6	1	1.59	(3,2,1,1,3,4,31)
	Particulates, > 2.5 um, and < 10um			kg	5.22E-3	1	2.95	composite
	Zinc			kg	2.50E-4	1	5.00	composite
	Tin			kg	1.61E-5	1	5.08	(3,2,1,1,3,4,22)
	Selenium			kg	5.05E-10	1	1.59	(3,2,1,1,3,4,31)
	Particulates, > 10 um			kg	7.47E-4	1	2.13	composite
	Particulates, < 2.5 um			kg	5.14E-3	1	2.31	composite
	Nickel			kg	3.18E-5	1	4.81	composite
	Mercury			kg	5.05E-10	1	1.59	(3,2,1,1,3,4,31)
	Manganese			kg	9.60E-6	1	1.59	(3,2,1,1,3,4,31)
	Lead			kg	7.68E-5	1	5.06	composite
	Heat, waste			MJ	3.34E+1	1	1.10	(2,2,2,3,1,3,2)
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	1.00E-11	1	3.07	(3,2,1,1,3,4,21)
	Copper			kg	9.87E-5	1	5.02	composite
	Cobalt			kg	3.02E-5	1	5.01	composite
	Chromium			kg	1.01E-6	1	1.59	(3,2,1,1,3,4,31)
air, unspecified	Carbon dioxide, fossil			kg	2.06E-1	1	1.58	(4,2,1,1,4,4,14); excluding stdev of
water, river	Aluminium			kg	6.91E-7	1	10.00	reported values
	Arsenic			kg	1.53E-7	1	10.00	composite
	BOD5, Biological Oxygen Demand			kg	8.34E-5	1	10.00	reported values
	Cadmium			kg	2.13E-8	1	10.00	composite
	Calcium			kg	5.49E-3	1	10.00	reported values
	Chromium			kg	2.02E-7	1	10.00	composite
	Cobalt			kg	6.25E-9	1	10.00	reported values
	COD, Chemical Oxygen Demand			kg	8.34E-5	1	10.00	reported values
	Copper			kg	4.27E-7	1	10.00	composite
	DOC, Dissolved Organic Carbon			kg	3.26E-5	1	10.00	reported values
	Iron			kg	2.32E-6	1	10.00	reported values
	Lead			kg	1.33E-7	1	10.00	composite
	Manganese			kg	1.97E-7	1	10.00	reported values
	Mercury			kg	2.27E-9	1	10.00	composite
	Nickel			kg	3.41E-7	1	10.00	composite
	Nitrogen, organic bound			kg	1.82E-4	1	10.00	reported values
	Suspended solids, unspecified			kg	4.14E-5	1	10.00	reported values
	Sulfate			kg	1.89E-2	1	10.00	reported values
	Tin			kg	1.97E-7	1	10.00	reported values
	TOC, Total Organic Carbon			kg	3.26E-5	1	10.00	reported values
	Zinc			kg	1.19E-6	1	10.00	composite
Outputs	ferronickel, 25% Ni, at plant	GLO	0	kg	1.00E+0			

Tab. A.5.2 Life cycle inventory of present production of 1 kg ferronickel

Explanations	401	Input-Group	Output-Group	Name	Location	Infrastructure-Process	Unit	ferronickel, 25% Ni, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	662			Location				GLO			
	493			InfrastructureProcess				0			
	403			Unit				kg			
Technosphere		5		diesel, burned in building machine, average	CH	0	MJ	1.91E+0	1	1.13	(2,2,2,1,1,4,4)
		5		heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	3.75E+0	1	1.10	(2,2,2,3,1,3,1)
		5		electricity, high voltage, production ENTSO, at grid	ENTSO	0	kWh	3.71E+0	1	1.10	composite
		5		hard coal, burned in industrial furnace 1-10MW	RER	0	MJ	4.00E+1	1	1.10	(2,2,2,3,1,3,1)
		5		natural gas, burned in industrial furnace >100kW	RER	0	MJ	2.98E+1	1	1.10	composite
		5		blasting	RER	0	kg	1.20E-3	1	1.13	(2,2,2,1,1,4,4)
		5		conveyor belt, at plant	RER	1	m	8.00E-7	1	1.26	(3,2,2,1,3,4,4)
		5		limestone, milled, packed, at plant	CH	0	kg	4.69E-1	1	1.51	(5,2,2,3,1,3,4)
		5		non-ferrous metal smelter	GLO	1	p	6.48E-11	1	3.07	(3,2,2,1,3,4,9)
		5		non-ferrous metal mine, surface	GLO	1	p	2.00E-9	1	3.07	(3,2,2,1,3,4,9)
		5		electricity, hydropower, at run-of-river power plant	RER	0	kWh	5.57E+0	1	1.10	composite
		5		disposal, nickel smelter slag, 0% water, to residual material landfill	CH	0	kg	1.27E+1	1	2.15	composite
resource, land		4		Occupation, mineral extraction site			m2a	1.65E-3	1	1.59	(3,2,2,1,3,4,7)
		4		Transformation, from unknown			m2	5.49E-5	1	3.07	(3,2,2,1,3,4,9)
		4		Transformation, to mineral extraction site			m2	5.49E-5	1	2.08	(3,2,2,1,3,4,8)
resource, in ground		4		Nickel, 1.98% in silicates, 1.04% in crude ore			kg	4.35E-1	0		(2,2,2,1,1,4,12)
air, low population density			4	Antimony			kg	2.02E-9	1	1.59	(3,2,1,1,3,4,31)
			4	Arsenic			kg	1.44E-5	1	5.07	composite
			4	Beryllium			kg	2.63E-8	1	1.59	(3,2,1,1,3,4,31)
			4	Boron			kg	1.01E-7	1	1.59	(3,2,1,1,3,4,31)
			4	Cadmium			kg	1.11E-9	1	1.59	(3,2,1,1,3,4,31)
			4	Fluorine			kg	9.60E-6	1	1.59	(3,2,1,1,3,4,31)
			4	Particulates, > 2.5 um, and < 10um			kg	5.22E-3	1	2.95	composite
			4	Zinc			kg	2.50E-4	1	5.00	composite
			4	Tin			kg	1.61E-5	1	5.08	(3,2,1,1,3,4,22)
			4	Selenium			kg	5.05E-10	1	1.59	(3,2,1,1,3,4,31)
			4	Particulates, > 10 um			kg	7.47E-4	1	2.13	composite
			4	Particulates, < 2.5 um			kg	5.14E-3	1	2.31	composite
			4	Nickel			kg	3.18E-5	1	4.81	composite
			4	Mercury			kg	5.05E-10	1	1.59	(3,2,1,1,3,4,31)
			4	Manganese			kg	9.60E-6	1	1.59	(3,2,1,1,3,4,31)
			4	Lead			kg	7.68E-5	1	5.06	composite
			4	Heat, waste			MJ	3.34E+1	1	1.10	(2,2,2,3,1,3,2)
			4	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	1.00E-11	1	3.07	(3,2,1,1,3,4,21)
			4	Copper			kg	9.87E-5	1	5.02	composite
			4	Cobalt			kg	3.02E-5	1	5.01	composite
			4	Chromium			kg	1.01E-6	1	1.59	(3,2,1,1,3,4,31)
air, unspecified			4	Carbon dioxide, fossil			kg	2.06E-1	1	1.58	(4,2,1,1,4,4,14); excluding stdev of
water, river			4	Aluminium			kg	6.91E-7	1	10.00	reported values
			4	Arsenic			kg	1.53E-7	1	10.00	composite
			4	BOD5, Biological Oxygen Demand			kg	8.34E-5	1	10.00	reported values
			4	Cadmium			kg	2.13E-8	1	10.00	composite
			4	Calcium			kg	5.49E-3	1	10.00	reported values
			4	Chromium			kg	2.02E-7	1	10.00	composite
			4	Cobalt			kg	6.25E-9	1	10.00	reported values
			4	COD, Chemical Oxygen Demand			kg	8.34E-5	1	10.00	reported values
			4	Copper			kg	4.27E-7	1	10.00	composite
			4	DOC, Dissolved Organic Carbon			kg	3.26E-5	1	10.00	reported values
			4	Iron			kg	2.32E-6	1	10.00	reported values
			4	Lead			kg	1.33E-7	1	10.00	composite
			4	Manganese			kg	1.97E-7	1	10.00	reported values
			4	Mercury			kg	2.27E-9	1	10.00	composite
			4	Nickel			kg	3.41E-7	1	10.00	composite
			4	Nitrogen, organic bound			kg	1.82E-4	1	10.00	reported values
			4	Suspended solids, unspecified			kg	4.14E-5	1	10.00	reported values
			4	Sulfate			kg	1.89E-2	1	10.00	reported values
			4	Tin			kg	1.97E-7	1	10.00	reported values
			4	TOC, Total Organic Carbon			kg	3.26E-5	1	10.00	reported values
			4	Zinc			kg	1.19E-6	1	10.00	composite
Outputs			0	ferronickel, 25% Ni, at plant	GLO	0	kg	1.00E+0			

A.6 Manufacture of steel

Tab. A.6.1: Life cycle inventory of future production of 1 kg hydrogen hot briquetted iron (HBI)

Explanations	Name	Location	Infrastructure-Process	Unit	hydrogen hot briquetted iron, future production, at plant	
	Location				RER	
	InfrastructureProcess				0	
	Unit				kg	
Technosphere	blast furnace	RER	1	p	1.33E-11	infrastructure
	hard coal coke, at plant	RER	0	MJ	0	
	hard coal mix, at regional storage	UCTE	0	kg	0	
	iron ore, 65% Fe, at beneficiation	GLO	0	kg	0	only iron pellets are used in this process
	limestone, at mine	CH	0	kg	0	no lime is used in this process
	natural gas, high pressure, at consumer	RER	0	MJ	0	natural gas as reducing agent is replaced by hydrogen
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	3.22E-1	Hybrit brochure
	pellets, iron, future production, at plant	GLO	0	kg	1.54E+0	Vogl et al. 2018
	refractory, fireclay, packed, at plant	DE	0	kg	2.00E-3	construction material
	sinter, iron, at plant	GLO	0	kg	0	only iron pellets are used in this process
	Hydrogen, steel production, at plant	RER	0	kg	5.10E-2	reducing agent, Vogl et al. 2018
	transport, barge	RER	-	tkm	1.59E-2	pellets and lump ore from mine to plant by ship (coastal)
	transport, freight, rail	RER	-	tkm	1.45E-1	pellets and lump ore from mine to plant by rail
	transport, freight, rail	RER	-	tkm	4.00E-4	limestone, refractories, coal & coke: 200 km
	transport, freight, lorry, fleet average	RER	-	tkm	4.00E-5	limestone, refractories, coal & coke: 20 km
	transport, transoceanic freight ship	OCE	-	tkm	1.43E+0	pellets and lump ore from mine to plant by ship (ocean)
	disposal, inert waste, 5% water, to inert material landfill	CH	-	kg	2.07E-2	rubble (refractory material)
	disposal, sludge, pig iron production, 8.6% water, to residual material landfill	CH	0	kg	0	sludge from BF gas treatment
	treatment, pig iron production effluent, to wastewater treatment, class 3	CH	0	m3	0	sludge from BF gas treatment
resource, in water	Water, unspecified natural origin/m3			m3	0	no water flows across system boundaries (closed cycle)
air, unspecified	Carbon dioxide, fossil			kg	0	
	Carbon monoxide, fossil			kg	0	
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	0	
	Heat, waste			MJ	0	
	Hydrogen sulfide			kg	0	
	Lead			kg	0	
	Manganese			kg	0	
	Nickel			kg	0	
	Nitrogen oxides			kg	0	
	Particulates, < 2.5 um			kg	0	
	Particulates, > 10 um			kg	0	
	Particulates, > 2.5 um, and < 10um			kg	0	
	Sulfur dioxide			kg	0	
Outputs	hydrogen hot briquetted iron, future production, at plant	RER	0	kg	1.00E+0	94% Fe

Tab. A.6.2: Life cycle inventory of present production of 1 kg pig iron

Explanations	Name	Location	Infrastructure-Process	Unit	pig iron, at plant	
	Location				GLO	
	InfrastructureProcess				0	
	Unit				kg	
Technosphere	blast furnace	RER	1	p	1.33E-11	
	hard coal coke, at plant	RER	0	MJ	9.72E+0	Menge in kg
	hard coal mix, at regional storage	UCTE	0	kg	1.50E-1	
	iron ore, 65% Fe, at beneficiation	GLO	0	kg	1.50E-1	
	limestone, at mine	CH	0	kg	1.00E-2	
	natural gas, high pressure, at consumer	RER	0	MJ	1.20E-1	
	pellets, iron, at plant	GLO	0	kg	4.00E-1	
	refractory, fireclay, packed, at plant	DE	0	kg	2.00E-3	
	sinter, iron, at plant	GLO	0	kg	1.05E+0	
	transport, barge	RER	0	tkm	1.65E-2	transports of iron ore calculated according to information about exports and imports
	transport, freight, rail	RER	0	tkm	2.52E-1	
	transport, freight, lorry, fleet average	RER	0	tkm	1.00E-2	
	transport, transoceanic freight ship	OCE	0	tkm	1.49E+0	
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	2.07E-2	
	disposal, sludge, pig iron production, 8.6% water, to residual material landfill	CH	0	kg	4.26E-3	
	treatment, pig iron production effluent, to wastewater treatment, class 3	CH	0	m3	1.81E-3	
resource, in water	Water, unspecified natural origin/m3			m3	6.00E-3	
air, unspecified	Carbon dioxide, fossil			kg	8.49E-1	
	Carbon monoxide, fossil			kg	1.34E-3	
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	2.66E-15	
	Heat, waste			MJ	1.43E+1	
	Hydrogen sulfide			kg	1.07E-5	
	Lead			kg	6.91E-8	
	Manganese			kg	7.45E-8	
	Nickel			kg	1.60E-8	
	Nitrogen oxides			kg	7.98E-5	
	Particulates, < 2.5 um			kg	2.87E-5	
	Particulates, > 10 um			kg	1.60E-6	
	Particulates, > 2.5 um, and < 10um			kg	1.60E-6	
	Sulfur dioxide			kg	1.33E-4	
Outputs	pig iron, at plant	GLO	0	kg	1.00E+0	

Tab. A.6.3: Life cycle inventory of future production of 1 kg electric steel from HBI

Explanations	Name	Location	Infrastructure-Process	Unit	steel, electric, un- and low-alloyed, from HBI, future production, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Outputs	steel, electric, un- and low-alloyed, from HBI, future production, at plant	RER	0	kg	1.00E+0			
Technosphere	anode, aluminium electrolysis	RER	0	kg	2.00E-3	1	1.11	(2,3,2,3,1,3,4)
	electric arc furnace converter	RER	1	p	4.00E-11	1	3.23	(5,nA,nA,nA,nA,nA,9)
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	7.53E-1	1	1.11	(2,3,2,3,1,3,2)
	hard coal mix, at regional storage	UCTE	0	kg	5.23E-3	1	1.11	(2,3,2,3,1,3,11)
	iron scrap, at plant	RER	0	kg	0	1	1.11	(2,3,2,3,1,3,3)
	hydrogen hot briquetted iron, future production, at plant	RER	0	kg	1.06E+0	1	1.11	(2,3,2,3,1,3,3)
	natural gas, high pressure, at consumer	RER	0	MJ	0	1	1.11	(2,3,2,3,1,3,11)
	oxygen, liquid, at plant	RER	0	kg	5.07E-2	1	1.11	(2,3,2,3,1,3,4)
	quicklime, in pieces, loose, at plant	CH	0	kg	5.00E-2	1	1.11	(2,3,2,3,1,3,4)
	refractory, basic, packed, at plant	DE	0	kg	1.35E-2	1	1.11	(2,3,2,3,1,3,4)
	transport, freight, rail	RER	0	tkm	1.49E-2	1	2.10	(4,5,nA,nA,nA,nA,5)
	transport, freight, lorry, fleet average	RER	0	tkm	7.07E-3	1	2.10	(4,5,nA,nA,nA,nA,5)
	disposal, dust, unalloyed EAF steel, 15.4% water, to residual material landfill	CH	0	kg	9.60E-3	1	1.11	(2,3,2,3,1,3,6)
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	5.00E-3	1	1.11	(2,3,2,3,1,3,6)
	Disposal, basic oxygen furnace wastes, 0% water, to residual material landfill	CH	0	kg	9.28E-2	1	1.11	(2,3,2,3,1,3,6)
air, unspecified	Carbon dioxide, fossil			kg	1.38E-2	1	1.11	(2,3,2,3,1,3,14)
	Benzene, hexachloro-			kg	0	1	2.01	(2,3,2,3,1,3,23)
	Benzene			kg	0	1	2.01	(2,3,2,3,1,3,23)
	Cadmium			kg	0	1	5.01	(2,3,2,3,1,3,22)
	Carbon monoxide, fossil			kg	2.32E-3	1	5.01	(2,3,2,3,1,3,17)
	Chromium			kg	0	1	5.01	(2,3,2,3,1,3,22)
	Copper			kg	0	1	5.01	(2,3,2,3,1,3,22)
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	3.32E-14	1	3.01	(2,3,2,3,1,3,21)
	Heat, waste			MJ	3.01E+0	1	1.08	(1,3,2,3,1,2,13)
	Hydrocarbons, aromatic			kg	0	1	1.52	(2,3,2,3,1,3,18)
	Hydrogen chloride			kg	0	1	1.52	(2,3,2,3,1,3,31)
	Hydrogen fluoride			kg	0	1	1.52	(2,3,2,3,1,3,31)
	Hydrogen sulfide			kg	1.07E-5	1	1.52	(2,3,2,3,1,3,31)
	Lead			kg	5.84E-7	1	5.01	(2,3,2,3,1,3,22)
	Manganese			kg	6.79E-7	1	5.01	(2,3,2,3,1,3,22)
	Mercury			kg	0	1	5.01	(2,3,2,3,1,3,22)
	Nickel			kg	1.60E-8	1	5.01	(2,3,2,3,1,3,22)
	Nitrogen oxides			kg	9.23E-5	1	1.52	(2,3,2,3,1,3,16)
	PAH, polycyclic aromatic hydrocarbons			kg	0	1	3.01	(2,3,2,3,1,3,21)
	Particulates, < 2.5 um			kg	7.62E-5	1	3.01	(2,3,2,3,1,3,27)
	Particulates, > 10 um			kg	1.60E-6	1	1.52	(2,3,2,3,1,3,25)
	Particulates, > 2.5 um, and < 10um			kg	1.60E-6	1	2.01	(2,3,2,3,1,3,26)
	Polychlorinated biphenyls			kg	0	1	3.01	(2,3,2,3,1,3,21)
	Sulfur dioxide			kg	7.70E-5	1	1.11	(2,3,2,3,1,3,15)
	Zinc			kg	0	1	5.01	(2,3,2,3,1,3,22)

Tab. A.6.4: Life cycle inventory of present production of 1 kg converter steel

Explanations	Name	Location	Infrastructure-Process	Unit	steel, converter, unalloyed, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Outputs	steel, converter, unalloyed, at plant	RER	0	kg	1,00E+0			
Technosphere	blast oxygen furnace converter	RER	1	p	1,33E-11	1	3,23	(5,nA,nA,nA,nA,9)
	dolomite, at plant	RER	0	kg	2,75E-3	1	1,11	(2,3,2,3,1,3,4)
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	2,19E-2	1	1,11	(2,3,2,3,1,3,2)
	ferronickel, 25% Ni, at plant	GLO	0	kg	6,00E-3	1	1,11	(2,3,2,3,1,3,3)
	hard coal coke, at plant	RER	0	MJ	2,50E-4	1	1,11	(2,3,2,3,1,3,11)
	iron ore, 65% Fe, at beneficiation	GLO	0	kg	2,20E-2	1	1,11	(2,3,2,3,1,3,3)
	iron scrap, at plant	RER	0	kg	2,13E-1	1	1,11	(2,3,2,3,1,3,3)
	natural gas, high pressure, at consumer	RER	0	MJ	3,75E-2	1	1,11	(2,3,2,3,1,3,11)
	oxygen, liquid, at plant	RER	0	kg	7,15E-2	1	1,11	(2,3,2,3,1,3,4)
	pig iron, at plant	GLO	0	kg	9,00E-1	1	1,11	(2,3,2,3,1,3,3)
	quicklime, in pieces, loose, at plant	CH	0	kg	4,25E-2	1	1,11	(2,3,2,3,1,3,4)
	transport, barge	RER	0	tkm	6,60E-4	1	2,01	(2,nA,1,3,1,3,5)
	transport, freight, rail	RER	0	tkm	1,44E-1	1	2,10	(4,5,nA,nA,nA,nA,5)
	transport, freight, lorry, fleet average	RER	0	tkm	2,23E-2	1	2,10	(4,5,nA,nA,nA,nA,5)
	transport, transoceanic freight ship	OCE	0	tkm	5,94E-2	1	2,01	(2,nA,1,1,1,3,5)
	disposal, basic oxygen furnace wastes, 0% water, to residual material landfill	CH	0	kg	3,21E-2	1	1,11	(2,3,2,3,1,3,6)
	disposal, dust, unalloyed EAF steel, 15.4% water, to residual material landfill	CH	0	kg	1,06E-3	1	1,11	(2,3,2,3,1,3,6)
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	2,90E-3	1	1,11	(2,3,2,3,1,3,6)
resource, in water	Water, unspecified natural origin/m3			m3	2,70E-3	1	1,11	(2,3,2,3,1,3,12)
air, unspecified	Carbon dioxide, fossil			kg	7,56E-2	1	1,11	(2,3,2,3,1,3,14)
	Carbon monoxide, fossil			kg	4,73E-3	1	5,01	(2,3,2,3,1,3,17)
	Chromium			kg	1,85E-7	1	5,01	(2,3,2,3,1,3,22)
	Copper			kg	2,50E-8	1	5,01	(2,3,2,3,1,3,22)
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	3,05E-14	1	3,01	(2,3,2,3,1,3,21)
	Heat, waste			MJ	1,17E-1	1	1,08	(1,3,2,3,1,2,13)
	Lead			kg	5,15E-7	1	5,01	(2,3,2,3,1,3,22)
	Manganese			kg	6,05E-7	1	5,01	(2,3,2,3,1,3,22)
	Nitrogen oxides			kg	1,25E-5	1	1,52	(2,3,2,3,1,3,16)
	PAH, polycyclic aromatic hydrocarbons			kg	1,20E-10	1	3,01	(2,3,2,3,1,3,21)
	Particulates, < 2.5 um			kg	4,75E-5	1	3,01	(2,3,2,3,1,3,27)

Tab. A.6.5: Life cycle inventory of future production of 1 kg hydrogen

Explanations	Name	Location	Infrastructure-Process	Unit	Hydrogen, steel production, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Outputs	Hydrogen, steel production, at plant	RER	0	kg	1.00E+0			
Technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	4.85E+1	1	1.51	Calculation based on Hybrit Development AB (2018) and Vogel et al. (2018)
	water, deionised, at plant	CH	0	kg	1.71E+1	1	1.51	According to manufacturer information from Proton OnSite electrolyzer Hogen C30 and H2 production volume per hour acc. Email from Urs Cabalzar
	cooling, at cold water aggregate, R134a with ENTSO mix	CH	0	MJ	1.08E+2	1	1.51	According to email from Urs Cabalzar from 27.05.2015
	metal working machine, unspecified, at plant	RER	1	kg	2.71E-2	1	1.51	According Bünger et al. 2014 and H2 production volume per hour according to email from Urs Cabalzar.
Emission	Heat, waste	-	-	MJ	1.75E+2	1	3.23	

Tab. A.6.6: Life cycle inventory of present production of 1 kg hydrogen

Explanations	Name	Location	Infrastructure-Process	Unit	hydrogen, from consumer mix, at electrolysis	uncertaintyType	GeneralComment
	Location				CH		
	InfrastructureProcess				0		
	Unit				kg		
Outputs	hydrogen, from consumer mix, at electrolysis	CH	0	kg	1.00E+0		
Technosphere	electricity, low voltage, consumer mix, according to BFE 2011, at grid	CH	0	kWh	6.45E+1	1	Gemäss Hersteller-Angaben von Proton OnSite zu Elektrolyseur Hogen C30
	water, deionised, at plant	CH	0	kg	1.71E+1	1	Gemäss Hersteller-Angaben von Proton OnSite zu Elektrolyseur Hogen C30 und der H2 Produktionsmenge pro Stunde gemäss Email von Urs Cabalzar
	cooling, at cold water aggregate, R134a with consumer mix	CH	0	MJ	1.08E+2	1	Gemäss Email von Urs Cabalzar vom 27.05.2015
	metal working machine, unspecified, at plant	RER	1	kg	2.71E-2	1	Gemäss Bünger et al. 2014 und der H2 Produktionsmenge pro Stunde gemäss Email von Urs Cabalzar
Emission	Heat, waste	-	-	MJ	2.32E+2	1	wegen Elektrizitätsverbrauch

Tab. A.6.7: Life cycle inventory of future production of 1 kg rolled steel

Explanations	Name	Location	Infrastructure-Process	Unit	rolled steel, at regional storage	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	iron scrap, at plant	RER	0	kg	1.10E+0	1	1.07	Summe external steel and beam blanks; Questionnaires
	aluminium sulphate, powder, at plant	RER	0	kg	1.24E-9	1	4.42	Aluminum sulfate; Questionnaires
	aluminium, production mix, at plant	RER	0	kg	1.98E-4	1	5.53	Aluminium; Questionnaires
	anode, aluminium electrolysis	RER	0	kg	1.38E-3	1	1.22	Anode; Questionnaires
	hard coal mix, at regional storage	UCTE	0	kg	4.40E-3	1	3.23	Hard coal; Questionnaires
	argon, liquid, at plant	RER	0	kg	2.75E-4	1	3.34	Argon; Questionnaires
	calcium carbide, technical grade, at plant	RER	0	kg	4.70E-5	1	3.80	Calciumcarbid CaC2; Questionnaires
	chemicals inorganic, at plant	GLO	0	kg	2.39E-4	1	4.86	Covering powder; Questionnaires
	dolomite, at plant	RER	0	kg	6.38E-3	1	2.74	Dolomit calcinated; Questionnaires
	ferrochromium, high-carbon, 68% Cr, at regional storage	RER	0	kg	9.94E-5	1	5.52	Ferro chromium; Questionnaires
	ferromanganese, high-coal, 74.5% Mn, at regional storage	RER	0	kg	7.70E-3	1	2.63	Silico manganese; Questionnaires
	rare earth concentrate, 70% REO, from bastnasite, at beneficiation	CN	0	kg	6.91E-5	1	3.08	Ferro niobium; Questionnaires
	silica sand, at plant	DE	0	kg	3.60E-3	1	5.53	Gravel/Sand; Questionnaires
	lime, hydrated, loose, at plant	CH	0	kg	3.29E-2	1	1.30	Lime; Questionnaires
	lubricating oil, at plant	RER	0	kg	4.98E-5	1	5.53	Lubricants; Questionnaires
	nitrogen, liquid, at plant	RER	0	kg	1.40E-3	1	3.62	Nitrogen gas; Questionnaires
	oxygen, liquid, at plant	RER	0	kg	9.88E-2	1	2.72	Oxygen; Questionnaires
	refractory, fireclay, packed, at plant	DE	0	kg	2.01E-3	1	5.53	Refractory clay (feuerfestes Material); Questionnaires
	sodium chloride, powder, at plant	RER	0	kg	4.48E-5	1	5.16	Sodium chloride; Questionnaires
	sulphuric acid, liquid, at plant	RER	0	kg	1.58E-5	1	4.32	Sulphuric acid 70%ig; Questionnaires
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	2.44E-5	1	5.53	Salzsäure; Questionnaires
	water, decarbonised, at plant	RER	0	kg	2.37E-2	1	5.53	decarbonized water; Questionnaires
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	5.68E-1	1	1.18	Electricity (medium voltage); Questionnaires
	methane, 96 vol-%, from biogas, high pressure, at consumer	RER	0	MJ	2.64E+0	1	1.66	Natural gas; Questionnaires
	diesel, at regional storage	RER	0	kg	1.61E-4	1	4.99	Diesel; Questionnaires
	electricity, hydropower, at small hydropower plant	CH	0	kWh	1.30E-3	1	4.87	Internal electricity production (and use) hydropower; Questionnaires
	light fuel oil, at regional storage	RER	0	kg	1.12E-5	1	4.98	Light fuel oil; Questionnaires
	diesel, burned in building machine, average	CH	0	MJ	7.48E-4	1	4.42	Diesel (internal transportation); Questionnaires
	heavy fuel oil, at regional storage	RER	0	kg	1.60E-5	1	6.23	Heavy fuel oil; Questionnaires
	hard coal coke, at plant	RER	0	MJ	5.13E-2	1	4.20	Koks; Questionnaires
	xxx Sawn timber, hardwood, planed, kiln dried, u=10%, at plant	RER	0	m3	2.23E-7	1	1.62	Wood; Questionnaires
	transport, freight, lorry, fleet average	RER	0	tkm	3.66E-1	1	2.57	Lorry to Switzerland; Questionnaires
	transport, freight, rail	RER	0	tkm	5.04E-1	1	1.89	Rail to Switzerland; Questionnaires
	transport, barge	RER	0	tkm	1.78E-3	1	1.00	Zulieferung / Ship; Questionnaires
	building, hall	CH	1	m2	2.38E-6	1	1.45	Buildings; Questionnaires
	disposal, slag, unalloyed electr. steel, 0% water, to residual material landfill	CH	0	kg	6.75E-3	1	2.20	EAF slag for deposit; Questionnaires
	disposal, electronics for control units	RER	0	kg	2.90E-6	1	1.62	Electronic waste; Questionnaires
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	4.35E-5	1	1.62	Hazardous waste; Questionnaires
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	4.35E-4	1	1.62	Municipal solid waste; Questionnaires
	disposal, sludge from steel rolling, 20% water, to residual material landfill	CH	0	kg	3.86E-2	1	1.62	Secondary steel making slag; Questionnaires
	disposal, separator sludge, 90% water, to hazardous waste incineration	CH	0	kg	6.09E-4	1	1.68	WWTP sludge (Summe Fettabscheider und Sandfang);
resource, in water	Water, unspecified, Europe			m3	1.53E-3	1	1.00	water CH; Questionnaires
resource, in air	Energy, waste heat, air			MJ	3.40E-4	1	4.42	Internal electricity production (and use) steam; Questionnaires
resource, land	Occupation, industrial area, built up			m2a	1.90E-4	1	1.45	Occupation Building area; Questionnaires
	Occupation, industrial area			m2a	1.09E-4	1	1.86	Occupation sealed area; Questionnaires
	Occupation, industrial area, vegetation			m2a	5.97E-4	1	1.53	Occupation unsealed area; Questionnaires
	Transformation, from unknown			m2	1.12E-5	1	1.42	Transformation to industrial area; Questionnaires
	Transformation, to industrial area			m2	1.12E-5	1	1.42	Transformation from industrial area; Questionnaires
air, unspecified	Water, Europe			kg	3.40E-1	1	1.00	Evaporation - emission to air LO; Questionnaires
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.63E-5	1	2.55	NMVOC; Questionnaires
	Manganese			kg	1.53E-7	1	1.62	Manganese (Mn); Questionnaires
	Carbon dioxide, fossil			kg	4.42E-2	1	1.42	Carbon dioxide (CO2); Questionnaires. Biogenic emissions
	Carbon dioxide, biogenic			kg	1.45E-1	1	1.42	Carbon dioxide (CO2) emissions biogas: 55g/MJ
air, high population density	Benzene			kg	3.19E-7	1	1.62	Aromatic hydrocarbons; Questionnaires
	Cadmium			kg	7.53E-9	1	1.88	Cadmium (Cd); Questionnaires
	Carbon monoxide, fossil			kg	1.41E-3	1	2.74	Carbon monoxide (CO); Questionnaires
	Chromium			kg	3.02E-8	1	2.67	Chromium (Cr); Questionnaires
	Copper			kg	4.91E-8	1	1.91	Copper (Cu); Questionnaires
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	1.47E-13	1	2.51	Dioxine (2,3,7,8,tetrachlorodibenzo-p-dioxin); Questionnaires
	Heat, waste			MJ	2.05E+0	1	1.18	Dust (unspecified); Questionnaires
	Hydrogen chloride			kg	6.59E-7	1	2.59	Hydrogen chloride (HCl); Questionnaires
	Lead			kg	3.74E-7	1	2.87	Lead (Pb); Questionnaires
	Mercury			kg	5.09E-8	1	2.65	Mercury (Hg); Questionnaires
	Methane, fossil			kg	8.17E-6	1	1.62	Methan; Questionnaires
	Nickel			kg	2.03E-8	1	3.59	Nickel (Ni); Questionnaires
	Nitrogen oxides			kg	3.38E-4	1	1.60	Nitrogen oxides (NOx); Questionnaires
	Particulates, > 10 um			kg	4.62E-6	1	3.04	Particulates PM10; Questionnaires
	Particulates, < 2.5 um			kg	5.27E-6	1	1.72	Particulates PM2.5; Questionnaires
	Particulates, > 2.5 um, and < 10um			kg	5.27E-6	1	1.72	PM 2.5-10; Questionnaires
	Polychlorinated biphenyls			kg	8.69E-10	1	1.62	Polychlorinated Biphenlys (PCB); Questionnaires
	PAH, polycyclic aromatic hydrocarbons			kg	1.83E-7	1	2.46	Polycyclic aromatic hydrocarbons (PAH); Questionnaires
	Sulfur dioxide			kg	1.37E-4	1	1.96	Sulfur dioxide (SO2) ; Questionnaires
	Zinc			kg	3.38E-6	1	2.18	Zink (Zn); Questionnaires
water, river	AOX, Adsorbable Organic Halogen as Cl			kg	1.87E-8	1	1.62	AOX; Questionnaires
	Arsenic			kg	4.25E-9	1	1.62	Arsen; Questionnaires
	Cadmium			kg	1.74E-10	1	1.62	Cd; Questionnaires
	Chromium			kg	2.50E-8	1	1.62	Chromium; Questionnaires
	COD, Chemical Oxygen Demand			kg	1.26E-5	1	3.36	COD; Questionnaires
	Copper			kg	8.55E-8	1	1.62	Cu; Questionnaires
	Fluoride			kg	1.85E-7	1	1.70	Fluorid; Questionnaires
	Mercury			kg	3.48E-10	1	1.62	Hg; Questionnaires
	Iron			kg	7.93E-7	1	1.62	Iron; Questionnaires
	Nickel			kg	2.64E-8	1	2.15	Ni; Questionnaires
	Nitrogen			kg	2.97E-6	1	1.98	Nitrogen; Questionnaires
	Lead			kg	2.09E-8	1	1.71	Pb; Questionnaires
	Phosphate			kg	1.79E-5	1	2.78	Phosphate; Questionnaires
	Sulfate			kg	2.69E-4	1	1.62	Sulphate; Questionnaires
	Suspended solids, unspecified			kg	5.14E-4	1	3.65	TSS; Questionnaires
	Zinc			kg	1.90E-7	1	2.00	Zn; Questionnaires
Outputs	rolled steel, at regional storage	CH	0	kg	1.00E+0			

Tab. A.6.8: Life cycle inventory of present production of 1 kg rolled steel

Explanations	Name	Location	Infrastructure-Process	Unit	rolled steel, at regional storage	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	iron scrap, at plant	RER	0	kg	1.10E+0	1	1.07	Summe external steel and beam
	aluminium sulphate, powder, at plant	RER	0	kg	1.24E-9	1	4.42	Aluminum sulfate; Questionnaires
	aluminium, production mix, at plant	RER	0	kg	1.98E-4	1	5.53	Aluminium; Questionnaires
	anode, aluminium electrolysis	RER	0	kg	1.38E-3	1	1.22	Anode; Questionnaires
	hard coal mix, at regional storage	UCTE	0	kg	4.40E-3	1	3.23	Hard coal; Questionnaires
	argon, liquid, at plant	RER	0	kg	2.75E-4	1	3.34	Argon; Questionnaires
	calcium carbide, technical grade, at plant	RER	0	kg	4.70E-5	1	3.80	Calciumcarbid CaC2; Questionnaires
	chemicals inorganic, at plant	GLO	0	kg	2.39E-4	1	4.86	Covering powder; Questionnaires
	dolomite, at plant	RER	0	kg	6.38E-3	1	2.74	Dolomit calcinated; Questionnaires
	ferrochromium, high-carbon, 68% Cr, at regional storage	RER	0	kg	9.94E-5	1	5.52	Ferro chromium; Questionnaires
	ferromanganese, high-coal, 74.5% Mn, at regional storage	RER	0	kg	7.70E-3	1	2.63	Silico manganese; Questionnaires
	rare earth concentrate, 70% REO, from bastnasite, at beneficiation	CN	0	kg	6.91E-5	1	3.08	Ferro niobium; Questionnaires
	silica sand, at plant	DE	0	kg	3.60E-3	1	5.53	Gravel/Sand; Questionnaires
	lime, hydrated, loose, at plant	CH	0	kg	3.29E-2	1	1.30	Lime; Questionnaires
	lubricating oil, at plant	RER	0	kg	4.98E-5	1	5.53	Lubricants; Questionnaires
	nitrogen, liquid, at plant	RER	0	kg	1.40E-3	1	3.62	Nitrogen gas; Questionnaires
	oxygen, liquid, at plant	RER	0	kg	9.88E-2	1	2.72	Oxygen; Questionnaires
	refractory, fireclay, packed, at plant	DE	0	kg	2.01E-3	1	5.53	Refractory clay (feuerfestes Material);
	sodium chloride, powder, at plant	RER	0	kg	4.48E-5	1	5.16	Sodium chloride; Questionnaires
	sulphuric acid, liquid, at plant	RER	0	kg	1.58E-5	1	4.32	Sulphuric acid 70%ig; Questionnaires
	hydrochloric acid, 30% in H2O, at plant	RER	0	kg	2.44E-5	1	5.53	Salzsäure; Questionnaires
	water, decarbonised, at plant	RER	0	kg	2.37E-2	1	5.53	decarbonized water; Questionnaires
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	5.68E-1	1	1.18	Electricity (medium voltage);
	natural gas, high pressure, at consumer	RER	0	MJ	2.64E+0	1	1.66	Natural gas; Questionnaires
	diesel, at regional storage	RER	0	kg	1.61E-4	1	4.99	Diesel; Questionnaires
	electricity, hydropower, at small hydropower plant	CH	0	kWh	1.30E-3	1	4.87	Internal electricity production (and
	light fuel oil, at regional storage	RER	0	kg	1.12E-5	1	4.98	Light fuel oil; Questionnaires
	diesel, burned in building machine, average	CH	0	MJ	7.48E-4	1	4.42	Diesel (internal transportation);
	heavy fuel oil, at regional storage	RER	0	kg	1.60E-5	1	6.23	Heavy fuel oil; Questionnaires
	hard coal coke, at plant	RER	0	MJ	5.13E-2	1	4.20	Koks; Questionnaires
	xxx Sawn timber, hardwood, planed, kiln dried, u=10%, at plant	RER	0	m3	2.23E-7	1	1.62	Wood; Questionnaires
	transport, freight, lorry, fleet average	RER	0	tkm	3.66E-1	1	2.57	Lorry to Switzerland; Questionnaires
	transport, freight, rail	RER	0	tkm	5.04E-1	1	1.89	Rail to Switzerland; Questionnaires
	transport, barge	RER	0	tkm	1.78E-3	1	1.00	Zulieferung / Ship; Questionnaires
	building, hall	CH	1	m2	2.38E-6	1	1.45	Buildings; Questionnaires
	disposal, slag, unalloyed electr. steel, 0% water, to residual material	CH	0	kg	6.75E-3	1	2.20	EAF slag for deposit; Questionnaires
	disposal, electronics for control units	RER	0	kg	2.90E-6	1	1.62	Electronic waste; Questionnaires
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	4.35E-5	1	1.62	Hazardous waste; Questionnaires
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	4.35E-4	1	1.62	Municipal solid waste;
	disposal, sludge from steel rolling, 20% water, to residual material	CH	0	kg	3.86E-2	1	1.62	Secondary steel making slag;
	disposal, separator sludge, 90% water, to hazardous waste incineration	CH	0	kg	6.09E-4	1	1.68	WWTP sludge (Summe
resource, in water	Water, unspecified, Europe			m3	1.53E-3	1	1.00	water CH; Questionnaires
resource, in air	Energy, waste heat, air			MJ	3.40E-4	1	4.42	Internal electricity production (and
resource, land	Occupation, industrial area, built up			m2a	1.90E-4	1	1.45	Occupation Building area;
	Occupation, industrial area			m2a	1.09E-4	1	1.86	Occupation sealed area;
	Occupation, industrial area, vegetation			m2a	5.97E-4	1	1.53	Occupation unsealed area;
	Transformation, from unknown			m2	1.12E-5	1	1.42	Transformation to industrial area;
	Transformation, to industrial area			m2	1.12E-5	1	1.42	Transformation from industrial area;
air, unspecified	Water, Europe			kg	3.40E-1	1	1.00	Evaporation - emission to air LU;
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.63E-5	1	2.55	NMVOC; Questionnaires
	Manganese			kg	1.53E-7	1	1.62	Manganese (Mn); Questionnaires
	Carbon dioxide, fossil			kg	1.90E-1	1	1.42	Carbon dioxide (CO2);
air, high population	Benzene			kg	3.19E-7	1	1.62	Aromatic hydrocarbons;
	Cadmium			kg	7.53E-9	1	1.88	Cadmium (Cd); Questionnaires
	Carbon monoxide, fossil			kg	1.41E-3	1	2.74	Carbon monoxide (CO);
	Chromium			kg	3.02E-8	1	2.67	Chromium (Cr); Questionnaires
	Copper			kg	4.91E-8	1	1.91	Copper (Cu); Questionnaires
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	1.47E-13	1	2.51	Dioxine (2,3,7,8,tetrachlorodibenzo-p-
	Heat, waste			MJ	2.05E+0	1	1.18	Dust (unspecified); Questionnaires
	Hydrogen chloride			kg	6.59E-7	1	2.59	Hydrogen chloride (HCl);
	Lead			kg	3.74E-7	1	2.87	Lead (Pb); Questionnaires
	Mercury			kg	5.09E-8	1	2.65	Mercury (Hg); Questionnaires
	Methane, fossil			kg	8.17E-6	1	1.62	Methan; Questionnaires
	Nickel			kg	2.03E-8	1	3.59	Nickel (Ni); Questionnaires
	Nitrogen oxides			kg	3.38E-4	1	1.60	Nitrogen oxides (NOx);
	Particulates, > 10 um			kg	4.62E-6	1	3.04	Particulates PM10; Questionnaires
	Particulates, < 2.5 um			kg	5.27E-6	1	1.72	Particulates PM2.5; Questionnaires
	Particulates, > 2.5 um, and < 10um			kg	5.27E-6	1	1.72	PM 2.5-10; Questionnaires
	Polychlorinated biphenyls			kg	8.69E-10	1	1.62	Polychlorinated Biphenlys (PCB);
	PAH, polycyclic aromatic hydrocarbons			kg	1.83E-7	1	2.46	Polycyclic aromatic hydrocarbons
	Sulfur dioxide			kg	1.37E-4	1	1.96	Sulfur dioxide (SO2) ; Questionnaires
	Zinc			kg	3.38E-6	1	2.18	Zink (Zn); Questionnaires
water, river	AOX, Adsorbable Organic Halogen as Cl			kg	1.87E-8	1	1.62	AOX; Questionnaires
	Arsenic			kg	4.25E-9	1	1.62	Arsen; Questionnaires
	Cadmium			kg	1.74E-10	1	1.62	Cd; Questionnaires
	Chromium			kg	2.50E-8	1	1.62	Chromium; Questionnaires
	COD, Chemical Oxygen Demand			kg	1.26E-5	1	3.36	COD; Questionnaires
	Copper			kg	8.55E-8	1	1.62	Cu; Questionnaires
	Fluoride			kg	1.85E-7	1	1.70	Fluorid; Questionnaires
	Mercury			kg	3.48E-10	1	1.62	Hg; Questionnaires
	Iron			kg	7.93E-7	1	1.62	Iron; Questionnaires
	Nickel			kg	2.64E-8	1	2.15	Ni; Questionnaires
	Nitrogen			kg	2.97E-6	1	1.98	Nitrogen; Questionnaires
	Lead			kg	2.09E-8	1	1.71	Pb; Questionnaires
	Phosphate			kg	1.79E-5	1	2.78	Phosphate; Questionnaires
	Sulfate			kg	2.69E-4	1	1.62	Sulphate; Questionnaires
	Suspended solids, unspecified			kg	5.14E-4	1	3.65	TSS; Questionnaires
	Zinc			kg	1.90E-7	1	2.00	Zn; Questionnaires
Outputs	rolled steel, at regional storage	CH	0	kg	1.00E+0			

A.7 Manufacture of zinc

Tab. A.7.1: Life cycle inventory of future production of 1 kg zinc concentrate, at beneficiation

Explanations	Name	Location	Infrastructure-Process	Unit	zinc concentrate, at beneficiation	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	blasting	RER	0	kg	1.31E-2	1	1.53	(2,2,2,1,4,4,4)
	chemicals inorganic, at plant	GLO	0	kg	3.83E-3	1	2.00	reported values
	chemicals organic, at plant	GLO	0	kg	1.12E-3	1	2.00	reported values
	conveyor belt, at plant	RER	1	m	1.68E-7	1	1.33	(4,2,2,1,3,4,4)
	ethanol, burned in building machine	GLO	0	MJ	9.19E-1	1	1.53	(2,2,2,1,4,4,4)
	electricity, medium voltage, production GLO, at grid	GLO	0	kWh	6.16E-1	1	1.83	(5,2,2,1,4,5,2)
	hydrogen cyanide, at plant	RER	0	kg	1.74E-4	1	2.00	reported values
	limestone, milled, packed, at plant	CH	0	kg	2.76E-3	1	2.00	reported values
	non-ferrous metal mine, underground	GLO	1	p	2.49E-10	1	3.32	(5,5,1,1,1,5,9)
	portland calcareous cement, at plant	CH	0	kg	1.89E-1	1	1.53	(2,2,2,1,4,4,4)
	sand, at mine	CH	0	kg	2.38E+0	1	1.53	(2,2,2,1,4,4,4)
	transport, freight, lorry, fleet average	RER	0	tkm	2.60E-1	1	2.11	(4,2,2,1,3,4,5)
	disposal, sulfidic tailings, off-site	GLO	0	kg	4.88E+0	1	1.53	(2,2,2,1,4,4,6)
resource, in water	Water, river			m3	2.92E-3	1	1.53	(2,2,2,1,4,4,12)
	Water, well, in ground			m3	1.04E-2	1	1.53	(2,2,2,1,4,4,12)
resource, in ground	Cadmium			kg	2.08E-2	1	1.58	(4,2,2,1,4,4,12)
	Indium			kg	3.46E-4	1	1.58	(4,2,2,1,4,4,12)
	Zinc			kg	6.24E-1	1	1.58	(4,2,2,1,4,4,12)
air, low population density	Cadmium			kg	5.07E-7	1	1.59	(3,2,1,1,3,4,31)
	Carbon dioxide, fossil			kg	1.22E-3	1	2.00	same value as for lime
	Carbon disulfide			kg	4.98E-4	1	2.26	(2,2,2,5,4,4,23)
	Heat, waste			MJ	7.11E-1	1	1.83	same as electricity consumption
	Lead			kg	2.53E-5	1	1.59	(3,2,1,1,3,4,31)
	Particulates, < 2.5 um			kg	2.58E-4	1	2.31	(4,2,2,5,4,4,23)
	Particulates, > 10 um			kg	2.49E-5	1	2.69	(3,2,1,1,5,4,19)
	Particulates, > 2.5 um, and < 10um			kg	2.24E-4	1	3.69	(3,2,1,1,5,4,20)
	Zinc			kg	4.56E-5	1	1.59	(3,2,1,1,3,4,31)
water, river	Aluminium			kg	9.02E-7	1	10.00	reported values
	Arsenic			kg	3.08E-8	1	10.00	reported values
	Cadmium			kg	3.30E-9	1	10.00	reported values
	Calcium			kg	7.16E-3	1	10.00	reported values
	Chromium			kg	5.71E-9	1	10.00	reported values
	Cobalt			kg	8.16E-9	1	10.00	reported values
	COD, Chemical Oxygen Demand			kg	1.09E-4	1	10.00	reported values
	Copper			kg	8.26E-8	1	10.00	reported values
	Cyanide			kg	1.87E-5	1	1.79	(2,2,2,3,4,4,33)
	Iron			kg	3.03E-6	1	10.00	reported values
	Lead			kg	2.92E-8	1	10.00	reported values
	Manganese			kg	2.58E-7	1	10.00	reported values
	Mercury			kg	3.93E-10	1	10.00	reported values
	Nickel			kg	2.54E-7	1	10.00	reported values
	Nitrogen, organic bound			kg	2.38E-4	1	10.00	reported values
	Suspended solids, unspecified			kg	5.40E-5	1	10.00	reported values
	Sulfate			kg	2.46E-2	1	10.00	reported values
	Zinc			kg	7.92E-7	1	10.00	reported values
Outputs	zinc concentrate, at beneficiation	GLO	0	kg	1.00E+0			

Tab. A.7.2: Life cycle inventory of present production of 1 kg zinc concentrate, at beneficiation

Explanations	Name	Location	Infrastructure-Process	Unit	zinc concentrate, at beneficiation	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	blasting	RER	0	kg	1.31E-2	1	1.53	(2,2,2,1,4,4,4)
	chemicals inorganic, at plant	GLO	0	kg	3.83E-3	1	2.00	reported values
	chemicals organic, at plant	GLO	0	kg	1.12E-3	1	2.00	reported values
	conveyor belt, at plant	RER	1	m	1.68E-7	1	1.33	(4,2,2,1,3,4,4)
	diesel, burned in building machine	GLO	0	MJ	5.86E-1	1	1.53	(2,2,2,1,4,4,4)
	electricity, hard coal, at power plant	US	0	kWh	4.94E-2	1	1.83	(5,2,2,1,4,5,2)
	electricity, natural gas, at power plant	US	0	kWh	1.48E-1	1	1.83	(5,2,2,1,4,5,2)
	hydrogen cyanide, at plant	RER	0	kg	1.74E-4	1	2.00	reported values
	limestone, milled, packed, at plant	CH	0	kg	2.76E-3	1	2.00	reported values
	non-ferrous metal mine, underground	GLO	1	p	2.49E-10	1	3.32	(5,5,1,1,1,5,9)
	portland calcareous cement, at plant	CH	0	kg	1.89E-1	1	1.53	(2,2,2,1,4,4,4)
	sand, at mine	CH	0	kg	2.38E+0	1	1.53	(2,2,2,1,4,4,4)
	transport, freight, lorry, fleet average	RER	0	tkm	2.60E-1	1	2.11	(4,2,2,1,3,4,5)
	disposal, sulfidic tailings, off-site	GLO	0	kg	4.88E+0	1	1.53	(2,2,2,1,4,4,6)
resource, in water	Water, river			m3	2.92E-3	1	1.53	(2,2,2,1,4,4,12)
	Water, well, in ground			m3	1.04E-2	1	1.53	(2,2,2,1,4,4,12)
resource, in ground	Cadmium			kg	2.08E-2	1	1.58	(4,2,2,1,4,4,12)
	Indium			kg	3.46E-4	1	1.58	(4,2,2,1,4,4,12)
	Zinc			kg	6.24E-1	1	1.58	(4,2,2,1,4,4,12)
air, low population density	Cadmium			kg	5.07E-7	1	1.59	(3,2,1,1,3,4,31)
	Carbon dioxide, fossil			kg	1.22E-3	1	2.00	same value as for lime
	Carbon disulfide			kg	4.98E-4	1	2.26	(2,2,2,5,4,4,23)
	Heat, waste			MJ	7.11E-1	1	1.83	same as electricity consumption
	Lead			kg	2.53E-5	1	1.59	(3,2,1,1,3,4,31)
	Particulates, < 2.5 um			kg	2.58E-4	1	2.31	(4,2,2,5,4,4,23)
	Particulates, > 10 um			kg	2.49E-5	1	2.69	(3,2,1,1,5,4,19)
	Particulates, > 2.5 um, and < 10um			kg	2.24E-4	1	3.69	(3,2,1,1,5,4,20)
	Zinc			kg	4.56E-5	1	1.59	(3,2,1,1,3,4,31)
water, river	Aluminium			kg	9.02E-7	1	10.00	reported values
	Arsenic			kg	3.08E-8	1	10.00	reported values
	Cadmium			kg	3.30E-9	1	10.00	reported values
	Calcium			kg	7.16E-3	1	10.00	reported values
	Chromium			kg	5.71E-9	1	10.00	reported values
	Cobalt			kg	8.16E-9	1	10.00	reported values
	COD, Chemical Oxygen Demand			kg	1.09E-4	1	10.00	reported values
	Copper			kg	8.26E-8	1	10.00	reported values
	Cyanide			kg	1.87E-5	1	1.79	(2,2,2,3,4,4,33)
	Iron			kg	3.03E-6	1	10.00	reported values
	Lead			kg	2.92E-8	1	10.00	reported values
	Manganese			kg	2.58E-7	1	10.00	reported values
	Mercury			kg	3.93E-10	1	10.00	reported values
	Nickel			kg	2.54E-7	1	10.00	reported values
	Nitrogen, organic bound			kg	2.38E-4	1	10.00	reported values
	Suspended solids, unspecified			kg	5.40E-5	1	10.00	reported values
	Sulfate			kg	2.46E-2	1	10.00	reported values
	Zinc			kg	7.92E-7	1	10.00	reported values
Outputs	zinc concentrate, at beneficiation	GLO	0	kg	1.00E+0			

Tab. A.7.3: Life cycle inventory of future production of 1 kg zinc, primary, at regional storage

Explanations	Name	Location	Infrastructure-Process	Unit	zinc, primary, at regional storage	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	ethanol, burned in building machine	GLO	0	MJ	7.22E-1	1	1.25	(3,3,2,1,3,3,2)
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	4.24E+0	1	2.07	(3,3,2,1,5,5,2)
	hard coal, burned in industrial furnace 1-10MW	RER	0	MJ	0	1	1.25	(3,3,2,1,3,3,1)
	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	1.70E+0	1	1.25	(3,3,2,1,3,3,1)
	oxygen, liquid, at plant	RER	0	kg	1.08E-1	1	1.25	(3,3,2,1,3,3,4)
	resource correction, PbZn, cadmium, negative	GLO	0	kg	3.96E-2	1	1.00	calculation
	steam, for chemical processes, at plant	RER	0	kg	1.09E+0	1	1.25	(3,3,2,1,3,3,1)
	transport, freight, rail	RER	0	tkm	1.88E+0	1	1.31	(4,3,1,1,3,3,2)
	transport, freight, lorry, fleet average	RER	0	tkm	3.17E-1	1	1.31	(4,3,1,1,3,3,2)
	zinc concentrate, at beneficiation	GLO	0	kg	1.90E+0	1	1.33	(3,3,2,1,3,5,4)
	resource correction, PbZn, zinc, positive	GLO	0	kg	1.66E-3	1	1.00	calculation
	resource correction, PbZn, indium, negative	GLO	0	kg	6.59E-4	1	1.00	calculation
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	3.20E-2	1	1.25	(3,3,2,1,3,3,6)
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	3.89E-2	1	1.25	(3,3,2,1,3,3,6)
resource, in water	Water, river			m3	3.89E-2	1	1.25	(3,3,2,1,3,3,2)
air, low population density	Arsenic			kg	2.33E-7	1	5.04	(3,4,2,1,1,4,22)
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	5.20E-15	1	10.00	reported
	Heat, waste			MJ	1.25E+1	1	1.13	(1,4,1,3,1,3,13)
	Lead			kg	5.83E-6	1	5.04	(3,4,2,1,1,4,22)
	Mercury			kg	4.68E-8	1	5.04	(3,4,2,1,1,4,22)
	Particulates, < 2.5 um			kg	1.88E-4	1	3.04	(3,4,2,1,1,4,27)
	Particulates, > 10 um			kg	3.60E-5	1	1.46	(3,4,2,1,1,4,29)
	Particulates, > 2.5 um, and < 10um			kg	3.60E-5	1	1.28	(3,4,2,1,1,4,28)
	Sulfur dioxide			kg	4.82E-3	1	1.19	(3,4,2,1,1,4,15)
	Zinc			kg	6.22E-5	1	5.04	(3,4,2,1,1,4,22)
water, river	Arsenic			kg	1.69E-7	1	5.02	(1,3,1,3,1,4,35)
	BOD5, Biological Oxygen Demand			kg	8.49E-6	1	1.65	(3,5,1,3,3,4,32)
	Cadmium			kg	1.33E-7	1	5.02	(1,3,1,3,1,4,35)
	COD, Chemical Oxygen Demand			kg	2.23E-5	1	1.60	(3,3,1,3,3,4,32)
	Copper			kg	4.03E-7	1	5.02	(1,3,1,3,1,4,35)
	DOC, Dissolved Organic Carbon			kg	4.15E-6	1	1.65	(3,5,1,3,3,4,32)
	Fluoride			kg	7.11E-6	1	1.58	(1,3,1,3,3,4,32)
	Lead			kg	6.48E-7	1	5.02	(1,3,1,3,1,4,35)
	Mercury			kg	1.62E-8	1	5.02	(1,3,1,3,1,4,35)
	TOC, Total Organic Carbon			kg	8.89E-7	1	1.65	(3,5,1,3,3,4,32)
	Zinc			kg	5.64E-6	1	5.02	(1,3,1,3,1,4,35)
Outputs	zinc, primary, at regional storage	RER	0	kg	1.00E+0			

Tab. A.7.4: Life cycle inventory of present production of 1 kg zinc, primary, at regional storage

Explanations	401	Input-Group	Output-Group	Name	Location	Infrastructure-Process	Unit	zinc, primary, at regional storage	uncertaintyType	StandardDeviation95%	GeneralComment
	662			Location				RER			
	493			InfrastructureProcess				0			
	403			Unit				kg			
Technosphere		5		diesel, burned in building machine	GLO	0	MJ	4.19E-2	1	1.25	(3,3,2,1,3,3,2)
		5		electricity, medium voltage, aluminium industry, at grid	GLO	0	kWh	3.28E+0	1	2.07	(3,3,2,1,5,5,2)
		5		electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	2.10E-1	1	2.07	(3,3,2,1,5,5,2)
		5		hard coal, burned in industrial furnace 1-10MW	RER	0	MJ	6.92E+0	1	1.25	(3,3,2,1,3,3,1)
		5		natural gas, burned in industrial furnace >100kW	RER	0	MJ	1.60E+0	1	1.25	(3,3,2,1,3,3,1)
		5		oxygen, liquid, at plant	RER	0	kg	1.08E-1	1	1.25	(3,3,2,1,3,3,4)
		5		resource correction, PbZn, cadmium, negative	GLO	0	kg	3.96E-2	1	1.00	calculation
		5		steam, for chemical processes, at plant	RER	0	kg	1.09E+0	1	1.25	(3,3,2,1,3,3,1)
		5		transport, freight, rail	RER	0	tkm	1.88E+0	1	1.31	(4,3,1,1,3,3,2)
		5		transport, freight, lorry, fleet average	RER	0	tkm	3.17E-1	1	1.31	(4,3,1,1,3,3,2)
		5		zinc concentrate, at beneficiation	GLO	0	kg	1.90E+0	1	1.33	(3,3,2,1,3,5,4)
		5		resource correction, PbZn, zinc, positive	GLO	0	kg	1.66E-3	1	1.00	calculation
		5		resource correction, PbZn, indium, negative	GLO	0	kg	6.59E-4	1	1.00	calculation
		5		disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	3.20E-2	1	1.25	(3,3,2,1,3,3,6)
		5		treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	3.89E-2	1	1.25	(3,3,2,1,3,3,6)
resource, in water		4		Water, river			m3	3.89E-2	1	1.25	(3,3,2,1,3,3,2)
air, low population density			4	Arsenic			kg	1.26E-5	1	5.04	(3,4,2,1,1,4,22)
			4	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	4.99E-11	1	10.00	reported
			4	Heat, waste			MJ	1.25E+1	1	1.13	(1,4,1,3,1,3,13)
			4	Lead			kg	1.04E-4	1	5.04	(3,4,2,1,1,4,22)
			4	Mercury			kg	3.99E-6	1	5.04	(3,4,2,1,1,4,22)
			4	Particulates, < 2.5 um			kg	1.88E-4	1	3.04	(3,4,2,1,1,4,27)
			4	Particulates, > 10 um			kg	3.60E-5	1	1.46	(3,4,2,1,1,4,29)
			4	Particulates, > 2.5 um, and < 10um			kg	3.60E-5	1	1.28	(3,4,2,1,1,4,28)
			4	Sulfur dioxide			kg	1.75E-2	1	1.19	(3,4,2,1,1,4,15)
			4	Zinc			kg	2.08E-3	1	5.04	(3,4,2,1,1,4,22)
water, river			4	Arsenic			kg	1.18E-6	1	5.02	(1,3,1,3,1,4,35)
			4	BOD5, Biological Oxygen Demand			kg	3.10E-4	1	1.65	(3,5,1,3,3,4,32)
			4	Cadmium			kg	3.67E-6	1	5.02	(1,3,1,3,1,4,35)
			4	COD, Chemical Oxygen Demand			kg	4.66E-4	1	1.60	(3,3,1,3,3,4,32)
			4	Copper			kg	3.99E-6	1	5.02	(1,3,1,3,1,4,35)
			4	DOC, Dissolved Organic Carbon			kg	1.82E-4	1	1.65	(3,5,1,3,3,4,32)
			4	Fluoride			kg	2.98E-5	1	1.58	(1,3,1,3,3,4,32)
			4	Lead			kg	4.19E-5	1	5.02	(1,3,1,3,1,4,35)
			4	Mercury			kg	1.72E-7	1	5.02	(1,3,1,3,1,4,35)
			4	TOC, Total Organic Carbon			kg	1.82E-4	1	1.65	(3,5,1,3,3,4,32)
			4	Zinc			kg	4.57E-5	1	5.02	(1,3,1,3,1,4,35)
Outputs			0	zinc, primary, at regional storage	RER	0	kg	1.00E+0			

A.8 Manufacture of wood materials

Tab. A.8.1: Life cycle inventory of future production of 1 kg fibreboard soft

Explanations	Name	Location	Infrastructure-Process	Unit	fibreboard soft, at plant (u=7%)	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	fibreboard soft, at plant (u=7%)	CH	0	m3	1.00E+0			
Technosphere	aluminium sulphate, powder, at plant	RER	0	kg	4.76E-3	1	1.05	(1,1,1,1,1,1,4)
	electricity, medium voltage, at grid	CH	0	kWh	7.98E+1	1	1.05	(1,1,1,1,1,1,2)
	heat, light fuel oil, at industrial furnace 1MW	CH	0	MJ	1.47E+2	1	1.07	(1,1,1,1,1,3,1)
	Heat, hardwood chips from industry, at furnace 300kW	CH	0	MJ	3.56E+2	1	1.05	(1,1,1,1,1,1,1)
	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	7.49E+1	1	1.05	(1,1,1,1,1,1,1)
	slab and siding, softwood, wet, measured as dry mass, at sawmill	CH	0	kg	1.49E+1	0		(1,1,1,1,1,1,4)
	pulpwood, softwood, sustainable forest management, measured as solid wood under bark, at forest road	CH	0	m3	2.42E-3	1	1.05	(1,1,1,1,1,1,4)
	light fuel oil, at regional storage	CH	0	kg	-3.60E+0	1	1.05	(1,1,1,1,1,1,1)
	paraffin, at plant	RER	0	kg	6.72E-1	1	1.05	(1,1,1,1,1,1,4)
	tap water, at user	CH	0	kg	3.07E+2	1	1.05	(1,1,1,1,1,1,4)
	transport, freight, lorry 32-40 metric ton, EURO 6	RER	0	tkm	1.22E+1	1	2.00	(1,1,1,1,1,1,5)
	transport, freight, lorry 16-32 metric ton, EURO 6	RER	0	tkm	9.86E-2	1	2.00	(1,1,1,1,1,1,5)
	vinyl acetate, at plant	RER	0	kg	2.10E+0	1	1.05	(1,1,1,1,1,1,4)
	wood chips, from industry, softwood, burned in furnace 1000kW	CH	0	MJ	3.71E+2	1	1.05	(1,1,1,1,1,1,1)
	wood chips, production mix, wet, measured as dry mass, at forest road & at sawmill	CH	0	kg	1.31E+2	0		(1,1,1,1,1,1,1)
	wooden board manufacturing plant, organic bonded boards	RER	1	p	6.67E-9	1	3.00	(1,1,1,1,1,1,9)
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	4.26E-2	1	1.05	(1,1,1,1,1,1,6)
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	2.26E+0	1	1.05	(1,1,1,1,1,1,6)
	disposal, raw sewage sludge, to municipal incineration	CH	0	kg	5.18E+0	1	1.05	(1,1,1,1,1,1,6)
	disposal, wood ash mixture, pure, 0% water, to sanitary landfill	CH	0	kg	4.72E-1	1	1.05	(1,1,1,1,1,1,6)
	treatment, soft fibreboard production effluent, to wastewater treatment, class 3	CH	0	m3	2.15E-1	1	1.21	(1,1,1,1,1,5,6)
resource, in water	Water, cooling, unspecified natural origin/m3			m3	8.07E-1	1	1.05	(1,1,1,1,1,1,4)
air, low population density	Carbon dioxide, biogenic			kg	1.14E+1	1	1.05	(1,1,1,1,1,1,1)
air, high population density	Carbon dioxide, fossil			kg	-1.14E+1	1	1.05	(1,1,1,1,1,1,1)
	Heat, waste			MJ	2.87E+2	1	1.05	(1,1,1,1,1,1,2)
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.93E-3	1	2.00	(1,1,1,1,1,1,23)
	Particulates, > 10 um			kg	5.42E-3	1	2.00	(1,1,1,1,1,1,26)

Tab. A.8.2: Life cycle inventory of present production production of 1 kg fibreboard soft

Explanations	Name	Location	Infrastructure-Process	Unit	fibreboard soft, at plant (u=7%)	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	fibreboard soft, at plant (u=7%)	CH	0	m3	1.00E+0			
Technosphere	aluminium sulphate, powder, at plant	RER	0	kg	4.76E-3	1	1.05	(1,1,1,1,1,1,4)
	electricity, medium voltage, at grid	CH	0	kWh	7.98E+1	1	1.05	(1,1,1,1,1,1,2)
	heat, light fuel oil, at industrial furnace 1MW	CH	0	MJ	1.47E+2	1	1.07	(1,1,1,1,1,3,1)
	heat, natural gas, at industrial furnace low-NOx >100kW	RER	0	MJ	3.56E+2	1	1.05	(1,1,1,1,1,1,1)
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	CH	0	MJ	7.49E+1	1	1.05	(1,1,1,1,1,1,1)
	slab and siding, softwood, wet, measured as dry mass, at sawmill	CH	0	kg	1.49E+1	0		(1,1,1,1,1,1,4)
	pulpwood, softwood, sustainable forest management, measured as solid wood under bark, at forest road	CH	0	m3	2.42E-3	1	1.05	(1,1,1,1,1,1,4)
	light fuel oil, at regional storage	CH	0	kg	-3.60E+0	1	1.05	(1,1,1,1,1,1,1)
	paraffin, at plant	RER	0	kg	6.72E-1	1	1.05	(1,1,1,1,1,1,4)
	tap water, at user	CH	0	kg	3.07E+2	1	1.05	(1,1,1,1,1,1,4)
	transport, freight, lorry 32-40 metric ton, EURO 3	RER	0	tkm	1.22E+1	1	2.00	(1,1,1,1,1,1,5)
	transport, freight, lorry 16-32 metric ton, EURO 3	RER	0	tkm	9.86E-2	1	2.00	(1,1,1,1,1,1,5)
	vinyl acetate, at plant	RER	0	kg	2.10E+0	1	1.05	(1,1,1,1,1,1,4)
	wood chips, from industry, softwood, burned in furnace 1000kW	CH	0	MJ	3.71E+2	1	1.05	(1,1,1,1,1,1,1)
	wood chips, production mix, wet, measured as dry mass, at forest road & at sawmill	CH	0	kg	1.31E+2	0		(1,1,1,1,1,1,1)
	wooden board manufacturing plant, organic bonded boards	RER	1	p	6.67E-9	1	3.00	(1,1,1,1,1,1,9)
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	4.26E-2	1	1.05	(1,1,1,1,1,1,6)
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	2.26E+0	1	1.05	(1,1,1,1,1,1,6)
	disposal, raw sewage sludge, to municipal incineration	CH	0	kg	5.18E+0	1	1.05	(1,1,1,1,1,1,6)
	disposal, wood ash mixture, pure, 0% water, to sanitary landfill	CH	0	kg	4.72E-1	1	1.05	(1,1,1,1,1,1,6)
	treatment, soft fibreboard production effluent, to wastewater treatment, class 3	CH	0	m3	2.15E-1	1	1.21	(1,1,1,1,1,5,6)
resource, in water	Water, cooling, unspecified natural origin/m3			m3	8.07E-1	1	1.05	(1,1,1,1,1,1,4)
air, low population density	Carbon dioxide, biogenic			kg	1.14E+1	1	1.05	(1,1,1,1,1,1,1)
air, high population density	Carbon dioxide, fossil			kg	-1.14E+1	1	1.05	(1,1,1,1,1,1,1)
	Heat, waste			MJ	2.87E+2	1	1.05	(1,1,1,1,1,1,2)
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.93E-3	1	2.00	(1,1,1,1,1,1,23)
	Particulates, > 10 um			kg	5.42E-3	1	2.00	(1,1,1,1,1,1,26)

Tab. A.8.3: Life cycle inventory of future production production of 1 kg particleboard

Explanations	Name	Location	Infrastructure-Process	Unit	particleboard, average glue mix, uncoated, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	particleboard, average glue mix, uncoated, at plant	RER	0	m3	1.00E+0			
Technosphere	methylene diphenyl diisocyanate, at plant	RER	0	kg	3.19E+0	1	1.17	Pedigree: (1,3,2,1,1).
	Heat, hardwood chips from industry, at furnace 300kW	CH	0	MJ	2.47E+1	1	1.17	Pedigree: (1,3,2,1,1).
	urea, as N, at regional storehouse	RER	0	kg	1.93E-1	1	1.17	Pedigree: (1,3,2,1,1).
	aluminium sulphate, powder, at plant	RER	0	kg	1.55E+0	1	1.17	Pedigree: (1,3,2,1,1).
	Heat, hardwood chips from industry, at furnace 300kW	CH	0	MJ	2.22E+1	1	1.17	Pedigree: (1,3,2,1,1).
	chemicals organic, at plant	GLO	0	kg	3.84E-1	1	1.17	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	AT	0	kWh	6.18E+0	1	1.17	Pedigree: (1,1,2,1,1).
	diesel, burned in building machine, average	CH	0	MJ	2.83E+1	1	1.17	Pedigree: (1,3,2,1,1).
	lubricating oil, at plant	RER	0	kg	2.49E-1	1	1.17	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	CZ	0	kWh	3.71E+0	1	1.17	Pedigree: (1,1,2,1,1).
	furnace, wood chips, mixed, 1000kW	CH	1	p	4.60E-5	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, at grid	BE	0	kWh	4.94E+0	1	1.17	Pedigree: (1,1,2,1,1).
	treatment, particle board production effluent, to wastewater treatment, class 1	RER	0	m3	7.03E-2	1	1.17	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	DE	0	kWh	1.90E+1	1	1.17	Pedigree: (1,1,2,1,1).
	saw dust, production mix, wet, measured as dry mass, at sawmill	RER	0	kg	2.41E+1	1	1.07	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	FR	0	kWh	1.20E+1	1	1.17	Pedigree: (1,1,2,1,1).
	biowaste, at collection point	CH	0	kg	4.76E+0	1	1.18	Pedigree: (2,3,2,1,1).
	electricity, medium voltage, at grid	PL	0	kWh	1.34E+1	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, at grid	IT	0	kWh	8.13E+0	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, at grid	ES	0	kWh	4.32E+0	1	1.17	Pedigree: (1,1,2,1,1).
	slab and siding, softwood, wet, measured as dry mass, at sawmill	RER	0	kg	1.24E+2	1	1.07	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	RO	0	kWh	5.04E+0	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, at grid	GB	0	kWh	7.21E+0	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	1.88E+1	1	1.17	Pedigree: (1,1,2,1,1).
	urea formaldehyde resin, at plant	RER	0	kg	4.43E+1	1	1.17	Pedigree: (1,3,2,1,1).
	wooden board manufacturing plant, organic bonded boards	RER	1	p	3.77E-8	1	1.17	Pedigree: (1,3,2,1,1).
	paraffin, at plant	RER	0	kg	2.99E+0	1	1.17	Pedigree: (1,3,2,1,1).
	phenolic resin, at plant	RER	0	kg	1.20E+0	1	1.17	Pedigree: (1,3,2,1,1).
	wood chips, production mix, wet, measured as dry mass, at forest road & at sawmill	RER	0	kg	1.88E+1	1	1.17	Pedigree: (1,3,2,1,1).
	tap water, at user	RER	0	kg	1.74E+2	1	1.17	Pedigree: (1,3,2,1,1).
	melamine formaldehyde resin, at plant	RER	0	kg	9.76E+0	1	1.17	Pedigree: (1,3,2,1,1).
	Heat, hardwood chips from industry, at furnace 300kW	CH	0	MJ	1.97E+2	1	1.17	Pedigree: (1,3,2,1,1).
	pulpwood, softwood, sustainable forest management, measured as solid wood under bark, at forest	RER	0	m3	2.55E-1	1	1.17	Pedigree: (1,3,2,1,1).
	pulpwood, softwood, sustainable forest management, measured as solid wood under bark, at forest	CH	0	m3	2.25E-3	1	1.17	Pedigree: (1,3,2,1,1).
	pulpwood, hardwood, sustainable forest management, measured as solid wood under bark, at forest	RER	0	m3	2.32E-3	1	1.17	Pedigree: (1,3,2,1,1).
	pulpwood, hardwood, sustainable forest management, measured as solid wood under bark, at forest	CH	0	m3	6.45E-5	1	1.17	Pedigree: (1,3,2,1,1).
	wood chips, production mix, wet, measured as dry mass, at forest road & at sawmill	CH	0	kg	1.55E+0	1	1.17	Pedigree: (1,3,2,1,1).
	transport, freight, lorry, fleet average	RER	0	tkm	6.33E+1	1	1.51	Pedigree: (1,1,4,5,4).
	transport, freight, rail	RER	0	tkm	1.52E+2	1	1.51	Pedigree: (1,1,4,5,4).
	disposal, wood ash mixture, pure, 0% water, to sanitary landfill	CH	0	kg	7.84E-1	0		
resource, in water	Water, river			m3	6.13E-2	1	1.17	Pedigree: (1,3,2,1,1).
	Water, well			m3	1.95E-3	1	1.17	Pedigree: (1,3,2,1,1).
air, high population	Calcium			kg	9.63E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Sulfur dioxide			kg	4.12E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Copper			kg	3.62E-5	1	1.94	Pedigree: (2,3,4,1,1).
	Hydrocarbons, aliphatic, alkanes, unspecified			kg	1.50E-3	1	1.94	Pedigree: (2,3,4,1,1).
air, low population	Methanol			kg	1.75E-2	1	1.94	Pedigree: (3,3,4,1,1).
air, high population	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	4.94E-11	1	1.94	Pedigree: (2,3,4,1,1).
	Particulates, < 2.5 um			kg	4.12E-3	1	1.33	Pedigree: (2,3,4,1,1).
	Benzo(a)pyrene			kg	8.23E-7	1	1.94	Pedigree: (2,3,4,1,1).
	Toluene			kg	4.94E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Chromium			kg	6.52E-6	1	1.94	Pedigree: (2,3,4,1,1).
	Manganese			kg	2.80E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Nitrogen oxides			kg	1.98E-1	1	1.33	Pedigree: (2,3,4,1,1).
	Cadmium			kg	1.15E-6	1	1.94	Pedigree: (2,3,4,1,1).
	Chlorine			kg	2.96E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Zinc			kg	4.94E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Ammonia			kg	2.85E-3	1	1.94	Pedigree: (2,3,4,1,1).
	m-Xylene			kg	1.98E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Sodium			kg	2.14E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Mercury			kg	4.94E-7	1	1.94	Pedigree: (2,3,4,1,1).
	Magnesium			kg	5.93E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Phosphorus			kg	4.94E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Methane, biogenic			kg	2.47E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Potassium			kg	3.85E-2	1	1.94	Pedigree: (2,3,4,1,1).
	PAH, polycyclic aromatic hydrocarbons			kg	1.83E-5	1	1.94	Pedigree: (2,3,4,1,1).
	Carbon monoxide, biogenic			kg	3.29E-1	1	1.19	Pedigree: (2,3,4,1,1).
	Arsenic			kg	1.65E-6	1	1.94	Pedigree: (2,3,4,1,1).
	Acetaldehyde			kg	4.35E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Nickel			kg	9.88E-6	1	1.94	Pedigree: (2,3,4,1,1).
	Fluorine			kg	8.23E-5	1	1.94	Pedigree: (2,3,4,1,1).
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.01E-1	1	1.51	Pedigree: (2,3,4,1,1).
	Benzene, hexachloro-			kg	1.19E-11	1	1.94	Pedigree: (2,3,4,1,1).
	Benzene, ethyl-			kg	4.94E-5	1	1.94	Pedigree: (2,3,4,1,1).
	Dinitrogen monoxide			kg	3.79E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Chromium VI			kg	6.59E-8	1	2.01	Pedigree: (2,3,4,1,1).
	Formaldehyde			kg	9.13E-2	1	1.94	Pedigree: (2,3,4,1,1).
	Hydrocarbons, aliphatic, unsaturated			kg	5.11E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Lead			kg	4.12E-5	1	1.94	Pedigree: (2,3,4,1,1).
	Phenol, pentachloro-			kg	1.33E-8	1	1.94	Pedigree: (2,3,4,1,1).
	Carbon dioxide, biogenic			kg	1.68E+2	1	1.10	Pedigree: (2,3,4,1,1).
	Benzene			kg	1.50E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Bromine			kg	9.88E-5	1	1.94	Pedigree: (2,3,4,1,1).
air, unspecified	Particulates, > 10 um			kg	7.73E-2	1	1.93	Pedigree: (3,3,2,1,1).

Tab. A.8.4: Life cycle inventory of present production production of 1 kg particleboard

Explanations	Name	Location	Infrastructure-Process	Unit	particleboard, average glue mix, uncoated, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	particleboard, average glue mix, uncoated, at plant	RER	0	m3	1.00E+0			
Technosphere	methylene diphenyl diisocyanate, at plant	RER	0	kg	3.19E+0	1	1.17	Pedigree: (1,3,2,1,1).
	heat, heavy fuel oil, at industrial furnace 1MW	RER	0	MJ	2.47E+1	1	1.17	Pedigree: (1,3,2,1,1).
	urea, as N, at regional storehouse	RER	0	kg	1.93E-1	1	1.17	Pedigree: (1,3,2,1,1).
	aluminium sulphate, powder, at plant	RER	0	kg	1.55E+0	1	1.17	Pedigree: (1,3,2,1,1).
	heat, light fuel oil, at industrial furnace 1MW	RER	0	MJ	2.22E+1	1	1.17	Pedigree: (1,3,2,1,1).
	chemicals organic, at plant	GLO	0	kg	3.84E-1	1	1.17	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	AT	0	kWh	6.18E+0	1	1.17	Pedigree: (1,1,2,1,1).
	diesel, burned in building machine, average	CH	0	MJ	2.83E+1	1	1.17	Pedigree: (1,3,2,1,1).
	lubricating oil, at plant	RER	0	kg	2.49E-1	1	1.17	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	CZ	0	kWh	3.71E+0	1	1.17	Pedigree: (1,1,2,1,1).
	furnace, wood chips, mixed, 1000kW	CH	1	p	4.60E-5	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, at grid	BE	0	kWh	4.94E+0	1	1.17	Pedigree: (1,1,2,1,1).
	treatment, particle board production effluent, to wastewater treatment, class 1	RER	0	m3	7.03E-2	1	1.17	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	DE	0	kWh	1.90E+1	1	1.17	Pedigree: (1,1,2,1,1).
	saw dust, production mix, wet, measured as dry mass, at sawmill	RER	0	kg	2.41E+1	1	1.07	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	FR	0	kWh	1.20E+1	1	1.17	Pedigree: (1,1,2,1,1).
	biowaste, at collection point	CH	0	kg	4.76E+0	1	1.18	Pedigree: (2,3,2,1,1).
	electricity, medium voltage, at grid	PL	0	kWh	1.34E+1	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, at grid	IT	0	kWh	8.13E+0	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, at grid	ES	0	kWh	4.32E+0	1	1.17	Pedigree: (1,1,2,1,1).
	slab and siding, softwood, wet, measured as dry mass, at sawmill	RER	0	kg	1.24E+2	1	1.07	Pedigree: (1,3,2,1,1).
	electricity, medium voltage, at grid	RO	0	kWh	5.04E+0	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, at grid	GB	0	kWh	7.21E+0	1	1.17	Pedigree: (1,1,2,1,1).
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	1.88E+1	1	1.17	Pedigree: (1,1,2,1,1).
	urea formaldehyde resin, at plant	RER	0	kg	4.43E+1	1	1.17	Pedigree: (1,3,2,1,1).
	wooden board manufacturing plant, organic bonded boards	RER	1	p	3.77E-8	1	1.17	Pedigree: (1,3,2,1,1).
	paraffin, at plant	RER	0	kg	2.99E+0	1	1.17	Pedigree: (1,3,2,1,1).
	phenolic resin, at plant	RER	0	kg	1.20E+0	1	1.17	Pedigree: (1,3,2,1,1).
	wood chips, production mix, wet, measured as dry mass, at forest road & at sawmill	RER	0	kg	1.88E+1	1	1.17	Pedigree: (1,3,2,1,1).
	tap water, at user	RER	0	kg	1.74E+2	1	1.17	Pedigree: (1,3,2,1,1).
	melamine formaldehyde resin, at plant	RER	0	kg	9.76E+0	1	1.17	Pedigree: (1,3,2,1,1).
	heat, natural gas, at boiler condensing modulating >100kW	RER	0	MJ	1.97E+2	1	1.17	Pedigree: (1,3,2,1,1).
	pulpwood, softwood, sustainable forest management, measured as solid wood under bark, at forest road	RER	0	m3	2.55E-1	1	1.17	Pedigree: (1,3,2,1,1).
	pulpwood, softwood, sustainable forest management, measured as solid wood under bark, at forest road	CH	0	m3	2.25E-3	1	1.17	Pedigree: (1,3,2,1,1).
	pulpwood, hardwood, sustainable forest management, measured as solid wood under bark, at forest road	RER	0	m3	2.32E-3	1	1.17	Pedigree: (1,3,2,1,1).
	pulpwood, hardwood, sustainable forest management, measured as solid wood under bark, at forest road	CH	0	m3	6.45E-5	1	1.17	Pedigree: (1,3,2,1,1).
	wood chips, production mix, wet, measured as dry mass, at forest road & at sawmill	CH	0	kg	1.55E+0	1	1.17	Pedigree: (1,3,2,1,1).
	transport, freight, lorry, fleet average	RER	0	tkm	6.33E+1	1	1.51	Pedigree: (1,1,4,5,4).
	transport, freight, rail	RER	0	tkm	1.52E+2	1	1.51	Pedigree: (1,1,4,5,4).
	disposal, wood ash mixture, pure, 0% water, to sanitary landfill	CH	0	kg	7.84E-1	0		
resource, in water	Water, river			m3	6.13E-2	1	1.17	Pedigree: (1,3,2,1,1).
	Water, well			m3	1.95E-3	1	1.17	Pedigree: (1,3,2,1,1).
air, high population	Calcium			kg	9.63E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Sulfur dioxide			kg	4.12E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Copper			kg	3.62E-5	1	1.94	Pedigree: (2,3,4,1,1).
	Hydrocarbons, aliphatic, alkanes, unspecified			kg	1.50E-3	1	1.94	Pedigree: (2,3,4,1,1).
air, low population	Methanol			kg	1.75E-2	1	1.94	Pedigree: (3,3,4,1,1).
air, high population	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	4.94E-11	1	1.94	Pedigree: (2,3,4,1,1).
	Particulates, < 2.5 um			kg	4.12E-3	1	1.33	Pedigree: (2,3,4,1,1).
	Benzo(a)pyrene			kg	8.23E-7	1	1.94	Pedigree: (2,3,4,1,1).
	Toluene			kg	4.94E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Chromium			kg	6.52E-6	1	1.94	Pedigree: (2,3,4,1,1).
	Manganese			kg	2.80E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Nitrogen oxides			kg	1.98E-1	1	1.33	Pedigree: (2,3,4,1,1).
	Cadmium			kg	1.15E-6	1	1.94	Pedigree: (2,3,4,1,1).
	Chlorine			kg	2.96E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Zinc			kg	4.94E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Ammonia			kg	2.85E-3	1	1.94	Pedigree: (2,3,4,1,1).
	m-Xylene			kg	1.98E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Sodium			kg	2.14E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Mercury			kg	4.94E-7	1	1.94	Pedigree: (2,3,4,1,1).
	Magnesium			kg	5.93E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Phosphorus			kg	4.94E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Methane, biogenic			kg	2.47E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Potassium			kg	3.85E-2	1	1.94	Pedigree: (2,3,4,1,1).
	PAH, polycyclic aromatic hydrocarbons			kg	1.83E-5	1	1.94	Pedigree: (2,3,4,1,1).
	Carbon monoxide, biogenic			kg	3.29E-1	1	1.19	Pedigree: (2,3,4,1,1).
	Arsenic			kg	1.65E-6	1	1.94	Pedigree: (2,3,4,1,1).
	Acetaldehyde			kg	4.35E-4	1	1.94	Pedigree: (2,3,4,1,1).
	Nickel			kg	9.88E-6	1	1.94	Pedigree: (2,3,4,1,1).
	Fluorine			kg	8.23E-5	1	1.94	Pedigree: (2,3,4,1,1).
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.01E-1	1	1.51	Pedigree: (2,3,4,1,1).
	Benzene, hexachloro-			kg	1.19E-11	1	1.94	Pedigree: (2,3,4,1,1).
	Benzene, ethyl-			kg	4.94E-5	1	1.94	Pedigree: (2,3,4,1,1).
	Dinitrogen monoxide			kg	3.79E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Chromium VI			kg	6.59E-8	1	2.01	Pedigree: (2,3,4,1,1).
	Formaldehyde			kg	9.13E-2	1	1.94	Pedigree: (2,3,4,1,1).
	Hydrocarbons, aliphatic, unsaturated			kg	5.11E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Lead			kg	4.12E-5	1	1.94	Pedigree: (2,3,4,1,1).
	Phenol, pentachloro-			kg	1.33E-8	1	1.94	Pedigree: (2,3,4,1,1).
	Carbon dioxide, biogenic			kg	1.68E+2	1	1.10	Pedigree: (2,3,4,1,1).
	Benzene			kg	1.50E-3	1	1.94	Pedigree: (2,3,4,1,1).
	Bromine			kg	9.88E-5	1	1.94	Pedigree: (2,3,4,1,1).
air, unspecified	Particulates, > 10 um			kg	7.73E-2	1	1.93	Pedigree: (3,3,2,1,1).

Tab. A.8.5: Life cycle inventory of future production production of 1 kg sawnwood

Explanations	Name	Location	Infrastructure-Process	Unit	sawnwood, softwood, raw, at saw	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	sawnwood, softwood, raw, at saw	CH	0	m3	1.00E+0			
Technosphere	sawmill/CH	I	0	p	2.00E-7	0		Pedigree: (2,1,2,1,1).
	electricity, medium voltage, at grid	CH	0	kWh	1.80E+1	0		Pedigree: (2,1,2,1,1).
	diesel, burned in building machine, average	CH	0	MJ	2.69E+1	0		Pedigree: (1,3,2,3,1).
	sawlog and veneer log, softwood, sustainable forest management, measured as solid wood under bark, at forest road	CH	0	m3	1.50E+0	0		Pedigree: (2,1,2,1,1).
	lubricating oil, at plant	RER	0	kg	9.79E-2	0		Pedigree: (1,5,2,3,1).
	transport, freight, lorry 16-32 metric ton, EURO 6	RER	0	tkm	5.73E+1	0		Pedigree: (1,1,4,5,4).
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.46E-2	0		
resource, in air	Carbon dioxide, in air			kg	-4.94E+2	0		Pedigree: (1,1,2,1,1).
resource, biotic	Energy, gross calorific value, in biomass			MJ	-5.56E+3	0		Pedigree: (1,1,2,1,1).

Tab. A.8.6: Life cycle inventory of present production production of 1 kg sawnwood

Explanations	Name	Location	Infrastructure-Process	Unit	sawnwood, softwood, raw, at saw	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	sawnwood, softwood, raw, at saw	CH	0	m3	1.00E+0			
Technosphere	sawmill/CH	I	0	p	2.00E-7	0		Pedigree: (2,1,2,1,1).
	electricity, medium voltage, at grid	CH	0	kWh	1.80E+1	0		Pedigree: (2,1,2,1,1).
	diesel, burned in building machine, average	CH	0	MJ	2.69E+1	0		Pedigree: (1,3,2,3,1).
	sawlog and veneer log, softwood, sustainable forest management, measured as solid wood under bark, at forest road	CH	0	m3	1.50E+0	0		Pedigree: (2,1,2,1,1).
	lubricating oil, at plant	RER	0	kg	9.79E-2	0		Pedigree: (1,5,2,3,1).
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	5.73E+1	0		Pedigree: (1,1,4,5,4).
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.46E-2	0		
resource, in air	Carbon dioxide, in air			kg	-4.94E+2	0		Pedigree: (1,1,2,1,1).
resource, biotic	Energy, gross calorific value, in biomass			MJ	-5.56E+3	0		Pedigree: (1,1,2,1,1).

Tab. A.8.7: Life cycle inventory of future production production of 1 kg glued laminated timber, outdoor use

Explanations	Name	Location	Infrastructure-Process	Unit	glued laminated timber, outdoor use, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	glued laminated timber, outdoor use, at plant	CH	0	m3	1.00E+0			
Technosphere	diesel, burned in building machine, average	CH	0	MJ	3.36E+1	1	2.01	(1,4,2,3,1,1,5)
	electricity, medium voltage, at grid	CH	0	kWh	1.29E+2	1	1.12	(1,4,2,3,1,1,2)
	Heat, hardwood chips from industry, at furnace 300kW	CH	0	MJ	2.30E+1	1	1.12	(1,4,2,3,1,1,1)
	melamine formaldehyde resin, at plant	RER	0	kg	1.20E+1	1	1.12	(1,4,2,3,1,1,3)
	sawnwood, board, softwood, raw, kiln dried (u=10%), at sawmill	CH	0	m3	1.37E+0	1	1.12	(1,4,2,3,1,1,4)
	softwood, allocation correction, 1	RER	0	m3	-5.19E-2	0		calculated correction term; adjusted to (real) basic wood density 422.4 kg/m3 from 450 kg/m3 as assumed in ecoinvent 2.2
	transport, freight, rail	RER	0	tkm	8.12E+1	1	2.09	(4,5,nA,nA,nA,nA,5)
	transport, freight, lorry, fleet average	RER	0	tkm	3.82E+1	1	2.09	(4,5,nA,nA,nA,nA,5)
	wood chips, from industry, softwood, burned in furnace 300kW	CH	0	MJ	2.66E+3	1	1.12	(1,4,2,3,1,1,1)
	wood chips, softwood, wet, measured as dry mass, at sawmill	CH	0	kg	-1.42E+2	0		calculated
	wooden board manufacturing plant, organic bonded boards	RER	1	p	3.33E-8	1	3.36	(4,5,2,3,4,5,9)
air, unspecified	Formaldehyde			kg	1.20E-2	1	2.81	(4,5,2,5,5,5,23)
	Heat, waste			MJ	4.63E+2	1	1.12	(1,4,2,3,1,1,13)

Tab. A.8.8: Life cycle inventory of present production production of 1 kg glued laminated timber, outdoor use

Explanations	Name	Location	Infrastructure-Process	Unit	glued laminated timber, outdoor use, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	glued laminated timber, outdoor use, at plant	CH	0	m3	1.00E+0			
Technosphere	diesel, burned in building machine, average	CH	0	MJ	3.36E+1	1	2.01	(1,4,2,3,1,1,5)
	electricity, medium voltage, at grid	CH	0	kWh	1.29E+2	1	1.12	(1,4,2,3,1,1,2)
	heat, light fuel oil, at industrial furnace 1MW	CH	0	MJ	2.30E+1	1	1.12	(1,4,2,3,1,1,1)
	melamine formaldehyde resin, at plant	RER	0	kg	1.20E+1	1	1.12	(1,4,2,3,1,1,3)
	sawnwood, board, softwood, raw, kiln dried (u=10%), at sawmill	CH	0	m3	1.37E+0	1	1.12	(1,4,2,3,1,1,4)
	softwood, allocation correction, 1	RER	0	m3	-5.19E-2	0		calculated correction term; adjusted to (real) basic wood density 422.4 kg/m3 from 450 kg/m3 as assumed in ecoinvent 2.2
	transport, freight, rail	RER	0	tkm	8.12E+1	1	2.09	(4,5,nA,nA,nA,nA,5)
	transport, freight, lorry, fleet average	RER	0	tkm	3.82E+1	1	2.09	(4,5,nA,nA,nA,nA,5)
	wood chips, from industry, softwood, burned in furnace 300kW	CH	0	MJ	2.66E+3	1	1.12	(1,4,2,3,1,1,1)
	wood chips, softwood, wet, measured as dry mass, at sawmill	CH	0	kg	-1.42E+2	0		calculated
	wooden board manufacturing plant, organic bonded boards	RER	1	p	3.33E-8	1	3.36	(4,5,2,3,4,5,9)
air, unspecified	Formaldehyde			kg	1.20E-2	1	2.81	(4,5,2,5,5,5,23)
	Heat, waste			MJ	4.63E+2	1	1.12	(1,4,2,3,1,1,13)

Tab. A.8.9: Life cycle inventory of future production production of 1 kg glued laminated timber, indoor use

Explanations	Name	Location	Infrastructure-Process	Unit	glued laminated timber, indoor use, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	glued laminated timber, indoor use, at plant	CH	0	m3	1.00E+0			
Technosphere	diesel, burned in building machine, average	CH	0	MJ	3.36E+1	1	2.01	(1,4,2,3,1,1,5)
	electricity, medium voltage, at grid	CH	0	kWh	1.29E+2	1	1.12	(1,4,2,3,1,1,2)
	Heat, hardwood chips from industry, at furnace 300kW	CH	0	MJ	2.30E+1	1	1.12	(1,4,2,3,1,1,1)
	sawnwood, board, softwood, raw, kiln dried (u=10%), at sawmill	CH	0	m3	1.37E+0	1	2.01	(1,4,2,3,1,1,5)
	softwood, allocation correction, 1	RER	0	m3	-4.90E-2	0		calculated correction term; adjusted to (real) basic wood density 422.4 kg/m3 from 450 kg/m3 as assumed in ecoinvent 2.2
	transport, freight, rail	RER	0	tkm	8.12E+1	1	2.09	(4,5,nA,nA,nA,nA,5)
	transport, freight, lorry, fleet average	RER	0	tkm	3.82E+1	1	2.09	(4,5,nA,nA,nA,nA,5)
	urea formaldehyde resin, at plant	RER	0	kg	1.20E+1	1	1.12	(1,4,2,3,1,1,3)
	wood chips, from industry, softwood, burned in furnace 300kW	CH	0	MJ	2.68E+3	1	1.12	(1,4,2,3,1,1,1)
	wood chips, softwood, wet, measured as dry mass, at sawmill	CH	0	kg	-1.43E+2	0		calculated
	wooden board manufacturing plant, organic bonded boards	RER	1	p	3.33E-8	1	3.36	(4,5,2,3,4,5,9)
	disposal, polyurethane, 0.2% water, to municipal incineration	CH	0	kg	9.74E-1	1	1.12	(1,4,2,3,1,1,2)
air, unspecified	Formaldehyde			kg	1.20E-2	1	2.81	(4,5,2,5,5,5,23)
	Heat, waste			MJ	4.63E+2	1	1.12	(1,4,2,3,1,1,13)

Tab. A.8.10: Life cycle inventory of present production production of 1 kg glued laminated timber, indoor use

Explanations	Name	Location	Infrastructure-Process	Unit	glued laminated timber, indoor use, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				m3			
Outputs	glued laminated timber, indoor use, at plant	CH	0	m3	1.00E+0			
Technosphere	diesel, burned in building machine, average	CH	0	MJ	3.36E+1	1	2.01	(1,4,2,3,1,1,5)
	electricity, medium voltage, at grid	CH	0	kWh	1.29E+2	1	1.12	(1,4,2,3,1,1,2)
	heat, light fuel oil, at industrial furnace 1MW	CH	0	MJ	2.30E+1	1	1.12	(1,4,2,3,1,1,1)
	sawnwood, board, softwood, raw, kiln dried (u=10%), at sawmill	CH	0	m3	1.37E+0	1	2.01	(1,4,2,3,1,1,5)
	softwood, allocation correction, 1	RER	0	m3	-4.90E-2	0		calculated correction term; adjusted to (real) basic wood density 422.4 kg/m3 from 450 kg/m3 as assumed in ecoinvent 2.2
	transport, freight, rail	RER	0	tkm	8.12E+1	1	2.09	(4,5,nA,nA,nA,nA,5)
	transport, freight, lorry, fleet average	RER	0	tkm	3.82E+1	1	2.09	(4,5,nA,nA,nA,nA,5)
	urea formaldehyde resin, at plant	RER	0	kg	1.20E+1	1	1.12	(1,4,2,3,1,1,3)
	wood chips, from industry, softwood, burned in furnace 300kW	CH	0	MJ	2.68E+3	1	1.12	(1,4,2,3,1,1,1)
	wood chips, softwood, wet, measured as dry mass, at sawmill	CH	0	kg	-1.43E+2	0		calculated
	wooden board manufacturing plant, organic bonded boards	RER	1	p	3.33E-8	1	3.36	(4,5,2,3,4,5,9)
	disposal, polyurethane, 0.2% water, to municipal incineration	CH	0	kg	9.74E-1	1	1.12	(1,4,2,3,1,1,2)
air, unspecified	Formaldehyde			kg	1.20E-2	1	2.81	(4,5,2,5,5,5,23)
	Heat, waste			MJ	4.63E+2	1	1.12	(1,4,2,3,1,1,13)

A.9 Manufacture of glass wool

Tab. A.9.1.: Life cycle inventory of future production of 1 kg glass wool

	Name	Location	Infrastructure Process	Unit	glass wool, market mix, at regional storage	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH			
	Infrastructure Process				0			
	Unit				kg			
product	glass wool, market mix, at regional storage	CH	0	kg	1			
raw materials	calcium nitrate, as N, at regional storehouse	RER	0	kg	8.90E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	manganese, at regional storage	RER	0	kg	6.43E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	chemicals organic, at plant	GLO	0	kg	3.05E-6	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	fluorspar, 97%, at plant	GLO	0	kg	7.03E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	formic acid, at plant	RER	0	kg	3.21E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	glass cullets, from fluorescent lamps treatment, at plant	GLO	0	kg	1.77E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	glass cullets, sorted, at sorting plant	RER	0	kg	7.52E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	maize starch, at plant	DE	0	kg	4.10E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	silicone product, at plant	RER	0	kg	6.73E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	soda, powder, at plant	RER	0	kg	1.72E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	sodium borates, at plant	US	0	kg	6.60E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	1.43E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	sodium phosphate, at plant	RER	0	kg	3.65E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	water, deionised, at plant	CH	0	kg	3.94E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
transports	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	4.25E-1	1	2.00	(1,1,1,1,1,1,BU:2); ;
	transport, transoceanic freight ship	OCE	0	tkm	6.59E-1	1	2.00	(1,1,1,1,1,1,BU:2); ;
	transport, freight, rail	DE	0	tkm	2.73E-3	1	2.00	(1,1,1,1,1,1,BU:2); ;
	transport, barge	RER	0	tkm	2.46E-2	1	2.00	(1,1,1,1,1,1,BU:2); ;
production Lucens (mat production)	tap water, at user	CH	0	kg	8.13E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	water, completely softened, at plant	RER	0	kg	8.83E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	heat, biogas, at boiler condensing modulating >100kW	RER	0	MJ	3.89E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	electricity, medium voltage, production from hydro power, at grid	CH	0	kWh	1.59E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	biogas, burned in boiler condensing modulating <100kW	RER	0	MJ	2.49E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	lubricating oil, at plant	RER	0	kg	5.96E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
emissions	Water, CH	-	-	kg	1.83E+0	1	1.50	(1,1,1,1,1,1,BU:1.5); ;
	Particulates, < 10 um	-	-	kg	9.09E-4	1	1.50	(1,1,1,1,1,1,BU:1.5); ;
	Nitrogen oxides	-	-	kg	2.96E-3	1	1.50	(1,1,1,1,1,1,BU:1.5); ;
	Carbon dioxide, fossil	-	-	kg	3.34E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Carbon monoxide, fossil	-	-	kg	9.67E-4	1	5.00	(1,1,1,1,1,1,BU:5); ;
disposal	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	6.29E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	0	kg	1.22E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.50E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
production Lucens (packaging)	vinyl acetate, at plant	RER	0	kg	1.66E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	corrugated board, mixed fibre, single wall, at plant	CH	0	kg	7.44E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	paper, woodcontaining, LWC, at plant	RER	0	kg	2.39E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	packaging film, LDPE, at plant	RER	0	kg	2.25E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	EUR-flat pallet	RER	0	unit	4.17E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	electricity, medium voltage, production from hydro power, at grid	CH	0	kWh	1.30E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	heat, biogas, at boiler condensing modulating >100kW	RER	0	MJ	3.26E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	2.11E-2	1	2.00	(1,1,1,1,1,1,BU:2); ;
infrastructure Lucens	refractory, fireclay, packed, at plant	DE	0	kg	8.61E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	rock wool plant	CH	1	unit	4.43E-10	1	3.00	(1,1,1,1,1,1,BU:3); ;
	molybdenum, at regional storage	RER	0	kg	1.65E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	iron-nickel-chromium alloy, at plant	RER	0	kg	7.32E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); ;

Tab. A.9.2.: Life cycle inventory of present production of 1 kg glass wool

	Name	Location	Infrastructure Process	Unit	glass wool, market mix, at regional storage	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH			
	Infrastructure Process				0			
	Unit				kg			
product	glass wool, market mix, at regional storage	CH	0	kg	1			
raw materials	calcium nitrate, as N, at regional storehouse	RER	0	kg	8.90E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	manganese, at regional storage	RER	0	kg	6.43E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	chemicals organic, at plant	GLO	0	kg	3.05E-6	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	fluorspar, 97%, at plant	GLO	0	kg	7.03E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	formic acid, at plant	RER	0	kg	3.21E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	glass cullets, from fluorescent lamps treatment, at plant	GLO	0	kg	1.77E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	glass cullets, sorted, at sorting plant	RER	0	kg	7.52E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	maize starch, at plant	DE	0	kg	4.10E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	silicone product, at plant	RER	0	kg	6.73E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	soda, powder, at plant	RER	0	kg	1.72E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	sodium borates, at plant	US	0	kg	6.60E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	1.43E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	sodium phosphate, at plant	RER	0	kg	3.65E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	water, deionised, at plant	CH	0	kg	3.94E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
transports	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	4.25E-1	1	2.00	(1,1,1,1,1,1,BU:2); ;
	transport, transoceanic freight ship	OCE	0	tkm	6.59E-1	1	2.00	(1,1,1,1,1,1,BU:2); ;
	transport, freight, rail	DE	0	tkm	2.73E-3	1	2.00	(1,1,1,1,1,1,BU:2); ;
	transport, barge	RER	0	tkm	2.46E-2	1	2.00	(1,1,1,1,1,1,BU:2); ;
production Lucens (mat production)	tap water, at user	CH	0	kg	8.13E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	water, completely softened, at plant	RER	0	kg	8.83E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	heat, natural gas, at boiler condensing modulating >100kW	RER	0	MJ	3.89E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	electricity, medium voltage, production from hydro power, at grid	CH	0	kWh	1.59E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	diesel, burned in building machine, average	CH	0	MJ	2.49E-2	1	2.00	(1,1,1,1,1,1,BU:2); ;
	lubricating oil, at plant	RER	0	kg	5.96E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
emissions	Water, CH	-	-	kg	1.83E+0	1	1.50	(1,1,1,1,1,1,BU:1.5); ;
	Particulates, < 10 um	-	-	kg	9.09E-4	1	1.50	(1,1,1,1,1,1,BU:1.5); ;
	Nitrogen oxides	-	-	kg	2.96E-3	1	1.50	(1,1,1,1,1,1,BU:1.5); ;
	Carbon dioxide, fossil	-	-	kg	3.34E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	Carbon monoxide, fossil	-	-	kg	9.67E-4	1	5.00	(1,1,1,1,1,1,BU:5); ;
disposal	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	6.29E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	0	kg	1.22E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.50E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
production Lucens (packaging)	vinyl acetate, at plant	RER	0	kg	1.66E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	corrugated board, mixed fibre, single wall, at plant	CH	0	kg	7.44E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	paper, woodcontaining, LWC, at plant	RER	0	kg	2.39E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	packaging film, LDPE, at plant	RER	0	kg	2.25E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	EUR-flat pallet	RER	0	unit	4.17E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	electricity, medium voltage, production from hydro power, at grid	CH	0	kWh	1.30E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	heat, natural gas, at boiler condensing modulating >100kW	RER	0	MJ	3.26E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	2.11E-2	1	2.00	(1,1,1,1,1,1,BU:2); ;
infrastructure Lucens	refractory, fireclay, packed, at plant	DE	0	kg	8.61E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	rock wool plant	CH	1	unit	4.43E-10	1	3.00	(1,1,1,1,1,1,BU:3); ;
	molybdenum, at regional storage	RER	0	kg	1.65E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	iron-nickel-chromium alloy, at plant	RER	0	kg	7.32E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); ;

A.10 Manufacture of rock wool

Tab. A.10.1.: Life cycle inventory of future production of 1 kg rock wool

Explanations	Name	Location	Infrastructure-Process	Unit	rock wool, Flumroc, at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				1			
	Unit				kg			
Technosphere	briquette, Flumroc, at plant	CH	0	kg	1.46E+0	1	1.24	(3,1,1,1,1,5,BU:1.05);
	acrylic dispersion, 65% in H2O, at plant	RER	0	kg	4.76E-3	1	1.24	(3,1,1,1,1,5,BU:1.05); div.
	aluminium, production mix, wrought alloy, at plant	RER	0	kg	5.14E-4	1	1.24	(3,1,1,1,1,5,BU:1.05);
	ammonia, liquid, at regional storehouse	CH	0	kg	6.55E-4	1	1.24	(3,1,1,1,1,5,BU:1.05);
	ammonium bicarbonate, at plant	RER	0	kg	1.47E-3	1	1.24	(3,1,1,1,1,5,BU:1.05);
	ethanol, burned in building machine	GLO	0	MJ	4.28E-2	1	1.24	(3,1,1,1,1,5,BU:1.05);
	electricity, medium voltage, at grid	CH	0	kWh	1.78E-1	1	1.24	(3,1,1,1,1,5,BU:1.05);
	formaldehyde, production mix, at plant	RER	0	kg	2.18E-2	1	1.24	(3,1,1,1,1,5,BU:1.05);
	glass wool mat, at plant	CH	0	kg	5.38E-4	1	1.24	(3,1,1,1,1,5,BU:1.05);
	biogas, burned in boiler condensing modulating	RER	0	MJ	5.45E+0	1	1.24	(3,1,1,1,1,5,BU:1.05); Koks,
	kraft paper, unbleached, at plant	RER	0	kg	2.56E-3	1	1.24	(3,1,1,1,1,5,BU:1.05);
	lime, hydrated, packed, at plant	CH	0	kg	1.17E-3	1	1.24	(3,1,1,1,1,5,BU:1.05);
	lubricating oil, at plant	RER	0	kg	2.25E-3	1	1.24	(3,1,1,1,1,5,BU:1.05);
	biogas, burned in boiler condensing modulating	RER	0	MJ	8.43E-1	1	1.24	(3,1,1,1,1,5,BU:1.05);
	oxygen, liquid, at plant	RER	0	kg	4.74E-5	1	1.24	(3,1,1,1,1,5,BU:1.05);
	phenol, at plant	RER	0	kg	2.11E-2	1	1.24	(3,1,1,1,1,5,BU:1.05);
	rock wool plant	CH	1	p	4.43E-10	1	3.06	(3,1,1,1,1,5,BU:3);
	sheet rolling, aluminium	RER	0	kg	5.14E-4	1	1.24	(3,1,1,1,1,5,BU:1.05);
	silane, at plant	RER	0	kg	1.94E-4	1	1.24	(3,1,1,1,1,5,BU:1.05); Silan;
	transport, freight, rail, electricity with shunting	CH	0	tkm	1.17E-1	1	2.10	(4,5,na,na,na,na,BU:2);
	transport, freight, lorry 16-32 metric ton, fleet	CH	0	tkm	3.26E-2	1	2.10	(4,5,na,na,na,na,BU:2);
	urea, as N, at regional storehouse	RER	0	kg	1.32E-3	1	1.24	(3,1,1,1,1,5,BU:1.05);
resource, in water	Water, well, in ground			m3	4.36E-3	1	1.24	(3,1,1,1,1,5,BU:1.05);
air, unspecified	Water, CH			kg	6.55E-1	1	1.58	(3,1,1,1,1,5,BU:1.5);
air, low population density	Ammonia			kg	5.54E-4	1	1.32	(3,1,1,1,1,5,BU:1.2);
	Cadmium			kg	9.11E-10	1	5.07	(3,1,2,1,1,5,BU:5);
	Carbon dioxide, fossil			kg	4.88E-2	1	1.24	(3,1,1,1,1,5,BU:1.05);
	Carbon monoxide, fossil			kg	0	1	5.07	(3,1,1,1,1,5,BU:5);
	Chromium			kg	0	1	5.07	(3,1,2,1,1,5,BU:5);
	Copper			kg	0	1	5.07	(3,1,2,1,1,5,BU:5); Kupfer,
	Formaldehyde			kg	9.37E-5	1	1.58	(3,1,1,1,1,5,BU:1.5);
	Heat, waste			MJ	5.12E+0	1	1.30	(4,1,1,1,1,5,BU:1.05);
	Hydrogen chloride			kg	0	1	1.58	(3,1,1,1,1,5,BU:1.5); gasf.
	Hydrogen fluoride			kg	0	1	1.58	(3,1,1,1,1,5,BU:1.5); gasf.
	Lead			kg	0	1	5.07	(3,1,2,1,1,5,BU:5); Blei;
	Nitrogen oxides			kg	6.67E-4	1	1.58	(3,1,1,1,1,5,BU:1.5);
	NMVOC, non-methane volatile organic			kg	0	1	1.58	(3,1,1,1,1,5,BU:1.5); flücht.
	Particulates, < 2.5 um			kg	3.01E-5	1	3.09	(4,1,1,1,1,5,BU:3); Feststoffe
	Particulates, > 10 um			kg	0	1	1.62	(4,1,1,1,1,5,BU:1.5);
	Particulates, > 2.5 um, and < 10um			kg	0	1	2.10	(4,1,1,1,1,5,BU:2); Feststoffe
	Phenol			kg	1.29E-4	1	1.58	(3,1,1,1,1,5,BU:1.5); Phenol;
	Sulfur dioxide			kg	1.94E-3	1	1.24	(3,1,1,1,1,5,BU:1.05);
	Zinc			kg	0	1	5.07	(3,1,2,1,1,5,BU:5); Zink;
water, river	Water			kg	3.35E+0	1	1.58	(3,1,1,1,1,5,BU:1.5); Abfluss
water, lake	Heat, waste			MJ	4.41E-2	1	1.24	(3,1,1,1,1,5,BU:1.05);
Outputs	rock wool, Flumroc, at plant	CH	1	kg	1.00E+0			

Tab. A.10.2.: Life cycle inventory of present production of 1 kg rock wool

Explanations	Name	Location	Infrastructure-Process	Unit	rock wool, Flumroc, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				1			
	Unit				kg			
Technosphere	briquette, Flumroc, at plant	CH	0	kg	1.46E+0	1	1.24	(3,1,1,1,1,5,BU:1.05); Briketts, als Rohstoff, extern hergestellt; Flumroc
	acrylic dispersion, 65% in H2O, at plant	RER	0	kg	4.76E-3	1	1.24	(3,1,1,1,1,5,BU:1.05); div. Konfektionsmaterial; Flumroc
	aluminium, production mix, wrought alloy, at plant	RER	0	kg	5.14E-4	1	1.24	(3,1,1,1,1,5,BU:1.05); Alufolie; Flumroc
	ammonia, liquid, at regional storehouse	CH	0	kg	6.55E-4	1	1.24	(3,1,1,1,1,5,BU:1.05); Ammoniak, in Zerfaserung; Flumroc
	ammonium bicarbonate, at plant	RER	0	kg	1.47E-3	1	1.24	(3,1,1,1,1,5,BU:1.05); Ammoniumbicarbonat, in Zerfaserung;
	diesel, burned in building machine, average	CH	0	MJ	4.28E-2	1	1.24	(3,1,1,1,1,5,BU:1.05); Dieselöl; ecoinvent assumption: 50% for internal transports
	electricity, medium voltage, certified electricity, at grid	CH	0	kWh	1.78E-1	1	1.24	(3,1,1,1,1,5,BU:1.05); elektrische Energie (60% Produktion, 40% Verpackung);
	formaldehyde, production mix, at plant	RER	0	kg	2.18E-2	1	1.24	(3,1,1,1,1,5,BU:1.05); Formaldehyd, in Zerfasern; Flumroc
	glass wool mat, at plant	CH	0	kg	5.38E-4	1	1.24	(3,1,1,1,1,5,BU:1.05); Glasfliess; Flumroc
	hard coal coke, at plant	RER	0	MJ	5.45E+0	1	1.24	(3,1,1,1,1,5,BU:1.05); Koks, in Schmelzen; Flumroc
	kraft paper, unbleached, at plant	RER	0	kg	2.56E-3	1	1.24	(3,1,1,1,1,5,BU:1.05); Kaschierungen; Flumroc
	lime, hydrated, packed, at plant	CH	0	kg	1.17E-3	1	1.24	(3,1,1,1,1,5,BU:1.05); Kalkhydrat, in Zerfasern; Flumroc
	lubricating oil, at plant	RER	0	kg	2.25E-3	1	1.24	(3,1,1,1,1,5,BU:1.05); Imprägnieröl, in Zerfasern; Flumroc
	natural gas, high pressure, at consumer	CH	0	MJ	8.43E-1	1	1.24	(3,1,1,1,1,5,BU:1.05); Erdgas (83% Produktion, 17% Verpackung); Flumroc
	oxygen, liquid, at plant	RER	0	kg	4.74E-5	1	1.24	(3,1,1,1,1,5,BU:1.05); Sauerstoff, in Schmelzen; Flumroc
	phenol, at plant	RER	0	kg	2.11E-2	1	1.24	(3,1,1,1,1,5,BU:1.05); Phenol, in Zerfasern; Flumroc
	rock wool plant	CH	1	p	4.43E-10	1	3.06	(3,1,1,1,1,5,BU:3); Infrastruktur; Flumroc
	sheet rolling, aluminium	RER	0	kg	5.14E-4	1	1.24	(3,1,1,1,1,5,BU:1.05); Alufolie; Flumroc
	silane, at plant	RER	0	kg	1.94E-4	1	1.24	(3,1,1,1,1,5,BU:1.05); Silan; Flumroc
	transport, freight, rail, electricity with shunting	CH	0	tkm	1.17E-1	1	2.10	(4,5,na,na,na,na,BU:2); Transport Materialien zu Flumroc; Flumroc, standard
	transport, freight, lorry 32-40 metric ton, fleet average	CH	0	tkm	3.26E-2	1	2.10	(4,5,na,na,na,na,BU:2); Transport Materialien zu Flumroc und
	urea, as N, at regional storehouse	RER	0	kg	1.32E-3	1	1.24	(3,1,1,1,1,5,BU:1.05); Harnstoff, in Zerfasern; Flumroc
resource, in water	Water, well			m3	4.36E-3	1	1.24	(3,1,1,1,1,5,BU:1.05); Betriebswasser; Flumroc
air, unspecified	Water, CH			kg	6.55E-1	1	1.58	(3,1,1,1,1,5,BU:1.5); Verdunstetes Wasser; Flumroc
air, low population density	Ammonia			kg	5.54E-4	1	1.32	(3,1,1,1,1,5,BU:1.2); Amoniak; Flumroc
	Cadmium			kg	9.52E-9	1	5.07	(3,1,2,1,1,5,BU:5); Cadmium, von Schmelzen; Flumroc
	Carbon dioxide, fossil			kg	6.14E-1	1	1.24	(3,1,1,1,1,5,BU:1.05); Kohlendioxid; Flumroc
	Carbon monoxide, fossil			kg	4.46E-5	1	5.07	(3,1,1,1,1,5,BU:5); Kohlenmonoxid, von Härten; Flumroc
	Chromium			kg	4.76E-9	1	5.07	(3,1,2,1,1,5,BU:5); Chromium, von Schmelzen; Flumroc
	Copper			kg	8.99E-9	1	5.07	(3,1,2,1,1,5,BU:5); Kupfer, von Schmelzen; Flumroc
	Formaldehyde			kg	9.42E-5	1	1.58	(3,1,1,1,1,5,BU:1.5); Formaldehyd, von Zerfasern; Flumroc
	Heat, waste			MJ	5.12E+0	1	1.30	(4,1,1,1,1,5,BU:1.05); Abwärme Produktion & Abwärme Stromverbrauch; Flumroc
	Hydrogen chloride			kg	1.81E-5	1	1.58	(3,1,1,1,1,5,BU:1.5); gasf. anorg. Chlorverb. (HCl); Flumroc
	Hydrogen fluoride			kg	9.73E-8	1	1.58	(3,1,1,1,1,5,BU:1.5); gasf. anorg. Fluorverb. (HF), von Schmelzen und Härten; Flumroc
	Lead			kg	5.92E-8	1	5.07	(3,1,2,1,1,5,BU:5); Blei; Flumroc
	Nitrogen oxides			kg	1.05E-3	1	1.58	(3,1,1,1,1,5,BU:1.5); Stickoxid; Flumroc
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	2.65E-6	1	1.58	(3,1,1,1,1,5,BU:1.5); flücht. org. Kohlenwasserst. (VOC), Phenol and
	Particulates, < 2.5 um			kg	5.75E-5	1	3.09	(4,1,1,1,1,5,BU:3); Feststoffe (Staub/Russ), 90% ; Flumroc, EPA
	Particulates, > 10 um			kg	3.83E-6	1	1.62	(4,1,1,1,1,5,BU:1.5); Feststoffe (Staub/Russ), 6%; Flumroc, EPA
	Particulates, > 2.5 um, and < 10um			kg	2.56E-6	1	2.10	(4,1,1,1,1,5,BU:2); Feststoffe (Staub/Russ), 4%; Flumroc, EPA
	Phenol			kg	1.30E-4	1	1.58	(3,1,1,1,1,5,BU:1.5); Phenol; Flumroc
	Sulfur dioxide			kg	4.33E-3	1	1.24	(3,1,1,1,1,5,BU:1.05); Schwefeldioxid; Flumroc
	Zinc			kg	2.54E-8	1	5.07	(3,1,2,1,1,5,BU:5); Zink; Flumroc
water, river	Water			kg	3.35E+0	1	1.58	(3,1,1,1,1,5,BU:1.5); Abfluss Wasser; Flumroc
water, lake	Heat, waste			MJ	4.41E-2	1	1.24	(3,1,1,1,1,5,BU:1.05); Abwärme Kühlwasser Seez; Flumroc
Outputs	rock wool, Flumroc, at plant	CH	1	kg	1.00E+0			

A.11 Manufacture of linoleum

Tab. A.11.1: Life cycle inventory of future production of 1 m^2 linoleum

Explanations	401	Input-Group	Output-Group	Name	Location	Infrastructure-Process	Unit	flooring, linoleum, at regional storage	uncertaintyType	StandardDeviation 95%
	662			Location				RER		
	493			InfrastructureProcess				0		
	403			Unit				m2		
Technosphere		5		transport, freight, rail	RER	0	tkm	1.52E-1	1	1.31
		5		transport, freight, lorry 32-40 metric ton, EURO 6	RER	0	tkm	2.27E+0	1	1.31
		5		saw dust, production mix, wet, measured as dry mass, at sawmill	RER	0	kg	1.02E+0	1	1.11
		5		limestone, milled, loose, at plant	CH	0	kg	5.76E-1	1	1.11
		5		titanium dioxide, production mix, at plant	RER	0	kg	9.46E-2	1	1.11
		5		electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	2.34E+0	1	1.11
		5		Linseed oil, at oil mill (WFLDB 3.1)	GLO	0	kg	8.00E-1	1	1.11
		5		acrylic dispersion, 65% in H2O, at plant	RER	0	kg	1.60E-2	1	1.20
		5		diesel, burned in building machine	GLO	0	MJ	0	1	1.11
		5		transport, transoceanic freight ship	OCE	0	tkm	1.90E+1	1	1.31
		5		sulphate pulp, average, at regional storage	RER	0	kg	0	1	1.11
		5		biogas, burned in boiler condensing modulating <100kW (Proj. 210)	RER	0	MJ	1.575E+1	1	1.11
		5		textile, jute, at plant	IN	0	kg	2.60E-1	1	1.11
		5		water, deionised, at plant	CH	0	kg	2.40E-2	1	1.11
		5		Pigments, paper production, unspecified, at plant	RER	0	kg	3.55E-3	1	1.20
		5		rosin size, in paper production, at plant	RER	0	kg	4.63E-1	1	1.20
		5		chemicals inorganic, at plant	GLO	0	kg	1.89E-2	1	1.20
		5		disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	1.80E-2	1	1.25
		5		disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	4.32E-1	1	1.25
resource, in water		4		Water, well, in ground			m3	8.00E-3	1	1.11
resource, land		4		Transformation, from unknown			m2	3.49E-4	1	1.25
		4		Occupation, industrial area, built up			m2a	1.74E-2	1	1.25
air, high population density			4	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	3.87E-4	1	1.11
Outputs			0	flooring, linoleum, at regional storage	RER	0	m2	1.00E+0		

Tab. A.11.2: Life cycle inventory of present production of 1 m^2 linoleum

Explanations	Name	Location	Infrastructure-Process	Unit	flooring, linoleum, at regional storage	uncertaintyType	StandardDeviation 95%
	Location				CH		
	InfrastructureProcess				0		
	Unit				m2		
Technosphere	transport, freight, rail	RER	0	tkm	1.52E-1	1	1.31
	transport, lorry >32t, EURO5	RER	0	tkm	2.27E+0	1	1.31
	raw cork, at forest road	RER	0	kg	1.38E+0	1	1.11
	limestone, milled, loose, at plant	CH	0	kg	5.50E-1	1	1.11
	titanium dioxide, production mix, at plant	RER	0	kg	1.52E-1	1	1.11
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	2.48E+0	1	1.11
	Linseed oil, at oil mill (WFLDB 3.1)	GLO	0	kg	6.26E-1	1	1.11
	acrylic dispersion, 65% in H2O, at plant	RER	0	kg	6.10E-2	1	1.20
	diesel, burned in building machine	GLO	0	MJ	2.50E-2	1	1.11
	transport, transoceanic freight ship	OCE	0	tkm	1.90E+1	1	1.31
	sulphate pulp, average, at regional storage	RER	0	kg	2.13E-1	1	1.11
	natural gas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	2.31E+1	1	1.11
	textile, jute, at plant	IN	0	kg	2.02E-1	1	1.11
	tap water, at user	RER	0	kg	1.21E+0	1	1.11
	kaolin, at plant	RER	0	kg	1.90E-2	1	1.20
	polyols, at plant	RER	0	kg	2.50E-2	1	1.20
	methylene diphenyl diisocyanate, at plant	RER	0	kg	2.50E-2	1	1.20
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	1.60E-2	1	1.25
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	3.84E-1	1	1.25
resource, in water	Water, well, in ground			m3	8.00E-3	1	1.11
resource, land	Transformation, from unknown			m2	3.49E-4	1	1.25
	Occupation, industrial area, built up			m2a	1.74E-2	1	1.25
air, high population density	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	3.87E-4	1	1.11
Outputs	flooring, linoleum, at regional storage	CH	0	m2	1.00E+0		

A.12 Manufacture of plastic materials

Tab. A.12.11.: Life cycle inventory of future production of 1 kg polystyrene, extruded

Explanations	Name	Location	Infrastructure-Process	Unit	polystyrene, extruded (XPS), at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	polystyrene, extruded (XPS), HFC-134a blown, at plant	RER	0	kg	0	1	1.40	(4,4,4,3,1,5,3)
	polystyrene, extruded (XPS), HFC-152a blown, at plant	RER	0	kg	0	1	1.40	(4,4,4,3,1,5,3)
	polystyrene, extruded (XPS) CO2 blown, at plant	RER	0	kg	1.00E+0	1	1.40	(4,4,4,3,1,5,3)
Outputs	polystyrene, extruded (XPS), at plant	RER	0	kg	1.00E+0			

Tab. A.12.12.: Life cycle inventory of present production of 1 kg polystyrene, extruded

Explanations	Name	Location	Infrastructure-Process	Unit	polystyrene, extruded (XPS), at plant	uncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	polystyrene, extruded (XPS), HFC-134a blown, at plant	RER	0	kg	2.50E-1	1	1.40	(4,4,4,3,1,5,3)
	polystyrene, extruded (XPS), HFC-152a blown, at plant	RER	0	kg	2.50E-1	1	1.40	(4,4,4,3,1,5,3)
	polystyrene, extruded (XPS) CO2 blown, at plant	RER	0	kg	5.00E-1	1	1.40	(4,4,4,3,1,5,3)
Outputs	polystyrene, extruded (XPS), at plant	RER	0	kg	1.00E+0			

Tab. A.12.13.: Life cycle inventory of future production of 1 kg PLA

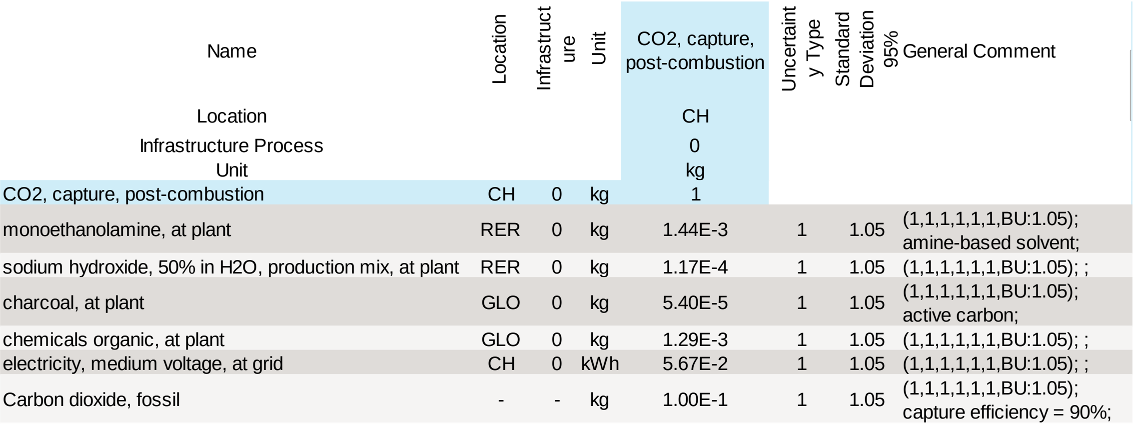
Explanations	Name	Location	Infrastructure-Process	Unit	polylactide, granulate, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	electricity, low voltage, production ENTSO, at grid	ENTSO	0	kWh	1.83E+0	1	1.24	(2,2,1,5,1,5); 0
	natural gas, at long-distance pipeline	RER	0	m3	3.60E-3	1	1.24	(2,2,1,5,1,5); 0
	naphtha, at refinery	RER	0	kg	7.00E-3	1	1.24	(2,2,1,5,1,5); 0
	transport, freight, lorry, fleet average	RER	0	tkm	2.00E-1	1	2.06	(2,2,1,5,1,5); 0
	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	1.85E+1	1	1.24	(2,2,1,5,1,5); 0
	biogas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	1.59E-1	1	1.24	(2,2,1,5,1,5); 0
	chemical plant, organics	RER	1	p	4.00E-10	1	3.28	(5,2,1,5,1,5); 0
	corn, at farm	US	0	kg	1.51E+0	1	1.24	(1,2,1,5,1,5); 0
	treatment, maize starch production effluent, to wastewater treatment, class 2	CH	0	m3	3.20E-3	1	1.24	(2,2,1,5,1,5); 0
	disposal, plastics, mixture, 15.3% water, to sanitary landfill	CH	0	kg	1.00E-3	1	1.09	(2,2,1,1,1,3);
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	6.40E-3	1	1.09	(2,2,1,1,1,3);
air, low population density	Heat, waste			MJ	6.58E+0	1	1.24	(2,2,1,5,1,5); 0
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	2.52E-3	1	1.58	(1,2,1,5,1,5); 0
Outputs	polylactide, granulate, at plant	GLO	0	kg	1.00E+0			

Tab. A.12.14.: Life cycle inventory of present production of 1 kg PLA

Explanations	Name	Location	Infrastructure-Process	Unit	polylactide, granulate, at plant	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				kg			
Technosphere	electricity, low voltage, production ENTSO, at grid	ENTSO	0	kWh	1.83E+0	1	1.24	(2,2,1,5,1,5); 0
	natural gas, at long-distance pipeline	RER	0	m3	3.60E-3	1	1.24	(2,2,1,5,1,5); 0
	naphtha, at refinery	RER	0	kg	7.00E-3	1	1.24	(2,2,1,5,1,5); 0
	transport, freight, lorry, fleet average	RER	0	tkm	2.00E-1	1	2.06	(2,2,1,5,1,5); 0
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	1.85E+1	1	1.24	(2,2,1,5,1,5); 0
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	1.59E-1	1	1.24	(2,2,1,5,1,5); 0
	chemical plant, organics	RER	1	p	4.00E-10	1	3.28	(5,2,1,5,1,5); 0
	corn, at farm	US	0	kg	1.51E+0	1	1.24	(1,2,1,5,1,5); 0
	treatment, maize starch production effluent, to wastewater treatment, class 2	CH	0	m3	3.20E-3	1	1.24	(2,2,1,5,1,5); 0
	disposal, plastics, mixture, 15.3% water, to sanitary landfill	CH	0	kg	1.00E-3	1	1.09	(2,2,1,1,1,3);
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	6.40E-3	1	1.09	(2,2,1,1,1,3);
air, low population density	Heat, waste			MJ	6.58E+0	1	1.24	(2,2,1,5,1,5); 0
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	2.52E-3	1	1.58	(1,2,1,5,1,5); 0
Outputs	polylactide, granulate, at plant	GLO	0	kg	1.00E+0			

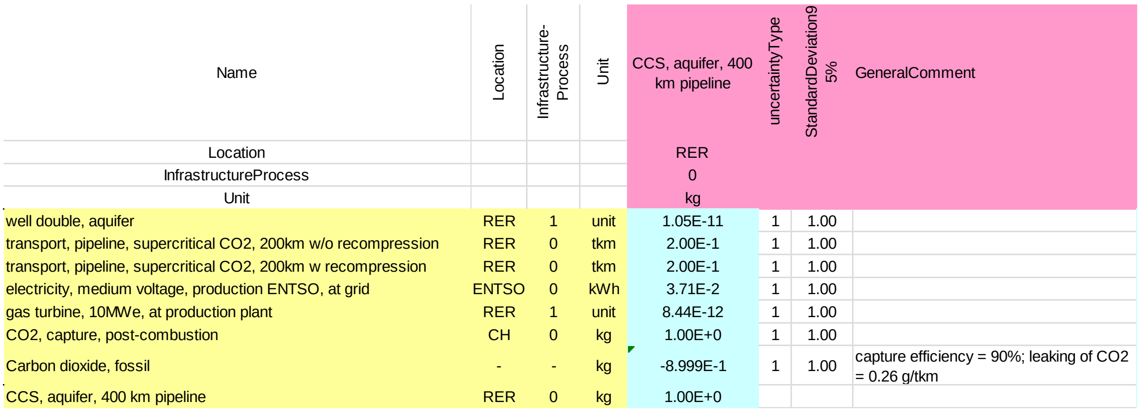
B Life cycle inventories of carbon capture and storage

Tab. B.1 Life cycle inventory of 1 kg CO_2 captured post combustion



Name	Location	Infrastructure	Unit	CO2, capture, post-combustion	Uncertainty Type	Standard Deviation 95%	General Comment
Location				CH			
Infrastructure Process				0			
Unit				kg			
CO2, capture, post-combustion	CH	0	kg	1			
monoethanolamine, at plant	RER	0	kg	1.44E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); amine-based solvent;
sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	1.17E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
charcoal, at plant	GLO	0	kg	5.40E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); active carbon;
chemicals organic, at plant	GLO	0	kg	1.29E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
electricity, medium voltage, at grid	CH	0	kWh	5.67E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
Carbon dioxide, fossil	-	-	kg	1.00E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); capture efficiency = 90%;

Tab. B.2 Life cycle inventory of 1 kg CO_2 captured, transported over 400 km and stored in aquifer



Name	Location	Infrastructure-Process	Unit	CCS, aquifer, 400 km pipeline	uncertaintyType	StandardDeviation95%	GeneralComment
Location				RER			
InfrastructureProcess				0			
Unit				kg			
well double, aquifer	RER	1	unit	1.05E-11	1	1.00	
transport, pipeline, supercritical CO2, 200km w/o recompression	RER	0	tkm	2.00E-1	1	1.00	
transport, pipeline, supercritical CO2, 200km w recompression	RER	0	tkm	2.00E-1	1	1.00	
electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	3.71E-2	1	1.00	
gas turbine, 10MWe, at production plant	RER	1	unit	8.44E-12	1	1.00	
CO2, capture, post-combustion	CH	0	kg	1.00E+0	1	1.00	
Carbon dioxide, fossil	-	-	kg	-8.999E-1	1	1.00	capture efficiency = 90%; leaking of CO2 = 0.26 g/tkm
CCS, aquifer, 400 km pipeline	RER	0	kg	1.00E+0			

C Life cycle inventories of fuel and electricity supply

Tab. C.1 Life cycle inventory of 1 kWh future Swiss electricity supply mix, at busbar

InputGroup	OutputGroup	Name	Location	Unit	electricity mix	UncertaintyType	StandardDeviation95%
		Location			CH		
		InfrastructureProcess			0		
		Unit			kWh		
-	0	electricity mix	CH	kWh	1.00E+0		
5	-	electricity, hydropower, at run-of-river power plant	CH	kWh	1.82E-1	1	1.57
5	-	electricity, hydropower, net, at reservoir power plant	CH	kWh	2.68E-1	1	1.57
5	-	electricity, hydropower, at small hydropower plant	CH	kWh	6.29E-2	1	1.57
5	-	electricity, hydropower, at pumped storage power plant	CH	kWh	8.11E-2	1	1.57
5	-	electricity, production mix photovoltaic, at plant	CH	kWh	1.50E-1	1	2.28
5	-	electricity, at wind power plant	CH	kWh	5.73E-2	1	1.62
5	-	electricity, at cogen 6400kWth, wood, allocation exergy	CH	kWh	1.67E-2	1	1.57
5	-	electricity, at cogen, biogas agricultural mix, allocation exergy	CH	kWh	1.17E-2	1	1.57
5	-	electricity, at cogen with biogas engine, allocation exergy	CH	kWh	9.53E-3	1	1.57
5	-	electricity, at wind power plant	RER	kWh	5.90E-2	1	2.28
5	-	electricity, nuclear, at power plant pressure water reactor	CH	kWh	0	1	1.57
5	-	electricity, nuclear, at power plant boiling water reactor	CH	kWh	0	1	1.57
5	-	electricity, at cogen 200kWe diesel SCR, allocation exergy	CH	kWh	3.21E-3	1	1.57
5		electricity, natural gas, at combined cycle plant, best technology	RER	kWh	0	1	1.57
5	-	electricity, at cogen 500kWe lean burn, allocation exergy	CH	kWh	2.53E-2	1	1.57
5	-	electricity from waste, at municipal waste incineration plant	CH	kWh	3.98E-2	1	1.57
5	-	electricity, production mix ENTSO	ENTSO	kWh	3.44E-2	1	1.57

Tab. C.2 Life cycle inventory of 1 kWh future European electricity mix, at busbar

	Name	Location	Unit	electricity, production mix ENTSO	UncertaintyType	StandardDeviation95%
	Location			ENTSO		
	InfrastructureProcess					
	Unit			kWh		
product	electricity, production mix ENTSO	ENTSO	kWh	1.00E+0		
technosphere	electricity, hydropower, at run-of-river power plant	RER	kWh	0.137	1	1.07
	electricity, hydropower, at reservoir power plant, non alpine regions	RER	kWh	0.026	1	1.07
	electricity, production mix photovoltaic, at plant	DE	kWh	0.093	1	1.07
	electricity, at wind power plant	RER	kWh	0.310	1	1.07
	electricity, at cogen 6400kWth, wood, allocation exergy	CH	kWh	0.016	1	1.07
	electricity, at cogen with biogas engine, agricultural covered, alloc. exergy	CH	kWh	0.005	1	1.07
	electricity, at cogen with biogas engine, methane 96%-vol allocation exergy	CH	kWh	0.012	1	1.07
	electricity from waste, at municipal waste incineration plant	CH	kWh	0.051	1	1.07
	electricity, at wind power plant	RER	kWh	0.009	1	1.07
	electricity, production mix photovoltaic, at plant	DE	kWh	0.009	1	1.07
	electricity, at wind power plant	RER	kWh	0.007	1	1.07
	electricity, nuclear, at power plant pressure water reactor	FR	kWh	0.196	1	1.07
	electricity, oil, at power plant	IT	kWh	0.002	1	1.07
	electricity, natural gas, at power plant	UCTE	kWh	0.112	1	1.07
	electricity, hard coal, at power plant	DE	kWh	0.013	1	1.07

Tab. C.3 Life cycle inventory of 1 kWh future South American electricity mix, at busbar

InputGroup	OutputGroup	Name	Location	Unit	electricity mix	UncertaintyType	StandardDeviation95%
		Location			RLA		
		InfrastructureProcess					
		Unit			kWh		
-	0	electricity mix	RLA	kWh	1.00E+0		
5	-	electricity, hydropower, at run-of-river power plant	RER	kWh	0.507	1	1.07
5	-	electricity, hydropower, at reservoir power plant, non alpine regions	RER	kWh	0.097	1	1.07
5	-	electricity, production mix photovoltaic, at plant	DE	kWh	0.062	1	1.07
5	-	electricity, at wind power plant	RER	kWh	0.134	1	1.07
5	-	electricity, at cogen 6400kWth, wood, allocation exergy	CH	kWh	0.013	1	1.07
5	-	electricity, at cogen with biogas engine, agricultural covered, alloc. exergy	CH	kWh	0.004	1	1.07
5	-	electricity, at cogen with biogas engine, methane 96%-vol allocation exergy	CH	kWh	0.010	1	1.07
5	-	electricity from waste, at municipal waste incineration plant	CH	kWh	0.041	1	1.07
5	-	electricity, at wind power plant	RER	kWh	0.015	1	1.07
5	-	electricity, production mix photovoltaic, at plant	DE	kWh	0.009	1	1.07
5	-	electricity, at wind power plant	RER	kWh	0.001	1	1.07
5	-	electricity, nuclear, at power plant pressure water reactor	FR	kWh	0.038	1	1.07
5	-	electricity, oil, at power plant	IT	kWh	0.006	1	1.07
5	-	electricity, natural gas, at power plant	UCTE	kWh	0.061	1	1.07
5	-	electricity, hard coal, at power plant	DE	kWh	0.003	1	1.07

Tab. C.4 Life cycle inventory of 1 kWh future Chinese electricity mix, at busbar

Name	Location	Unit	electricity mix	UncertaintyType	StandardDeviation95%
Location			CN		
InfrastructureProcess					
Unit			kWh		
electricity mix	CN	kWh	1.00E+0		
electricity, hydropower, at run-of-river power plant	RER	kWh	0.146	1	1.07
electricity, hydropower, at reservoir power plant, non alpine regions	RER	kWh	0.028	1	1.07
electricity, production mix photovoltaic, at plant	DE	kWh	0.214	1	1.07
electricity, at wind power plant	RER	kWh	0.208	1	1.07
electricity, at cogen 6400kWth, wood, allocation exergy	CH	kWh	0.010	1	1.07
electricity, at cogen with biogas engine, agricultural covered, alloc. exergy	CH	kWh	0.003	1	1.07
electricity, at cogen with biogas engine, methane 96%-vol allocation exergy	CH	kWh	0.007	1	1.07
electricity from waste, at municipal waste incineration plant	CH	kWh	0.030	1	1.07
electricity, at wind power plant	RER	kWh	0.002	1	1.07
electricity, production mix photovoltaic, at plant	DE	kWh	0.017	1	1.07
electricity, at wind power plant	RER	kWh	0.000	1	1.07
electricity, nuclear, at power plant pressure water reactor	FR	kWh	0.149	1	1.07
electricity, oil, at power plant	IT	kWh	0.000	1	1.07
electricity, natural gas, at power plant	UCTE	kWh	0.070	1	1.07
electricity, hard coal, at power plant	DE	kWh	0.115	1	1.07

Tab. C.5 Life cycle inventory of 1 kWh future global electricity mix, at busbar

Name	Location	Unit	electricity, production mix GLO	UncertaintyType	StandardDeviation95%
Location			GLO		
InfrastructureProcess					
Unit			kWh		
electricity, production mix GLO	GLO	kWh	1.00E+0		
electricity, hydropower, at run-of-river power plant	RER	kWh	15.83%	1	1.07
electricity, hydropower, at reservoir power plant, non alpine regions	RER	kWh	3.02%	1	1.07
electricity, production mix photovoltaic, at plant	DE	kWh	17.28%	1	1.07
electricity, at wind power plant	RER	kWh	20.85%	1	1.07
electricity, at cogen 6400kWth, wood, allocation exergy	CH	kWh	1.02%	1	1.07
electricity, at cogen with biogas engine, agricultural covered, alloc. exergy	CH	kWh	0.33%	1	1.07
electricity, at cogen with biogas engine, methane 96%-vol allocation exergy	CH	kWh	0.75%	1	1.07
electricity from waste, at municipal waste incineration plant	CH	kWh	3.20%	1	1.07
electricity, at wind power plant	RER	kWh	1.50%	1	1.07
electricity, production mix photovoltaic, at plant	DE	kWh	2.31%	1	1.07
electricity, at wind power plant	RER	kWh	0.21%	1	1.07
electricity, nuclear, at power plant pressure water reactor	FR	kWh	13.38%	1	1.07
electricity, oil, at power plant	IT	kWh	0.53%	1	1.07
electricity, natural gas, at power plant	UCTE	kWh	14.45%	1	1.07
electricity, hard coal, at power plant	DE	kWh	5.34%	1	1.07

D Life cycle inventories of transport services

D.1 Lorry transport

Tab. D.1.1 Life cycle inventories of 1 tkm transport with a future ethanol-powered and electric lorry 3.5-7.5t

Explanations	Name	Location	Infrastructure-Process	Unit	transport, freight, lorry 3.5-7.5 metric ton, EURO 6	transport, freight, e-lorry 3.5-7.5 metric ton
	Location				RER	RER
	InfrastructureProcess				0	0
	Unit				tkm	tkm
Technosphere	lorry 16t	RER	1	p	1.88E-6	1.88E-6
	maintenance, lorry 16t	CH	1	p	1.88E-6	1.88E-6
	road	CH	1	my	2.89E-3	2.89E-3
	operation, maintenance, road	CH	1	my	1.20E-3	1.20E-3
	Ethanol, 99.7% in H2O, from wood, at service station	RER	0	kg	1.67E-1	
	electricity, low voltage, production ENTSO, at grid	ENTSO	0	kWh		5.65E-1
	Battery, Lilo, rechargeable, prismatic, at plant	GLO	0	kg		1.13E+3
	Electric motor, electric vehicle, at plant	RER	0	kg		5.29E-4
	refrigerant R134a, at plant	RER	0	kg	1.76E-6	1.76E-6
	brake wear emissions, lorry	RER	0	kg	4.13E-5	4.13E-5
	road wear emissions, lorry	RER	0	kg	3.56E-5	3.56E-5
	tyre wear emissions, lorry	RER	0	kg	4.10E-4	4.10E-4
	disposal, lorry 16t	CH	1	p	1.88E-6	1.88E-6
	disposal, road	RER	1	my	2.89E-3	2.89E-3
air, unspecified	Carbon dioxide, biogenic			kg	3.48E-1	0
	Carbon monoxide, biogenic			kg	2.45E-4	0
	Methane, biogenic			kg	2.05E-7	0
	NMVOC, non-methane volatile organic compounds,			kg	6.77E-6	0
	Ethane			kg	3.00E-9	0
	Propane			kg	9.99E-9	0
	Butane			kg	1.50E-8	0
	Pentane			kg	6.00E-9	0
	Heptane			kg	3.00E-8	0
	Benzene			kg	7.00E-9	0
	Toluene			kg	9.99E-10	0
	m-Xylene			kg	9.79E-8	0
	o-Xylene			kg	4.00E-8	0
	Formaldehyde			kg	7.00E-7	0
	Acetaldehyde			kg	3.81E-7	0
	Benzaldehyde			kg	1.14E-7	0
	Acrolein			kg	1.47E-7	0
	Styrene			kg	4.66E-8	0
	Nitrogen oxides			kg	1.14E-4	0
	Ammonia			kg	3.05E-6	0
	Dinitrogen monoxide			kg	1.60E-5	0
	Sulfur dioxide			kg	0	0
	Particulates, < 2.5 um			kg	1.36E-8	0
	PAH, polycyclic aromatic hydrocarbons			kg	8.57E-9	0
	Arsenic			kg	1.10E-11	0
	Selenium			kg	1.10E-11	0
	Zinc			kg	0	0
	Copper			kg	0	0
	Nickel			kg	0	0
	Chromium			kg	0	0
	Chromium VI			kg	0	0
	Cadmium			kg	0	0
	Mercury			kg	0	0
	Lead			kg	0	0
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a			kg	1.76E-6	1.76E-6
non-material, unspecified	Noise, road, lorry, average			km	1.02E+0	1.02E+0
Outputs	transport, freight, lorry 3.5-7.5 metric ton, EURO 6	RER	0	tkm	1.00E+0	
	transport, freight, e-lorry 3.5-7.5 metric ton	RER	0	tkm		1.00E+0

Tab. D.1.2 Life cycle inventories of 1 tkm transport with a future ethanol-powered and electric lorry 7.5-16t

Explanations	Name	Location	Infrastructure-Process	Unit	transport, freight, lorry 7.5-16 metric ton, EURO 6	transport, freight, e-lorry 7.5-16 metric ton
	Location				RER	RER
	InfrastructureProcess				0	0
	Unit				tkm	tkm
Technosphere	lorry 16t	RER	1	p	5.63E-7	5.63E-7
	maintenance, lorry 16t	CH	1	p	5.63E-7	5.63E-7
	road	CH	1	my	1.56E-3	1.56E-3
	operation, maintenance, road	CH	1	my	3.58E-4	3.58E-4
	Ethanol, 99.7% in H2O, from wood, at service station	RER	0	kg	7.19E-2	
	electricity, low voltage, production ENTSO, at grid	ENTSO	0	kWh		2.43E-1
	Battery, LiIo, rechargeable, prismatic, at plant	GLO	0	kg		2.17E+3
	Electric motor, electric vehicle, at plant	RER	0	kg		1.58E-4
	refrigerant R134a, at plant	RER	0	kg	5.27E-7	5.27E-7
	brake wear emissions, lorry	RER	0	kg	1.30E-5	1.30E-5
	road wear emissions, lorry	RER	0	kg	1.12E-5	1.12E-5
	tyre wear emissions, lorry	RER	0	kg	1.29E-4	1.29E-4
	disposal, lorry 16t	CH	1	p	5.63E-7	5.63E-7
	disposal, road	RER	1	my	1.56E-3	1.56E-3
air, unspecified	Carbon dioxide, biogenic			kg	1.49E-1	0
	Carbon monoxide, biogenic			kg	1.14E-4	0
	Methane, biogenic			kg	9.42E-8	0
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	3.11E-6	0
	Ethane			kg	1.38E-9	0
	Propane			kg	4.60E-9	0
	Butane			kg	6.90E-9	0
	Pentane			kg	2.76E-9	0
	Heptane			kg	1.38E-8	0
	Benzene			kg	3.22E-9	0
	Toluene			kg	4.60E-10	0
	m-Xylene			kg	4.51E-8	0
	o-Xylene			kg	1.84E-8	0
	Formaldehyde			kg	3.22E-7	0
	Acetaldehyde			kg	1.75E-7	0
	Benzaldehyde			kg	5.25E-8	0
	Acrolein			kg	6.78E-8	0
	Styrene			kg	2.15E-8	0
	Nitrogen oxides			kg	5.74E-5	0
	Ammonia			kg	9.13E-7	0
	Dinitrogen monoxide			kg	7.85E-6	0
	Sulfur dioxide			kg	0	0
	Particulates, < 2.5 um			kg	5.99E-9	0
	PAH, polycyclic aromatic hydrocarbons			kg	3.69E-9	0
	Arsenic			kg	4.72E-12	0
	Selenium			kg	4.72E-12	0
	Zinc			kg	0	0
	Copper			kg	0	0
	Nickel			kg	0	0
	Chromium			kg	0	0
	Chromium VI			kg	0	0
	Cadmium			kg	0	0
	Mercury			kg	0	0
	Lead			kg	0	0
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a			kg	5.27E-7	5.27E-7
non-material, unspecified	Noise, road, lorry, average			km	3.04E-1	3.04E-1
Outputs	transport, freight, lorry 7.5-16 metric ton, EURO 6	RER	0	tkm	1.00E+0	
	transport, freight, e-lorry 7.5-16 metric ton	RER	0	tkm		1.00E+0

Tab. D.1.3 Life cycle inventories of 1 tkm transport with a future ethanol-powered and electric lorry 16-32t

Explanations	Name	Location	Infrastructure-Process	Unit	transport, freight, lorry 16-32 metric ton, EURO 6	transport, freight, e-lorry 16-32 metric ton
	Location				RER	RER
	InfrastructureProcess				0	0
	Unit				tkm	tkm
Technosphere	lorry 28t	RER	1	p	3.20E-7	3.20E-7
	maintenance, lorry 28t	CH	1	p	3.20E-7	3.20E-7
	road	CH	1	my	1.29E-3	1.29E-3
	operation, maintenance, road	CH	1	my	2.03E-4	2.03E-4
	Ethanol, 99.7% in H2O, from wood, at service station	RER	0	kg	5.58E-2	
	electricity, low voltage, production ENTSO, at grid	ENTSO	0	kWh		2.12E-1
	Battery, LiIo, rechargeable, prismatic, at plant	GLO	0	kg		4.16E+3
	Electric motor, electric vehicle, at plant	RER	0	kg		8.96E-5
	refrigerant R134a, at plant	RER	0	kg	2.99E-7	2.99E-7
	brake wear emissions, lorry	RER	0	kg	3.90E-5	3.90E-5
	road wear emissions, lorry	RER	0	kg	3.36E-5	3.36E-5
	tyre wear emissions, lorry	RER	0	kg	3.86E-4	3.86E-4
	disposal, lorry 28t	CH	1	p	3.20E-7	3.20E-7
	disposal, road	RER	1	my	1.29E-3	1.29E-3
air, unspecified	Carbon dioxide, biogenic			kg	1.15E-1	0
	Carbon monoxide, biogenic			kg	1.01E-4	0
	Methane, biogenic			kg	8.11E-8	0
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	2.68E-6	0
	Ethane			kg	1.19E-9	0
	Propane			kg	3.96E-9	0
	Butane			kg	5.93E-9	0
	Pentane			kg	2.37E-9	0
	Heptane			kg	1.19E-8	0
	Benzene			kg	2.77E-9	0
	Toluene			kg	3.96E-10	0
	m-Xylene			kg	3.88E-8	0
	o-Xylene			kg	1.58E-8	0
	Formaldehyde			kg	2.77E-7	0
	Acetaldehyde			kg	1.51E-7	0
	Benzaldehyde			kg	4.52E-8	0
	Acrolein			kg	5.83E-8	0
	Styrene			kg	1.85E-8	0
	Nitrogen oxides			kg	4.70E-5	0
	Ammonia			kg	5.18E-7	0
	Dinitrogen monoxide			kg	6.14E-6	0
	Sulfur dioxide			kg	0	0
	Particulates, < 2.5 um			kg	4.94E-9	0
	PAH, polycyclic aromatic hydrocarbons			kg	2.87E-9	0
	Arsenic			kg	3.66E-12	0
	Selenium			kg	3.66E-12	0
	Zinc			kg	0	0
	Copper			kg	0	0
	Nickel			kg	0	0
	Chromium			kg	0	0
	Chromium VI			kg	0	0
	Mercury			kg	0	0
	Cadmium			kg	0	0
	Lead			kg	0	0
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a			kg	2.99E-7	2.99E-7
non-material, unspecified	Noise, road, lorry, average			km	1.73E-1	1.73E-1
Outputs	transport, freight, lorry 16-32 metric ton, EURO 6	RER	0	tkm	1.00E+0	
	transport, freight, e-lorry 16-32 metric ton	RER	0	tkm		1.00E+0

Tab. D.1.4 Life cycle inventories of 1 tkm transport with a future ethanol-powered and electric lorry 32-40t

Explanations	Name	Location	Infrastructure-Process	Unit	transport, freight, lorry 32-40 metric ton, EURO 6	transport, freight, e-lorry 32-40 metric ton
	Location				RER	RER
	InfrastructureProcess				0	0
	Unit				tkm	tkm
Technosphere	lorry 40t	RER	1	p	1.60E-7	1.59E-7
	maintenance, lorry 40t	CH	1	p	1.60E-7	1.59E-7
	road	CH	1	my	1.17E-3	1.17E-3
	operation, maintenance, road	CH	1	my	1.01E-4	1.01E-4
	Ethanol, 99.7% in H2O, from wood, at service station	RER	0	kg	3.47E-2	
	electricity, low voltage, production ENTSO, at grid	ENTSO	0	kWh		1.29E-1
	Battery, LiIo, rechargeable, prismatic, at plant	GLO	0	kg		6.11E+3
	Electric motor, electric vehicle, at plant	RER	0	kg		4.47E-5
	refrigerant R134a, at plant	RER	0	kg	1.49E-7	1.49E-7
	road wear emissions, lorry	RER	0	kg	1.73E-5	1.73E-5
	tyre wear emissions, lorry	RER	0	kg	1.99E-4	1.99E-4
	brake wear emissions, lorry	RER	0	kg	2.00E-5	2.00E-5
	disposal, lorry 40t	CH	1	p	1.60E-7	1.60E-7
	disposal, road	RER	1	my	1.17E-3	1.17E-3
air, unspecified	Carbon dioxide, biogenic			kg	7.23E-2	0
	Carbon monoxide, biogenic			kg	9.62E-6	0
	Methane, biogenic			kg	5.46E-8	0
	NMVOC, non-methane volatile organic compounds, unspecified origin			kg	1.80E-6	0
	Ethane			kg	7.99E-10	0
	Propane			kg	2.66E-9	0
	Butane			kg	3.99E-9	0
	Pentane			kg	1.60E-9	0
	Heptane			kg	7.99E-9	0
	Benzene			kg	1.86E-9	0
	Toluene			kg	2.66E-10	0
	m-Xylene			kg	2.61E-8	0
	o-Xylene			kg	1.07E-8	0
	Formaldehyde			kg	1.86E-7	0
	Acetaldehyde			kg	1.01E-7	0
	Benzaldehyde			kg	3.04E-8	0
	Acrolein			kg	3.93E-8	0
	Styrene			kg	1.24E-8	0
	Nitrogen oxides			kg	2.49E-5	0
	Ammonia			kg	2.58E-7	0
	Dinitrogen monoxide			kg	4.38E-6	0
	Sulfur dioxide			kg	0	0
	Particulates, < 2.5 um			kg	3.17E-9	0
	PAH, polycyclic aromatic hydrocarbons			kg	1.78E-9	0
	Arsenic			kg	2.28E-12	0
	Selenium			kg	2.28E-12	0
	Zinc			kg	0	0
	Copper			kg	0	0
	Nickel			kg	0	0
	Chromium			kg	0	0
	Chromium VI			kg	0	0
	Mercury			kg	0	0
	Cadmium			kg	0	0
	Lead			kg	0	0
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a			kg	1.49E-7	1.49E-7
non-material, unspecified	Noise, road, lorry, average			km	8.61E-2	8.61E-2
Outputs	transport, freight, lorry 32-40 metric ton, EURO 6	RER	0	tkm	1.00E+0	
	transport, freight, e-lorry 32-40 metric ton	RER	0	tkm		1.00E+0

Tab. D.1.5 Life cycle inventory of 1 tkm transport with a future lorry, fleet average Europe

Explanations	Name	Location	Infrastructure-Process	Unit	transport, freight, lorry, fleet average	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				tkm			
Technosphere	transport, freight, lorry 3.5-7.5 metric ton, EURO 3	RER	0	tkm				
	transport, freight, lorry 3.5-7.5 metric ton, EURO 4	RER	0	tkm				
	transport, freight, lorry 3.5-7.5 metric ton, EURO 5	RER	0	tkm				
	transport, freight, lorry 3.5-7.5 metric ton, EURO 6	RER	0	tkm	8.66E-3	1	2.05	(2,1,1,2,1,5,BU:2); Share for Germany in 2015; HBEFA v3.2
	transport, freight, e-lorry 3.5-7.5 metric ton	RER	0	tkm	3.71E-3	1	2.05	(2,1,1,2,1,5,BU:2); Share for Germany in 2015; HBEFA v3.2
	transport, freight, lorry 7.5-16 metric ton, EURO 3	RER	0	tkm				
	transport, freight, lorry 7.5-16 metric ton, EURO 4	RER	0	tkm				
	transport, freight, lorry 7.5-16 metric ton, EURO 5	RER	0	tkm				
	transport, freight, lorry 7.5-16 metric ton, EURO 6	RER	0	tkm	1.05E-2	1	2.05	(2,1,1,2,1,5,BU:2); Share for Germany in 2015; HBEFA v3.2
	transport, freight, e-lorry 7.5-16 metric ton	RER	0	tkm	3.50E-3	1	2.05	(2,1,1,2,1,5,BU:2); Share for Germany in 2015; HBEFA v3.2
	transport, freight, lorry 16-32 metric ton, EURO 3	RER	0	tkm				
	transport, freight, lorry 16-32 metric ton, EURO 4	RER	0	tkm				
	transport, freight, lorry 16-32 metric ton, EURO 5	RER	0	tkm				
	transport, freight, lorry 16-32 metric ton, EURO 6	RER	0	tkm	1.02E-1	1	2.05	(2,1,1,2,1,5,BU:2); Share for Germany in 2015; HBEFA v3.2
	transport, freight, e-lorry 16-32 metric ton	RER	0	tkm	3.16E-3	1	2.05	(2,1,1,2,1,5,BU:2); Share for Germany in 2015; HBEFA v3.2
	transport, freight, lorry 32-40 metric ton, EURO 3	RER	0	tkm				
	transport, freight, lorry 32-40 metric ton, EURO 4	RER	0	tkm				
	transport, freight, lorry 32-40 metric ton, EURO 5	RER	0	tkm				
	transport, freight, lorry 32-40 metric ton, EURO 6	RER	0	tkm	8.42E-1	1	2.05	(2,1,1,2,1,5,BU:2); Share for Germany in 2015; HBEFA v3.2
	transport, freight, e-lorry 32-40 metric ton	RER	0	tkm	2.61E-2	1	2.05	(2,1,1,2,1,5,BU:2); Share for Germany in 2015; HBEFA v3.2
Outputs	transport, freight, lorry, fleet average	RER	0	tkm	1.00E+0			

Tab. D.1.6 Life cycle inventory of 1 tkm transport with a future lorry, fleet average Switzerland

Explanations	Name	Location	Infrastructure-Process	Unit	transport, freight, lorry, fleet average	uncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				tkm			
Technosphere	transport, freight, lorry 3.5-7.5 metric ton, EURO 3	RER	0	tkm				
	transport, freight, lorry 3.5-7.5 metric ton, EURO 4	RER	0	tkm				
	transport, freight, lorry 3.5-7.5 metric ton, EURO 5	RER	0	tkm				
	transport, freight, lorry 3.5-7.5 metric ton, EURO 6	RER	0	tkm	1.90E-3	1	2.05	(2,1,1,2,1,5,BU:2); Share for Switzerland in 2015; HBEFA v3.2
	transport, freight, elorry 3.5-7.5 metric ton	CH	0	tkm	8.14E-4	1	2.05	(2,1,1,2,1,5,BU:2); Share for Switzerland in 2015; HBEFA v3.2
	transport, freight, lorry 7.5-16 metric ton, EURO 3	RER	0	tkm				
	transport, freight, lorry 7.5-16 metric ton, EURO 4	RER	0	tkm				
	transport, freight, lorry 7.5-16 metric ton, EURO 5	RER	0	tkm				
	transport, freight, lorry 7.5-16 metric ton, EURO 6	RER	0	tkm	2.37E-2	1	2.05	(2,1,1,2,1,5,BU:2); Share for Switzerland in 2015; HBEFA v3.2
	transport, freight, e-lorry 7.5-16 metric ton	CH	0	tkm	7.90E-3	1	2.05	(2,1,1,2,1,5,BU:2); Share for Switzerland in 2015; HBEFA v3.2
	transport, freight, lorry 16-32 metric ton, EURO 3	RER	0	tkm				
	transport, freight, lorry 16-32 metric ton, EURO 4	RER	0	tkm				
	transport, freight, lorry 16-32 metric ton, EURO 5	RER	0	tkm				
	transport, freight, lorry 16-32 metric ton, EURO 6	RER	0	tkm	3.18E-1	1	2.05	(2,1,1,2,1,5,BU:2); Share for Switzerland in 2015; HBEFA v3.2
	transport, freight, e-lorry 16-32 metric ton	CH	0	tkm	9.83E-3	1	2.05	(2,1,1,2,1,5,BU:2); Share for Switzerland in 2015; HBEFA v3.2
	transport, freight, lorry 32-40 metric ton, EURO 3	RER	0	tkm				
	transport, freight, lorry 32-40 metric ton, EURO 4	RER	0	tkm				
	transport, freight, lorry 32-40 metric ton, EURO 5	RER	0	tkm				
	transport, freight, lorry 32-40 metric ton, EURO 6	RER	0	tkm	6.19E-1	1	2.05	(2,1,1,2,1,5,BU:2); Share for Switzerland in 2015; HBEFA v3.2
	transport, freight, e-lorry 32-40 metric ton	CH	0	tkm	1.91E-2	1	2.05	(2,1,1,2,1,5,BU:2); Share for Switzerland in 2015; HBEFA v3.2
Outputs	transport, freight, lorry, fleet average	CH	0	tkm	1.00E+0			

D.2 Cargo train transport

Tab. D.2.1: Life cycle inventory of future SBB electricity mix

Input-Group	Output-Group	Name	Location	Category	Sub-Category	Infrastructure-Process	Unit	electricity mix, SBB	uncertaintyType	StandardDeviation95%	GeneralComment
		Location						CH			
		InfrastructureProcess						0			
		Unit						kWh			
5		electricity, nuclear, at power plant	CH			0	kWh	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ; personal communication SBB (2015)
5		electricity, nuclear, at power plant pressure water reactor	FR			0	kWh	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ; personal communication SBB (2015)
5		electricity, at wind power plant	RER			0	kWh	2.24E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ; personal communication SBB (2015)
5		electricity, hydropower, at run-of-river power plant	CH			0	kWh	1.56E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); ; personal communication SBB (2015)
5		electricity, hydropower, net, at reservoir power plant	CH			0	kWh	6.24E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); ; personal communication SBB (2015)
5		electricity, hydropower, at power plant	CH			0	kWh	3.21E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ; personal communication SBB (2015)
5		electricity, hydropower, at run-of-river power plant	RER			0	kWh	2.26E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); ; personal communication SBB (2015)
5		electricity, production mix photovoltaic, at plant	CH			0	kWh	8.96E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ; personal communication SBB (2015)
5		electricity, at cogen with biogas engine, allocation exergy	CH			0	kWh	2.67E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ; personal communication SBB (2015)
	0	electricity mix, SBB	CH			0	kWh	1.00E+0			

Tab. D.2.2: Life cycle inventory of future electricity mix of the German railways (DB)

Input-Group	Output-Group	Name	Location	Category	Sub-Category	Infrastructure-Process	Unit	electricity mix, DB	uncertaintyType	StandardDeviation95%	GeneralComment
		Location						DE			
		InfrastructureProcess						0			
		Unit						kWh			
5		electricity, hard coal, at power plant	DE			0	kWh	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ; yearly report DB (2014)
5		electricity, lignite, at power plant	DE			0	kWh	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ; yearly report DB (2014)
5		electricity, natural gas, at power plant	DE			0	kWh	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ; yearly report DB (2014)
5		electricity, nuclear, at power plant	DE			0	kWh	0	1	1.05	(1,1,1,1,1,1,BU:1.05); ; yearly report DB (2014)
5		electricity, at wind power plant	RER			0	kWh	1.32E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); ; yearly report DB (2014)
5		electricity, hydropower, at power plant	DE			0	kWh	6.46E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); ; yearly report DB (2014)
5		electricity, at cogen with biogas engine, allocation exergy	CH			0	kWh	1.23E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); ; yearly report DB (2014)
5		electricity, production mix photovoltaic, at plant	DE			0	kWh	8.90E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ; yearly report DB (2014)
5		electricity from waste, at municipal waste incineration plant	CH			0	kWh	1.00E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); ; yearly report DB (2014)
	0	electricity mix, DB	DE			0	kWh	1.00E+0			

D.3 Ship transport

Tab. D.3.1 Life cycle inventory of 1 tkm transport with a future container ship

Name	Location	Infrastructure-Process	Unit	transport, transoceanic container ship	uncertaintyType	StandardDeviation95%	GeneralComment
Location				OCE			
InfrastructureProcess				0			
Unit				tkm			
transoceanic freight ship	OCE	1	p	7.15E-12	1	3.06	(2,4,1,3,1,5,BU:3); scaled with the transport capacity (65'000dwt container ship; 100'000dwt freight ship); calculation based on the assumption of a life time of 20 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
maintenance, transoceanic freight ship	RER	1	p	7.15E-12	1	3.07	(3,4,1,3,1,5,BU:3); ;
port facilities	RER	1	p	8.99E-15	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port Rotterdam in 2014: 444733000t/a; Yearly report of the port Rotterdam 2014
operation, maintenance, port	RER	1	p	8.99E-13	1	3.06	(2,4,1,3,1,5,BU:3); port facility multiplied by 100 a (life span of a port);
Methanol, from biomass, at regional storage	RER	0	kg	7.87E-3	1	1.24	(2,4,1,3,1,5,BU:1.05); ; CO2 Emissions according to Ellis & Tanneberger 2015
wrecking, transocean container ship	IN	0	p	5.66E-12	1	2.06	(2,3,1,3,1,5,BU:2); assumed life time 20 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
disposal, bilge oil, 90% water, to hazardous waste incineration	CH	0	kg	0	1	1.22	(2,3,1,3,1,5,BU:1.05);
Benzene			kg	2.24E-7	1	3.34	(3,5,2,5,4,5,BU:3); emission factor of heavy fuel: 5.85E-2 g/kg heavy fuel; VOC profile from ecoinvent 2.2
Methane, biogenic			kg	0	1	1.57	(2,3,1,3,1,5,BU:1.5); no methane slip
Carbon monoxide, biogenic			kg	1.06E-5	1	5.06	(2,3,1,3,1,5,BU:5); CO-emissions: < 1g/kWh
Carbon dioxide, biogenic			kg	1.09E-2	1	1.22	(2,3,1,3,1,5,BU:1.05); emission factor of methanol: 69.1g/MJ fuel; IMO
Dinitrogen monoxide			kg	6.11E-7	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 1.60E-1 g/kg heavy fuel; IMO
Ammonia			kg	1.56E-6	1	1.70	(3,5,2,5,4,5,BU:1.2); emission factor of heavy fuel: 4.07E-1 g/kg heavy fuel; ecoinvent 2.2, heavy fuel oil burned in industrial furnance
NMVOC, non-methane volatile organic compounds, unspecified origin			kg	1.14E-5	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 2.97E+0 g/kg heavy fuel; IMO
Nitrogen oxides			kg	1.75E-4	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of methanol:1.11 g/MJ fuel; IMO
Sulfur dioxide			kg	2.02E-6	1	1.22	(2,3,1,3,1,5,BU:1.05); emission factor of heavy fuel: 5.28E+1 g/kg heavy fuel; IMO; 99% reduction with methanol
Toluene			kg	9.41E-8	1	1.90	(3,5,2,5,4,5,BU:1.5); emission factor of heavy fuel: 2.46E-2 g/kg heavy fuel; ecoinvent 2.2
Xylene			kg	9.41E-8	1	1.90	(3,5,2,5,4,5,BU:1.5); emission factor of heavy fuel: 2.46E-2 g/kg heavy fuel; ecoivnent 2.2
Particulates, > 2.5 um, and < 10um			kg	1.15E-7	1	2.06	(2,3,1,3,1,5,BU:2); emission factor of heavy fuel: 6.00E-1 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013; 99% reduction with methanol
Particulates, < 2.5 um			kg	1.07E-6	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 5.60E+0 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013; 99% reduction with methanol
Lead			kg	6.88E-10	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.80E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Cadmium			kg	7.64E-11	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.00E-5 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Copper			kg	4.78E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.25E-3 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Chromium			kg	2.75E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 7.20E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Nickel			kg	1.22E-7	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 3.20E-2 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Selenium			kg	8.02E-10	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.10E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Zinc			kg	4.59E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.20E-3 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Mercury			kg	7.64E-11	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.00E-5 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Arsenic			kg	2.60E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 6.80E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Hydrogen chloride			kg	2.20E-7	1	1.57	(2,3,1,3,1,5,BU:1.5); Cl content of heavy fuel, emission factor of heavy fuel: 5.76E-2 g/kg heavy fuel; Cl content of heavy fuel, ecoinvent 2.2
Hydrogen fluoride			kg	2.20E-8	1	1.57	(2,3,1,3,1,5,BU:1.5); Fl content of heavy fuel, emission factor of heavy fuel: 5.76E-3 g/kg heavy fuel; F contant of heavy fuel, ecoinvent 2.2
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	3.82E-15	1	3.34	(3,5,2,5,4,5,BU:3); emission factor of heavy fuel: 4.70E-10 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013, ecoinvent
PAH, polycyclic aromatic hydrocarbons			kg	9.90E-11	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 2.59E-5 g/kg heavy fuel; Cooper & Gustavson 2004
Benzo(a)pyrene			kg	1.95E-11	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 5.10E-6 g/kg heavy fuel; Cooper & Gustavson 2004
Heat, waste			MJ	1.57E-1	1	1.22	(2,3,1,3,1,5,BU:1.05); default value;
Copper			kg	1.01E-7	1	3.05	(2,3,1,3,1,5,BU:3); leaching factor 200mg/m2d; Assessment leaching antifouling agent 2014
transport, transoceanic container ship	OCE	0	tkm	1.00E+0			

Tab. D.3.2 Life cycle inventory of 1 tkm transport with a future freight ship

Name	Location	Infrastructure-Process	Unit	transport, transoceanic freight ship	uncertaintyType	StandardDeviation95%	GeneralComment
Location				OCE			
InfrastructureProcess				0			
Unit				tkm			
transoceanic freight ship	OCE	1	p	1.08E-11	1	3.06	(2,4,1,3,1,5,BU:3); scaled with the transport capacity (65'000dwt container ship; 100'000dwt freight ship); calculation based on the assumption of a life time of 20 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
maintenance, transoceanic freight ship	RER	1	p	1.08E-11	1	3.07	(3,4,1,3,1,5,BU:3); ;
port facilities	RER	1	p	8.99E-15	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port Rotterdam in 2014: 444733000t/a; Yearly report of the port Rotterdam 2014
operation, maintenance, port	RER	1	p	8.99E-13	1	3.06	(2,4,1,3,1,5,BU:3); port facility multiplied by 100 a (life span of a port);
Methanol, from biomass, at regional storage	RER	0	kg	3.18E-3	1	1.24	(2,4,1,3,1,5,BU:1.05); ; CO2 Emissions according to Ellis & Tanneberger 2015
wrecking, transocean ship	IN	0	p	5.58E-12	1	2.06	(2,3,1,3,1,5,BU:2); assumed life time 20 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
disposal, bilge oil, 90% water, to hazardous waste incineration	CH	0	kg	0	1	1.22	(2,3,1,3,1,5,BU:1.05);
Benzene			kg	9.02E-8	1	3.34	(3,5,2,5,4,5,BU:3); emission factor of heavy fuel: 5.85E-2 g/kg heavy fuel; VOC profile from ecoinvent 2.2
Methane, biogenic			kg	0	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 6.00E-2 g/kg heavy fuel; IMO
Carbon monoxide, biogenic			kg	4.27E-6	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.77E+0 g/kg heavy fuel; IMO
Carbon dioxide, biogenic			kg	4.39E-3	1	1.22	(2,3,1,3,1,5,BU:1.05); emission factor of methanol: 69.1g/MJ fuel; IMO
Dinitrogen monoxide			kg	2.47E-7	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 1.60E-1 g/kg heavy fuel; IMO
Ammonia			kg	6.28E-7	1	1.70	(3,5,2,5,4,5,BU:1.2); emission factor of heavy fuel: 4.07E-1 g/kg heavy fuel; ecoinvent 2.2, heavy fuel oil burned in industrial furnance
NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.58E-6	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 2.97E+0 g/kg heavy fuel; IMO
Nitrogen oxides			kg	7.06E-5	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of methanol:1.11 g/MJ fuel; IMO
Sulfur dioxide			kg	8.14E-7	1	1.22	(2,3,1,3,1,5,BU:1.05); emission factor of heavy fuel: 5.28E+1 g/kg heavy fuel; IMO; 99% reduction with methanol
Toluene			kg	3.80E-8	1	1.90	(3,5,2,5,4,5,BU:1.5); emission factor of heavy fuel: 2.46E-2 g/kg heavy fuel; ecoinvent 2.2
Xylene			kg	3.80E-8	1	1.90	(3,5,2,5,4,5,BU:1.5); emission factor of heavy fuel: 2.46E-2 g/kg heavy fuel; ecoivnent 2.2
Particulates, > 2.5 um, and < 10um			kg	4.63E-8	1	2.06	(2,3,1,3,1,5,BU:2); emission factor of heavy fuel: 6.00E-1 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013; 99% reduction with methanol
Particulates, < 2.5 um			kg	4.32E-7	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 5.60E+0 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013; 99% reduction with methanol
Lead			kg	2.78E-10	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.80E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Cadmium			kg	3.08E-11	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.00E-5 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Copper			kg	1.93E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.25E-3 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Chromium			kg	1.11E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 7.20E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Nickel			kg	4.93E-8	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 3.20E-2 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Selenium			kg	3.24E-10	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.10E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Zinc			kg	1.85E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.20E-3 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Mercury			kg	3.08E-11	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.00E-5 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Arsenic			kg	1.05E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 6.80E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Hydrogen chloride			kg	8.88E-8	1	1.57	(2,3,1,3,1,5,BU:1.5); Cl content of heavy fuel, emission factor of heavy fuel: 5.76E-2 g/kg heavy fuel; Cl content of heavy fuel, ecoinvent 2.2
Hydrogen fluoride			kg	8.88E-9	1	1.57	(2,3,1,3,1,5,BU:1.5); Fl content of heavy fuel, emission factor of heavy fuel: 5.76E-3 g/kg heavy fuel; F contant of heavy fuel, ecoinvent 2.2
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	1.54E-15	1	3.34	(3,5,2,5,4,5,BU:3); emission factor of heavy fuel: 4.70E-10 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013, ecoinvent
PAH, polycyclic aromatic hydrocarbons			kg	3.99E-11	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 2.59E-5 g/kg heavy fuel; Cooper & Gustavson 2004
Benzo(a)pyrene			kg	7.86E-12	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 5.10E-6 g/kg heavy fuel; Cooper & Gustavson 2004
Heat, waste			MJ	6.35E-2	1	1.22	(2,3,1,3,1,5,BU:1.05); default value;
Copper			kg	1.17E-7	1	3.05	(2,3,1,3,1,5,BU:3); leaching factor 200mg/m2d; Assessment leaching antifouling agent 2014
transport, transoceanic freight ship	OCE	0	tkm	1.00E+0			

Tab. D.3.3 Life cycle inventory of 1 tkm transport with a future tanker

Name	Location	Infrastructure-Process	Unit	transport, transoceanic tanker	uncertaintyType	StandardDeviation95%	GeneralComment
Location				OCE			
InfrastructureProcess				0			
Unit				tkm			
transoceanic tanker	OCE	1	p	1.97E-12	1	3.30	(3,4,1,3,4,5,BU:3); scaled for the assumed transport capacity 200'000dwt, calculated based on the assumption of a life time of 30 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
maintenance, transoceanic freight ship	RER	1	p	1.97E-12	1	3.07	(3,4,1,3,1,5,BU:3); ;
port facilities	RER	1	p	5.11E-15	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port Rotterdam in 2014: 444733000t/a; Yearly report of the port Rotterdam 2014
operation, maintenance, port	RER	1	p	5.11E-13	1	3.06	(2,4,1,3,1,5,BU:3); port facility multiplied by 100 a (life span of a port);
Methanol, from biomass, at regional storage	RER	0	kg	2.93E-3	1	1.24	(2,4,1,3,1,5,BU:1.05); ; CO2 Emissions according to Ellis & Tanneberger 2015
wrecking, transocean tanker	IN	0	p	1.97E-12	1	2.06	(2,3,1,3,1,5,BU:2); assumed life time 30 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
disposal, bilge oil, 90% water, to hazardous waste incineration	CH	0	kg	0	1	1.22	(2,3,1,3,1,5,BU:1.05);
Benzene			kg	8.33E-8	1	3.34	(3,5,2,5,4,5,BU:3); emission factor of heavy fuel: 5.85E-2 g/kg heavy fuel; VOC profile from ecoinvent 2.2
Methane, biogenic			kg	0	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 6.00E-2 g/kg heavy fuel; IMO
Carbon monoxide, biogenic			kg	3.94E-6	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.77E+0 g/kg heavy fuel; IMO
Carbon dioxide, biogenic			kg	4.05E-3	1	1.22	(2,3,1,3,1,5,BU:1.05); emission factor of methanol: 69.1g/MJ fuel; IMO
Dinitrogen monoxide			kg	2.28E-7	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 1.60E-1 g/kg heavy fuel; IMO
Ammonia			kg	5.80E-7	1	1.70	(3,5,2,5,4,5,BU:1.2); emission factor of heavy fuel: 4.07E-1 g/kg heavy fuel; ecoinvent 2.2, heavy fuel oil burned in industrial furnance
NMVOC, non-methane volatile organic compounds, unspecified origin			kg	4.23E-6	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 2.97E+0 g/kg heavy fuel; IMO
Nitrogen oxides			kg	6.52E-5	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of methanol:1.11 g/MJ fuel; IMO
Sulfur dioxide			kg	7.52E-7	1	1.22	(2,3,1,3,1,5,BU:1.05); emission factor of heavy fuel: 5.28E+1 g/kg heavy fuel; IMO; 99% reduction with methanol
Toluene			kg	3.51E-8	1	1.90	(3,5,2,5,4,5,BU:1.5); emission factor of heavy fuel: 2.46E-2 g/kg heavy fuel; ecoinvent 2.2
Xylene			kg	3.51E-8	1	1.90	(3,5,2,5,4,5,BU:1.5); emission factor of heavy fuel: 2.46E-2 g/kg heavy fuel; ecoivnent 2.2
Particulates, > 2.5 um, and < 10um			kg	4.27E-8	1	2.06	(2,3,1,3,1,5,BU:2); emission factor of heavy fuel: 6.00E-1 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013; 99% reduction with
Particulates, < 2.5 um			kg	3.99E-7	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 5.60E+0 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013; 99% reduction with
Lead			kg	2.56E-10	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.80E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Cadmium			kg	2.85E-11	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.00E-5 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Copper			kg	1.78E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.25E-3 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Chromium			kg	1.03E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 7.20E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Nickel			kg	4.56E-8	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 3.20E-2 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Selenium			kg	2.99E-10	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.10E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Zinc			kg	1.71E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.20E-3 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Mercury			kg	2.85E-11	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.00E-5 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Arsenic			kg	9.68E-10	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 6.80E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
Hydrogen chloride			kg	8.20E-8	1	1.57	(2,3,1,3,1,5,BU:1.5); Cl content of heavy fuel, emission factor of heavy fuel: 5.76E-2 g/kg heavy fuel; Cl content of heavy fuel, ecoinvent 2.2
Hydrogen fluoride			kg	8.20E-9	1	1.57	(2,3,1,3,1,5,BU:1.5); Fl content of heavy fuel, emission factor of heavy fuel: 5.76E-3 g/kg heavy fuel; F contant of heavy fuel, ecoinvent 2.2
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-			kg	1.42E-15	1	3.34	(3,5,2,5,4,5,BU:3); emission factor of heavy fuel: 4.70E-10 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013, ecoinvent
PAH, polycyclic aromatic hydrocarbons			kg	3.69E-11	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 2.59E-5 g/kg heavy fuel; Cooper & Gustavson 2004
Benzo(a)pyrene			kg	7.26E-12	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 5.10E-6 g/kg heavy fuel; Cooper & Gustavson 2004
Heat, waste			MJ	5.87E-2	1	1.22	(2,3,1,3,1,5,BU:1.05); default value;
Copper			kg	9.53E-8	1	3.05	(2,3,1,3,1,5,BU:3); leaching factor 200mg/m2d; Assessment leaching antifouling agent 2014
Oils, unspecified			kg	1.64E-5	1	1.57	(2,3,1,3,1,5,BU:1.5); assumed oil spill between 1988-1999: 179'000t; GESAMP, 2007; UNCTAD 1988-1999
BOD5, Biological Oxygen Demand			kg	5.17E-5	1	1.57	(2,3,1,3,1,5,BU:1.5); ; own calculation, according to quality guidelines, derived from emissions of oil.
COD, Chemical Oxygen Demand			kg	5.17E-5	1	1.57	(2,3,1,3,1,5,BU:1.5); ; own calculation, according to quality guidelines, derived from emissions of oil.
TOC, Total Organic Carbon			kg	1.42E-5	1	1.57	(2,3,1,3,1,5,BU:1.5); ; own calculation, according to quality guidelines, derived from emissions of oil.
DOC, Dissolved Organic Carbon			kg	1.42E-5	1	1.57	(2,3,1,3,1,5,BU:1.5); ; own calculation, according to quality guidelines, derived from emissions of oil.
transport, transoceanic tanker	OCE	0	tkm	1.00E+0			

Tab. D.3.4 Life cycle inventory of 1 tkm transport with a future barge

Name	Location	Infrastructure-Process	Unit	transport, barge	uncertaintyType	StandardDeviation95%	GeneralComment
Location				RER			
InfrastructureProcess				0			
Unit				tkm			
barge	RER	1	p	4.44E-10	1	3.05	(2,3,1,3,1,5,BU:3); assumed transport distance: 850km, assuming 50 rides a year and a life time of 45 years; own assumption, ecoinvent report 14, Tremod 2012
maintenance, barge	RER	1	p	4.44E-10	1	3.09	(4,3,1,3,1,5,BU:3); ;
port facilities	RER	1	p	5.29E-14	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port in Rotterdam: 444733000t per year ; Yearly report, Port Rotterdam 2014
operation, maintenance, port	RER	1	p	5.29E-12	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port in Rotterdam: 44473300000t per year; Yearly report, Port Rotterdam 2014
canal	RER	1	my	2.05E-5	1	3.33	(4,4,1,3,4,5,BU:3); calculated based on the total yearly transport performance on the Rhein: 41400000000tkm and a transport distance of 850km; Marktbeobachtung 2014 Binnenschiffffahrt Europa
maintenance, operation, canal	RER	1	my	2.05E-5	1	3.33	(4,4,1,3,4,5,BU:3); assumed total yearly transport performance on the Rhein: 41400000000tkm and a transport distance of 850km; 0
Methanol, from biomass, at regional storage	RER	0	kg	1.71E-2	1	1.24	(2,4,1,3,1,5,BU:1.05); assumed diesel consumption 8g/tkm for barge ship and 10g/tkm for barge tanker; Tremod 2012
Benzene			kg	1.33E-7	1	3.15	(3,5,2,3,3,5,BU:3); emission factor of diesel: 1.66E-2 g/kg diesel; BAFU 2015: non road database
Benzo(a)pyrene			kg	6.16E-11	1	3.15	(3,5,2,3,3,5,BU:3); emission factor of diesel: 7.70E-6 g/kg diesel; ecoinvent report 14
Carbon dioxide, biogenic			kg	2.37E-2	1	1.40	(3,5,2,3,3,5,BU:1.05); emission factor of methanol: 69.1 g/kg methanol
Carbon monoxide, biogenic			kg	1.68E-4	1	5.17	(3,5,2,3,3,5,BU:5); emission factor of diesel: 2.10E+1 g/kg diesel; BAFU 2015: non road database
Dinitrogen monoxide			kg	1.23E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.54E-1 g/kg diesel; BAFU 2015: non road database
Methane, biogenic			kg	0	1	1.69	no methane slip
Nitrogen oxides			kg	3.80E-4	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of methanol: 4 g/kg methanol
Sulfur dioxide			kg	1.60E-9	1	1.40	(3,5,2,3,3,5,BU:1.05); emission factor of diesel: 2.00E-2 g/kg diesel; HBEFA 3.1.; 99% reduction with methanol
Particulates, < 2.5 um			kg	5.32E-7	1	3.15	(3,5,2,3,3,5,BU:3); emission factor of diesel: 1.33E+0 g/kg diesel; BAFU 2015: non road database; 95% reduction with methanol
Particulates, > 10 um			kg	2.25E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 5.62E-2 g/kg diesel; 95% reduction with methanol
Particulates, > 2.5 um, and < 10um			kg	2.19E-8	1	2.16	(3,5,2,3,3,5,BU:2); emission factor of diesel: 5.47E-2 g/kg diesel; 95% reduction with methanol
NMVOC, non-methane volatile organic compounds, unspecified origin			kg	6.82E-5	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 8.52E+0 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Ethane			kg	2.52E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 3.15E-3 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Propane			kg	8.39E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.05E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Butane			kg	1.26E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.57E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Pentane			kg	5.03E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 6.29E-3 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Heptane			kg	2.52E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 3.15E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Toluene			kg	8.39E-9	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.05E-3 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
m-Xylene			kg	8.22E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.03E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
o-Xylene			kg	3.36E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 4.19E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Formaldehyde			kg	7.05E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 8.81E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Acetaldehyde			kg	3.83E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 4.79E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Benzaldehyde			kg	1.15E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.44E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Acrolein			kg	1.49E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.86E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Styrene			kg	4.70E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 5.87E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Cadmium			kg	6.96E-11	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 8.70E-9 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Chromium			kg	2.40E-10	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 3.00E-8 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Copper			kg	1.70E-10	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 2.12E-8 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Nickel			kg	7.04E-11	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 8.80E-9 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Selenium			kg	8.00E-13	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 1.00E-10 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Lead			kg	4.17E-10	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 5.21E-8 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Mercury			kg	4.24E-11	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 5.30E-9 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Zinc			kg	1.39E-8	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 1.74E-6 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Arsenic			kg	8.00E-13	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 1.00E-10 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Chromium VI			kg	4.80E-13	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 6.00E-11 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Heat, waste			MJ	3.30E-1	1	1.38	(2,5,2,3,3,5,BU:1.05); devault value;
transport, barge	RER	0	tkm	1.00E+0			

Tab. D.3.5 Life cycle inventory of 1 tkm transport with a future barge tanker

Name	Location	Infrastructure-Process	Unit	transport, barge tanker	uncertaintyType	StandardDeviation95%	GeneralComment
Location				RER			
InfrastructureProcess				0			
Unit				tkm			
barge tanker	RER	1	p	7.02E-10	1	3.05	(2,3,1,3,1,5,BU:3); assumed transport distance: 850km and 50 rides a year and a average life time of 33 years; own assumption, ecoinvent report 14, Tremod 2012
maintenance, barge	RER	1	p	7.02E-10	1	3.09	(4,3,1,3,1,5,BU:3); ;
port facilities	RER	1	p	5.29E-14	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port in Rotterdam: 444733000t per year ; Yearly report, Port Rotterdam 2014
operation, maintenance, port	RER	1	p	5.29E-12	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port in Rotterdam: 44473300000t per year; Yearly report, Port Rotterdam 2014
canal	RER	1	my	2.05E-5	1	3.33	(4,4,1,3,4,5,BU:3); calculated based on the total yearly transport performance on the Rhein: 41400000000tkm and a transport distance of 850km; Marktbeobachtung 2014 Binnenschifffahrt Europa
maintenance, operation, canal	RER	1	my	2.05E-5	1	3.33	(4,4,1,3,4,5,BU:3); assumed total yearly transport performance on the Rhein: 41400000000tkm and a transport distance of 850km; 0
Methanol, from biomass, at regional storage	RER	0	kg	2.08E-2	1	1.24	(2,4,1,3,1,5,BU:1.05); assumed diesel consumption 8g/tkm for barge ship and 10g/tkm for barge tanker: Tremod 2012
Benzene			kg	1.61E-7	1	3.15	(3,5,2,3,3,5,BU:3); emission factor of diesel: 1.66E-2 g/kg diesel; BAFU 2015: non road database
Benzo(a)pyrene			kg	7.47E-11	1	3.15	(3,5,2,3,3,5,BU:3); emission factor of diesel: 7.70E-6 g/kg diesel; ecoinvent report 14
Carbon dioxide, biogenic			kg	2.87E-2	1	1.40	(3,5,2,3,3,5,BU:1.05); emission factor of methanol: 69.1 g/kg methanol
Carbon monoxide, biogenic			kg	2.03E-4	1	5.17	(3,5,2,3,3,5,BU:5); emission factor of diesel: 2.10E+1 g/kg diesel; BAFU 2015: non road database
Dinitrogen monoxide			kg	1.50E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.54E-1 g/kg diesel; BAFU 2015: non road database
Methane, biogenic			kg	0	1	1.69	no methane slip
Nitrogen oxides			kg	4.61E-4	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of methanol: 4 g/kg methanol
Sulfur dioxide			kg	1.94E-9	1	1.40	(3,5,2,3,3,5,BU:1.05); emission factor of diesel: 2.00E-2 g/kg diesel; HBEFA 3.1.; 99% reduction with methanol
Particulates, < 2.5 um			kg	6.45E-7	1	3.15	(3,5,2,3,3,5,BU:3); emission factor of diesel: 1.33E+0 g/kg diesel; BAFU 2015: non road database; 95% reduction with methanol
Particulates, > 10 um			kg	2.72E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 5.62E-2 g/kg diesel; 95% reduction with methanol
Particulates, > 2.5 um, and < 10um			kg	2.65E-8	1	2.16	(3,5,2,3,3,5,BU:2); emission factor of diesel: 5.47E-2 g/kg diesel; 95% reduction with methanol
NMVOC, non-methane volatile organic compounds, unspecified origin			kg	8.26E-5	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 8.52E+0 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Ethane			kg	3.05E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 3.15E-3 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Propane			kg	1.02E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.05E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Butane			kg	1.53E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.57E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Pentane			kg	6.10E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 6.29E-3 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Heptane			kg	3.05E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 3.15E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Toluene			kg	1.02E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.05E-3 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
m-Xylene			kg	9.97E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.03E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
o-Xylene			kg	4.07E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 4.19E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Formaldehyde			kg	8.55E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 8.81E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Acetaldehyde			kg	4.65E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 4.79E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Benzaldehyde			kg	1.39E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.44E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Acrolein			kg	1.80E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.86E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Styrene			kg	5.70E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 5.87E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Cadmium			kg	8.44E-11	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 8.70E-9 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Chromium			kg	2.91E-10	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 3.00E-8 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Copper			kg	2.06E-10	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 2.12E-8 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Nickel			kg	8.54E-11	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 8.80E-9 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Selenium			kg	9.70E-13	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 1.00E-10 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Lead			kg	5.05E-10	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 5.21E-8 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Mercury			kg	5.14E-11	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 5.30E-9 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Zinc			kg	1.69E-8	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 1.74E-6 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Arsenic			kg	9.70E-13	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 1.00E-10 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Chromium VI			kg	5.82E-13	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 6.00E-11 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
Heat, waste			MJ	4.00E-1	1	1.38	(2,5,2,3,3,5,BU:1.05); devault value;
transport, barge tanker	RER	0	tkm	1.00E+0			

E Materialisation of case study buildings

E.1 Office building ARE, Ittigen

EKG-Number	Label	Amount	Materialisation
D0	Excavation	680 m^2	Excavation machines
D1	Backfilling	209 m^2	Excavation machines
D2	Foundation	648.2 m^2	Floor slab basement and ground floor, predominantly insulated
E0	Slabs	2304.1 m^2	71 % thereof wooden slabs (3 layered board) and 29 % concrete slabs, 28 cm cement type: CEM II/A
E1	Roofs	594.9 m^2 66.2 m^2	wooden flat roof (3 layered board), insulated with extensive greenery and skylights flat roof above concrete core, cement type: CEM II/A, insulated.
E2	Pillars	-	-
E3	External walls basement	279 m^2	Concrete walls 25 cm, interior insulation
E4	External walls above ground	1367.1 m^2	Wooden framework with glass wool insulation, 86 % on 3 layered board and 14 % on concrete, 20 cm
E5	Windows	369 m^2	3-IV glazing, wood-aluminium frame
E6	Interior walls, load bearing	695.8 m^2 222 m^2	Concrete walls 20-25 cm, cement type: CEM II/A lime sand bricks 12-20cm
M1	Partitions / interior doors	21 m^2 1344.8 m^2	Wooden doors 91 % lightweight framework walls with plasterboard and 9 % glass partitions (2-IV glazing, LSG)
M3	Floor coverings	1574.7 m^2 755.5 m^2 370.7 m^2 72 m^2	Anhydrite floor with no covering, glass wool sound insulation Parquet with anhydrite floor and glass wool sound insulation cement floor without sound insulation ceramic/stoneware tiles with cement floor and foam glass insulation
M4	Wall finishes	277.2 m^2	Cement plaster, only on massive walls. No finishes on all other external and interior walls.
M5	Ceiling finishes	787.3 m^2 756.8 m^2	only 50 % of ceilings are covered Acoustic ceilings in cement bounded wood wool plasterboard covering
I	Building technology	2552 m^2 14 m^2	Electrical equipment/ sanitary equipment/ heat pumps/ distribution via floor heating/ ventilation equipment/ flat plate collectors (hot water)

E.2 Residential building Rautistrasse, Zurich

EKG-Number	Label	Amount	Materialisation
D0	Excavation	2452 m^3	Excavation machines
D1	Backfilling	835 m^3	Excavation machines
D2	Foundation	522 m^2	Floor slab
E0	Slabs	2063 m^2	Concrete slab
E1	Roofs	532 m^2	Concrete slab / Concrete slab underground car park/ Insulation entry/ insulation and greenery
E2	Pillars	61 m	Concrete pillars
E3	External walls basement	321 m^2	External walls concrete/ insulation base course / interior insulation in the basement
E4	External walls above ground	740 m^2	External walls concrete / bricks / insulation
E5	Windows	788 m^2	2- and 3-IV glazing / wood-aluminium frame / aluminium frame
E6	Interior walls, load bearing	761 m^2	External walls concrete / bricks / insulation
M1	Partitions / interior doors	1265 m^2	framework walls / gypsum walls / glass partitionings and glass interior doors
M3	Floor coverings	1840 m^2	Floor / parquet / PU-casted floor covering
M4	Wall finishes	4310 m^2	Plaster / painting/ ceramic tiles
M5	Ceiling finishes	2230 m^2	Painting / plaster
I	Building technology	2156 m^2	Electrical equipment/ sanitary equipment/ heat pumps / geothermal heat exchanger / automatic ventilation

F Results of case study buildings

F.1 Office building ARE, Ittigen

Tab. F.1.1: Non-renewable primary energy demand in kWh/m²a

ECG-Nr.	KBOB	KBOB future	Difference	Share KBOB	Share KBOB future
D0	0.04	0.03	-29%	0%	0%
D1	0.01	0.01	-29%	0%	0%
D2	1.72	0.83	-52%	2%	4%
E0	2.01	0.81	-59%	2%	4%
E1	2.95	2.05	-30%	3%	9%
E2	-	-	-	0%	0%
E3	0.62	0.39	-36%	1%	2%
E4	2.85	1.62	-43%	3%	7%
E5	1.90	0.95	-50%	2%	4%
E6	0.88	0.48	-46%	1%	2%
M1	1.64	0.91	-44%	2%	4%
M3	4.09	2.76	-33%	4%	12%
M4	0.02	0.01	-30%	0%	0%
M5	0.34	0.20	-42%	0%	1%
I	9.19	6.28	-32%	10%	28%
B	63.76	5.04	-92%	69%	23%
Building	**92.0**	**22.4**	**-76%**	**100%**	**100%**
Building without operation	**28.3**	**17.3**	**-39%**	**31%**	**77%**

Tab. F.1.2: Greenhouse gas emissions in kg CO_2-eq/m^{2}a

ECG-Nr.	**KBOB**	**KBOB future**	**Difference**	**Share KBOB**	**Share KBOB future**
D0	0.01	0.01	-30%	0%	0%
D1	0.00	0.00	-30%	0%	0%
D2	0.60	0.18	-71%	6%	4%
E0	0.55	0.17	-69%	6%	4%
E1	0.69	0.49	-29%	7%	11%
E2	-	-	#DIV/0!	0%	0%
E3	0.23	0.08	-64%	2%	2%
E4	0.59	0.33	-43%	6%	7%
E5	0.46	0.20	-57%	5%	4%
E6	0.34	0.12	-63%	4%	3%
M1	0.37	0.19	-48%	4%	4%
M3	0.84	0.45	-47%	9%	10%
M4	0.01	0.00	-62%	0%	0%
M5	0.10	0.04	-60%	1%	1%
I	2.04	1.22	-40%	22%	26%
B	2.58	1.16	-55%	27%	25%
Building	**9.4**	**4.6**	**-51%**	**100%**	**100%**
Building without operation	**6.8**	**3.5**	**-49%**	**73%**	**75%**

Tab. F.1.3: Overall environmental impact in UBP/m^{2}a

ECG-Nr.	KBOB	KBOB future	Difference	Share KBOB	Share KBOB future
D0	14	9	-37%	0%	0%
D1	4	3	-37%	0%	0%
D2	1’080	856	-21%	5%	8%
E0	1’112	839	-25%	5%	8%
E1	808	609	-25%	4%	6%
E2	-	-	#DIV/0!	0%	0%
E3	302	216	-28%	1%	2%
E4	1’048	878	-16%	5%	8%
E5	585	361	-38%	3%	3%
E6	522	409	-22%	2%	4%
M1	403	307	-24%	2%	3%
M3	1’087	806	-26%	5%	8%
M4	6	4	-39%	0%	0%
M5	139	102	-27%	1%	1%
I	6’612	3’421	-48%	29%	32%
B	8’855	1’792	-80%	39%	17%
Building	**22’576**	**10’611**	**-53%**	**100%**	**100%**
Building without operation	**13’721**	**8’820**	**-36%**	**61%**	**83%**

F.2 Residential building Rautistrasse, Zurich

Tab. F.2.1 Non-renewable energy demand in kWh/m^{2}a

ECG-Nr.	**KBOB**	**KBOB future**	**Difference**	**Share KBOB**	**Share KBOB future**
D0	0.04	0.03	-29%	0%	0%
D1	0.01	0.01	-29%	0%	0%
D2	1.19	0.59	-50%	1%	2%
E0	2.94	1.48	-50%	3%	6%
E1	2.32	1.62	-30%	2%	6%
E2	0.05	0.03	-50%	0%	0%
E3	0.50	0.31	-36%	1%	1%
E4	2.11	1.22	-42%	2%	5%
E5	4.80	2.40	-50%	5%	9%
E6	1.21	0.61	-50%	1%	2%
M1	3.24	1.82	-44%	3%	7%
M3	3.22	2.07	-36%	3%	8%
M4	1.11	0.94	-15%	1%	4%
M5	0.42	0.39	-5%	0%	1%
I	12.14	8.28	-32%	13%	31%
B	59.16	4.68	-92%	63%	18%
Building	**94.5**	**26.5**	**-72%**	**100%**	**100%**
Building without operation	**35.3**	**21.8**	**-38%**	**37%**	**82%**

Tab. F.2.2 Greenhouse gas emissions in kg CO_2-eq/m^2a

ECG-Nr.	KBOB	KBOB future	Difference	Share KBOB	Share KBOB future
D0	0.01	0.0	-30%	0%	0%
D1	0.00	0.0	-30%	0%	0%
D2	0.46	0.1	-72%	4%	3%
E0	1.10	0.3	-71%	9%	6%
E1	0.71	0.3	-57%	6%	6%
E2	0.02	0.0	-68%	0%	0%
E3	0.20	0.1	-75%	2%	1%
E4	0.63	0.2	-74%	5%	3%
E5	1.16	0.5	-57%	10%	10%
E6	0.42	0.1	-68%	4%	3%
M1	0.75	0.4	-53%	6%	7%
M3	0.84	0.3	-65%	7%	6%
M4	0.29	0.2	-29%	2%	4%
M5	0.10	0.1	-5%	1%	2%
I	2.69	1.5	-45%	23%	29%
B	2.39	1.07	-55%	20%	21%
Building	**11.8**	**5.1**	**-57%**	**100%**	**100%**
Building without operation	**9.4**	**4.1**	**-57%**	**80%**	**79%**

Tab. F.2.3 Overall environmental impact in UBP/m^{2}a

ECG-Nr.	KBOB	KBOB future	Difference	Share KBOB	Share KBOB future
D0	15	9	-37%	0%	0%
D1	5	3	-37%	0%	0%
D2	745	577	-23%	3%	5%
E0	1’814	1’407	-22%	8%	12%
E1	1’018	794	-22%	4%	7%
E2	36	30	-16%	0%	0%
E3	266	177	-34%	1%	2%
E4	559	302	-46%	2%	3%
E5	1’485	920	-38%	7%	8%
E6	709	557	-21%	3%	5%
M1	1’142	770	-33%	5%	7%
M3	997	637	-36%	4%	6%
M4	391	330	-16%	2%	3%
M5	97	93	-5%	0%	1%
I	5’151	3’189	-38%	23%	28%
B	8’234	1’681	-80%	36%	15%
Building	**22’665**	**11’476**	**-49%**	**100%**	**100%**
Building without operation	**14’430**	**9’795**	**-32%**	**64%**	**85%**