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Environmental hotspots in the supply chain of Swiss companies

Chemical industry

Excerpt from final report

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Abbreviations and Acronyms

BAVC	Bundesarbeitgeberverband Chemie
CHF	Swiss franc
CSR	Corporate Social Responsibility
EE-IOT	Environmentally extended Input Output Table
EE-MRIO	Environmentally-extended multi-regional input-output-analysis
EU	European Union
Eq.	Equivalent
ERM	Enterprise risk management
ESG	Environmental, social and governance
FOEN	Federal office for the environment
FTE	Full time equivalents
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
ICT	International Comparison Program
IG BCE	Industriegewerkschaft Bergbau, Chemie, Energie
IOT	Input Output Table
KBOB	Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren
Kt	Kiloton
LCA	Life cycle assessment
LCI	Life cycle inventory
MRIOT	Multi-regional input-output table
Mt	Megaton
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
NMVOC	Non-methane volatile organic compounds
NRP	National Research Program
OECD	Organisation for Economic Co-operation and Development
PDF	Potentially disappeared fraction
PPM	Parts per million
PPP	Purchasing power parity
REFF	Ressourceneffizienz Schweiz
SDG	Sustainable Development Goal
SITC	Standard International Trade Classification
TOC	Total organic carbon
TRAIL	Trade-information and LCA
UBP	Umweltbelastungspunkt
US	United States of America
VCI	Verband der chemischen Industrie e.V.
WTO	World Trade Organisation

Content

Summary

With this study, the Federal Office for the Environment (FOEN) would like to promote effective environmental management in Swiss companies by increasing the awareness for the environmental relevance of the supply chains. At present, most of the environmental goals of Swiss companies relate to their own production activities. However, effective corporate environmental management and reporting crucially depends on identifying the most important levers in the supply chain. For small, open economies like Switzerland who are strongly involved in global trade, the importance of the supply chains is particularly high. To enable companies to reduce their life cycle based environmental impacts in a targeted manner, identifying the most relevant value-added stages and processes with regard to their environmental impacts is of crucial importance. If these so-called environmental hotspots are known, companies can focus their efforts for resource-efficient innovations, their corporate environmental management and also reporting on these areas.

In order to support Swiss companies to efficiently and effectively reduce their environmental footprints, this study analyses the environmental impacts of selected Swiss industries including their supply chains and the use phase of their products, if relevant. The environmental hotspots in the supply chains are identfied and options for reducing the environmental footprints of Swiss companies are presented.

For calculating the environmental footprints of the Swiss industries, environmentally extended input-output analysis was applied. Two input-output-based approaches were used, namely an environmentally-extended multi-regional input-output-analysis (EE-MRIOA) and environmentally-extended input-output-analysis of a single country combined with trade data and LCA (IO-TRAIL). In the first approach, the Swiss EE-IOT 2008 was used for the calculation of environmental impacts in Switzerland and combined with EXIOBASE for the calculation of environmental impacts in foreign countries. The second approach was used to complement the analysis with results for the environmental footprint according to the ecological scarcity method that cannot be calculated with the EE-MRIO database.

In a first step a screening of all Swiss industries was performed. Eight industries were then selected for further detailed analysis. These industries are: meat production, production of chemical products, production of machinery, real estate services and construction, health and social work, food trade, trade with clothing, textiles and footwear and trade with household devices.

The six environmental indicators greenhouse gas footprint, biodiversity footprint, eutrophication footprint, water footprint, air pollution footprint and environmental footprint were analysed. Industry-specific target values that can serve the industries as starting point for their reduction targets were derived from the planetary boundaries given for each environmental indicator and related to the economic industries analysed.

The analysis of economic impacts demonstrated how supply chains span across industries and countries for all analysed industries. Significant shares of total value added are induced in foreign countries. In all industries analysed, most of the environmental impacts do not occur in the industry itself, but in its supply chain.

The food related industries food trade and meat production cause the highest environmental impacts per gross output, which shows the high environmental intensity and relevance of food products. For these industries particularly relevant are the eutrophication and biodiversity loss footprints. Also relatively high environmental impacts per gross output exhibits the industry textiles trade, where the water and the greenhouse gas footprints are especially relevant. Other industries clearly have their hotspots in greenhouse gas emissions and air pollution, especially real estate services, machinery and household equipment trade. For the chemical and the health and social work industries the greenhouse gas footprint is most important.

With regard to the relevance of supply chain stages, the biodiversity, the water and the eutrophication footprints are dominated by raw material extraction and production, respectively. For the greenhouse gas and the air pollution footprint also other supply chain stages can be important, usually the intermediate suppliers between raw material extraction and direct suppliers. The effect of the industry itself is mostly small, if not negligible.

Measures to reduce the environmental impact of Swiss industries should therefore imperatively include the supply chains. As a first step, transparency over the supply chain should be created as far as possible. This allows the identification of hotspots in the supply chain and the development of targeted measures adapted to the respective manufacturer or raw material producer. There are various options for implementing environmental improvements in the supply chains: Specific environmental requirements can be taken into account in purchasing criteria and specifications. Cooperation with suppliers can lead to knowledge transfer and capacity building among suppliers worldwide. Product design changes (e.g. longer lifespans, lower material consumption or the use of more sustainable product components) can be an important lever for reducing environmental impacts in the supply chain. For industries related with food production or food trade, agriculture is the most important stage to be addressed. Reducing food waste has major leverage effects.

A crucial area affecting all industries is energy supply. In order to reduce greenhouse gas emissions below the limits of the earth’s carrying capacity, it is essential to replace fossil fuels with renewable energy sources at all stages of the supply chain and in the respective industry itself. This should be accompanied by measures to increase the energy efficiency. This applies not only to production but also to the use phase.

1 Background and project goal

1.1 Background

The 2030 Agenda for sustainable development, adopted by the member states of the United Nations in 2015, sets the globally applicable framework for national and international efforts to find shared solutions to the world's greatest challenges, amongst others climate change and environmental degradation. Sustainable development goal 12 aims at ensuring sustainable consumption and production patterns. It encourages companies to adopt sustainable practices and to integrate sustainability information into their reporting cycle (United Nations 2015). The CSR-Guidelines of the European Union demand that among other subjects, enterprises should have in place a process to integrate environmental concerns into their business operations with the aim of identifying, preventing and mitigating possible adverse impacts, also in their supply chains (European Commission 2011). Directive 2014/95 of the European Union (European Commission 2014) requires large companies to include a "non-financial statement" in their management report, which contains information on the effects of its activities on environmental issues. The World Business Council on Sustainable Development (WBCSD) states that four of the top five business risks are societal or environmental and prompts companies to include environmental, social and governance (ESG)-related risks into their enterprise risk management (ERM; COSO & WBCSD 2018).

With this study, the Federal Office for the Environment (FOEN) would like to promote environmental management in Swiss companies by identifying key sustainability issues and possible fields of action.

An enterprise has several basic options to reduce the life cycle environmental impacts caused by its products. It can reduce

- the direct environmental impacts related to its own production activities,
- the environmental impacts of the supply chains by changing the design of the products,
- the environmental impacts of enterprises in its supply chain through negotiation or choice of suppliers,
- the environmental impacts during use of its products (if there are any) and
- the environmental impacts of its products’ disposal.

At present, most of the environmental goals of Swiss companies relate to their own production activities (Daub et al. 2016). However, effective corporate environmental management and reporting crucially depends on identifying the most important levers in the supply chain. For small, open economies like Switzerland who are strongly involved in global trade, the importance of the supply chains is particularly high.

Frischknecht et al. (2018a) show that a significant proportion of the environmental impacts of Swiss consumption and production occurs abroad. This means that a great share of the environmental impacts of products manufactured in Switzerland are caused by precursor products manufactured in other countries. To enable companies to reduce their life cycle based environmental impacts in a targeted manner, identifying the most relevant value-added stages and processes with regard to their environmental impacts is of crucial importance. If these so-called environmental hotspots are known, companies can focus their efforts for resource-efficient innovations, their corporate environmental management and also reporting on these areas.

This is amongst others also increasingly acknowledged by the Global Reporting Initiative (GRI), who demands materialy disclosures in sustainability reports to reflect the organization's significant economic, environmental and social impacts.

1.2 Project goal and research questions

The overarching project goal is to contribute to increasing the awareness of Swiss companies for the environmental relevance of their supply chains in addition to their own direct environmental impacts, to identify environmental hotspots in their supply chains and to present options for Swiss companies to reduce their environmental footprint.

To reach this goal the environmental impacts of selected Swiss industries are analysed by including their supply chains and the use phase of their products, if relevant. Environmentally relevant industries are identified on the basis of selected footprint indicators. In doing so, the entire value chain from the extraction of raw materials through pre-production and direct suppliers to the environmental impacts in Swiss companies is examined. For products that are delivered to end customers and cause relevant environmental impacts during their use, the use phase is also taken into account. The drivers for the environmental impacts of the environmentally relevant industries are analysed in detail and carefully checked for plausibility. Options for improvement measures are being identified to support Swiss companies to efficiently and effectively reduce their environmental footprints.

The project provides answers to the following questions:

- Which industries cause particularly high environmental impacts considering their complete supply chain and the use phase of their end consumer products?
- Which industries are particularly important with regard to their supply chain based environmental impacts, their economic significance or their environmental improvement potential?
- Where in the value chain of selected industries do the environmental impacts occur?

- How big is the share of domestic environmental impacts? In which countries do the environmental impacts occur caused by imports of raw materials and products?
- Which raw materials, products and processes are responsible for a significant share in the environmental impacts of selected industries?
- Do the environmental footprints of the industries analysed in depth surpass the planetary boundaries or not?
- How do the Sustainable Development Goals (SDGs) relate to the relevant environmental impacts of industries?
- What measures help to efficiently and effectively reduce the environmental impacts of the industries analysed in depth?
- Which indicators are suitable to monitor the success of measures taken by the industries analysed in depth in reducing their environmental impacts by optimising production processes, supply chains and/or product designs?

1.3 Structure of this report

The methodology used is documented in Chapter 2. Chapter 3 contains the results of the process to select the industries for detailed analysis and Chapter 4 shows detailed results for the selected industries. Chapter 5 contains the synthesis of the results shown in the previous chapters, and Chapter 6 gives the conclusions and an outlook.

2 Methodology

2.1 Overview

In this project the environmental footprint of an industry is defined as the total environmental impacts caused by an industry's products from resource extraction to the factory (exit) gate. In the case of end user products causing relevant environmental impacts the use phase is also considered[1]. The post-consumer disposal stage is disregarded due to missing data on the actual disposal of each industry's products. Disposal services as intermediate inputs however are included in the supply chain. The scope thus includes the

[1] In contrast to other studies, the term "footprint" in this study thus does not cover the entire life cycle of a product (cradle to grave), but only its production (cradle to gate) and - if relevant - its use.

- direct environmental impacts of the industry itself,
- environmental impacts of the industry's complete supply chain, i.e. all economic activities from resource extraction to the factory (entry) gate of the industry's enterprises and
- the environmental impacts occurring during the entire use phase of the industry's end user products (if relevant).

Whereas the calculation of environmental footprints of single enterprises is often done with life cycle assessment, calculating the environmental footprints of whole industries calls for a different approach due to their large heterogeneity with regard to companies, products and supply chains, which can involve many different industries and countries. Environmentally extended input-output analysis allows for analysing the impact of economic activities on environmental impacts at the industry level and for tracing supply chains across industries and countries. Two input-output-based approaches can be distinguished, namely

- environmentally-extended multi-regional input-output-analysis (EE-MRIOA, used e.g. by Jungmichel et al. 2017) to analyse environmental hotspots in the supply chains of German industries and
- environmentally-extended input-output-analysis of a single country combined with trade data and LCA (IO-TRAIL[2]).

Both approaches are used in this study to complement each other's strengths and limitations. The two methodologies are described in Subchapter 2.2, their respective databases in Subchapter 2.3.

In this study six environmental indicators are used to characterise the environmental footprints of the Swiss industries. They are described in Subchapter 2.4. The industries' environmental footprints refer to the current situation. Industry-specific target values that can serve the industries as starting point for their reduction targets are derived from the planetary boundaries given for each environmental indicator and related to the economic industries analysed. Subchapter 2.5 explains the derivation of these reduction targets.

In a first step a screening of all Swiss industries is performed to select eight industries for further detailed analysis (cf. chapter 3 for details and the screening results). The screening includes an estimation of all industries' six environmental footprints and the collection of other information used in the industry selection process (e.g. industry size and growth, share of small and medium enterprises). Eight industries are then selected based on a set of objective criteria as well as having a good mix of different industries in mind.

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2 TRAIL: Trade-Information and LCA

In a second step a detailed assessment of the eight selected industries is then performed including

- a detailed analysis of the environmental footprints,
- an assessment of their environmental impact reduction requirements based on a comparison to planetary boundaries and
- the elaboration of options and measures to reduce the environmental footprints, of monitoring indicators to evaluate progress and of instruments and guidelines that may prove helpful to companies.

The methodological approach chosen for the calculation of industry footprints and the assessment of reduction requirements are described in the following subchapters.

2.2 Calculation of industries' environmental footprints

As mentioned above two approaches were used to calculate the industries' environmental footprints. The EE-MRIO approach was used as the primary approach since it allows to quantify the contribution of industries and countries to the footprint. The IO-TRAIL approach was used to complement the analysis with results for the environmental footprint according to the ecological scarcity method that cannot be calculated with the EE-MRIO database.

2.2.1 Environmentally-extended multi-regional input-output-analysis

The environmental footprints of industries are analysed using environmentally-extended multi-regional input-output tables (EE-MRIOT). This approach is widely used in applied economics to analyse global value chains and in environmental economics, e.g. to assess the consumption footprint of nations.

An EE-MRIOT consists of an economic core (MRIOT) that is extended with environmental indicators. The MRIOT records the flow of goods and services between countries at the industry level. It consists of three submatrices (cf Figure 2.1),

- a matrix of interindustry flows of goods and services (mrIOT[3] in the figure),
- a matrix of flows from industries to final demand (consisting of consumption of private households, non-profit organisations and government as well as gross capital formation; mrFinalDemand in the figure),
- a matrix of factor inputs in industries mainly consisting of gross value added (mrFactorInputs).

[3] mr: multi-regional

The MRIOT disaggregates the global economy into several countries and regions and each country or region into several industries. Each entry of the interindustry matrix contains the flow of goods and services from a specific industry in a specific country to a specific industry in a specific country.

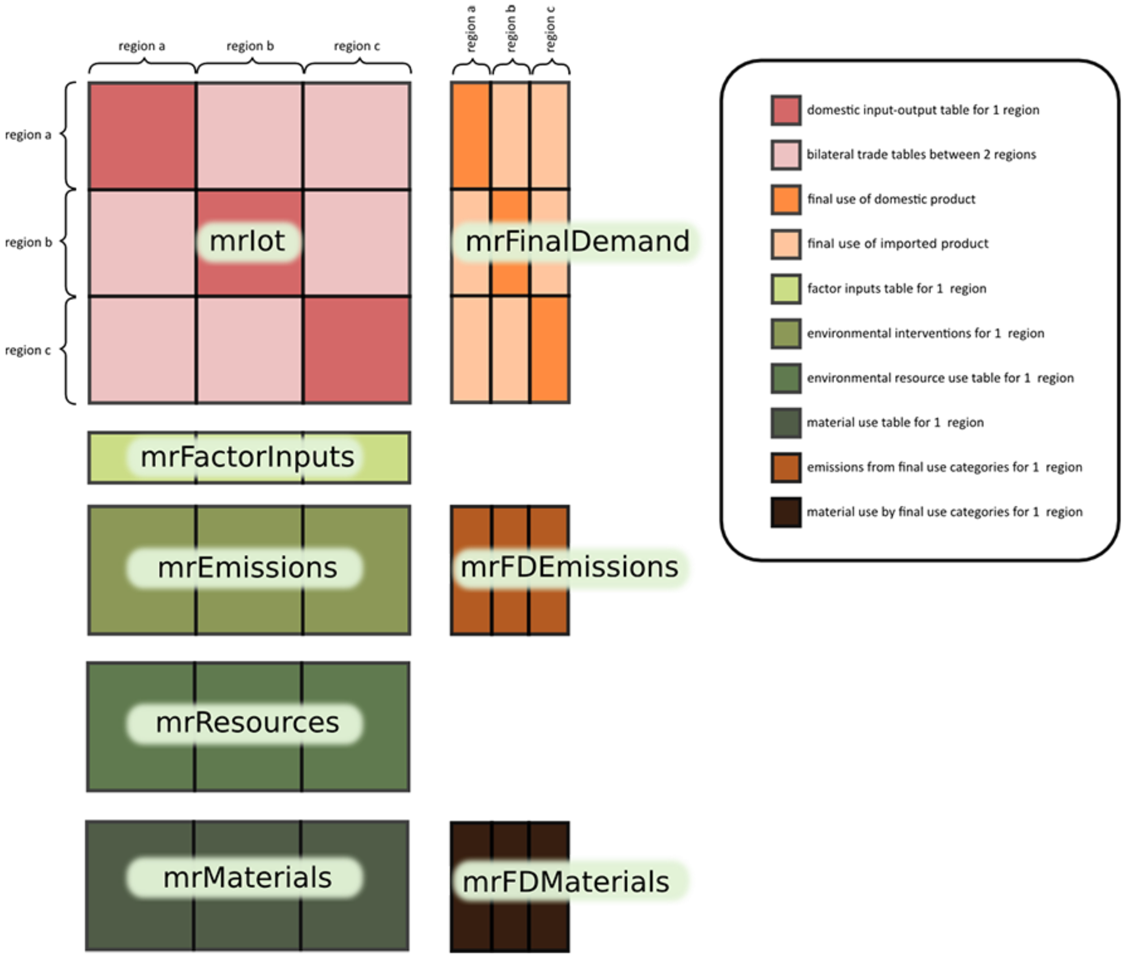

Figure 2.1: Scheme of an environmentally extended multiregional input-output table (Source: http:/www.exiobase.eu)

This economic table is extended with an environmental part, which contains country- and industry-specific data on direct environmental impacts (emission of pollutants and use of resources; matrices mrEmissions, mrFDEmissions, mrResources[4], mrMaterials and mrFDEmissions in the figure). The environmental impacts of each industry (and private households) in each country are recorded and allow to calcu-

[4] The term «resources» is used in the Exiobase database for land use, whereas the term «materials» is used for the use of other resources like raw materials and water

late industry specific environmental impact intensities, measured as environmental impact per unit of industry output.

This MRIOT allows to calculate the environmental footprint of any industry in any country, including its complete supply chain until the factory exit gate. The use phase needs to be calculated separately. The main calculation steps are the following:

- The focal industry's output is multiplied with the so-called Leontief inverse derived from the interindustry matrix of the MRIOT. This calculation delivers the output in each industry in each country induced by the focal industry's output (i.e. the industry's complete supply chain across industries and countries). The result is adjusted to eliminate double-counting of intermediate inputs of the focal industry.
- The industry output in each country is multiplied with the industry specific environmental impact intensities to yield the total environmental impacts in each industry in each country. The total of environmental impacts across industries and countries is equal to the environmental footprint of the focal industry.

In this study we used a variation of this approach. In EXIOBASE, the EE-MRIOT used in this project, the data for Switzerland are based on the official Swiss IOT for 2008. In a recent project a new version of the Swiss IOT 2008 was developed, that includes substantial disaggregation and improved data quality for the environmentally relevant energy, transport and food sectors and a wide range of environmental data (Nathani et al. 2016, Frischknecht et al. 2015). We therefore used a two-step approach, combining the new Swiss EE-IOT for the calculation of environmental impacts in Switzerland and EXIOBASE for the calculation of environmental impacts in foreign countries. In this two-step approach the calculation steps are as follows:

- Starting with the total production output of the focal industry, the total output and gross value added induced in other Swiss industries are calculated with the Swiss EE-IOT. The results are again adjusted to eliminate double-counting of intermediate inputs of the focal industry.
- The environmental impacts in Swiss industries are then determined by multiplying the output with industry-specific environmental impact coefficients as reported in the Swiss EE-IOT.
- The calculation also yields the imports by product group that are induced in the supply chain of the focal industry. These imports are then distributed to source countries. For this a table of product-group specific country shares was developed, distributing imported product groups to source countries. The table was derived from the Swiss foreign trade statistics (for source countries of goods), the Swiss balance of payments and the OECD-WTO Balanced Trade in Services Statistics (for source countries of services). The table distinguishes between im-

ported product groups used for intermediate consumption and for final consumption.

- The imports by product group and source country are then fed into EXIOBASE, which is used to calculate the total output in all industries in all countries induced by these imports and the total environmental impacts caused by these foreign production activities. The environmental impacts are quantified using the selected footprint indicators described in Subchapter 2.4.

A further adaptation of the approach refers to the inclusion of investment goods into the supply chain calculations. In input-output tables only the use of intermediate inputs in industries is recorded and included in the calculation of output multipliers. The use of investment goods in industries is recorded in total as depreciation in the factor inputs matrix, but not allocated to supplying industries. We therefore roughly estimated the use of investment goods in the industries by distributing each industry's depreciation to product groups. The estimation of the investment matrix in the Swiss EE-IOT is explained in Nathani et al. (2018). It includes the estimation of each industry's depreciation (distinguishing between buildings and other equipment) and the distribution of depreciation to supplying industries (e.g. construction, machinery, planning) with shares from the final demand matrix and assuming same shares for all investing industries, since specific data are not available. In the Exiobase MRIOT each industry's depreciation is recorded but it is not differentiated between buildings and other equipment. We therefore assumed that depreciation of the real estate services industry can be fully allocated to construction and that depreciation of other industries can be allocated to supplying industries according to the shares from the final demand matrix (after deduction of the above-mentioned construction values).

The investment matrix was then included in the calculation of multipliers that are used to determine total output effects.

The following Table 2.1 displays the elements of this approach.

Table 2.1: Elements of the adapted EE-MRIOT approach (Source: own depiction)

	Results		
	Output and value added	**Imports into Switzerland**	**Environmental impacts**
Focal industry	Swiss EE-IOT		Swiss EE-IOT
Domestic suppliers	Swiss EE-IOT		Swiss EE-IOT
Imports into Switzerland (by country of origin)		Swiss EE-IOT, Swiss and OECD trade statistics	-
Suppliers in foreign countries	EE-MRIOT		EE-MRIOT

The results of these calculations are

- total economic output and gross value added in all industries and all countries caused by the focal Swiss industry's production activities,
- total environmental impacts in all industries and all countries caused by the focal Swiss industry's production activities.

The economic and environmental impacts are structured by supply chain stages, distinguishing between the focal industry itself, direct suppliers to the focal industry, resource extraction industries and other industries of the supply chain. Resource extraction industries are defined as agriculture (NOGA 2002: 01), forestry (NOGA 2002: 02), fishery (NOGA 2002: 05) and mining and quarrying (NOGA 2002: 10 - 14). When direct suppliers belong to the resource extraction industries, they are recorded in the latter group, not as direct suppliers.

In a different perspective the environmental impacts are allocated to the direct suppliers. Thus each direct supplier is presented with its total (cradle to exit gate) environmental footprint. In this perspective the total environmental footprint of the focal industry comprises its direct environmental impacts and the environmental footprints of its direct suppliers. This perspective allows the companies from an industry to prioritise the suppliers that they should address for optimisation measures.

2.2.2 Environmentally-extended input-output-analysis combined with trade data and LCA (IO-TRAIL)

The second approach was originally developed to estimate the environmental footprint of Swiss consumption (Jungbluth et al. 2011). It relies on two elements,

- the above mentioned Swiss EE-IOT, but with a different representation of imports,

- LCA data to calculate the environmental impacts of imported products.

In this version of the Swiss EE-IOT the representation of imports distinguishes between goods and services. The use of imported goods by industries and final demand is recorded in physical units and follows the SITC classification used in trade statistics. This allows to link the imported goods to LCA data that are used to calculate the environmental impacts and are available in physical units. The import of services is recorded in monetary units.

The Swiss EE-IOT was used as described above to calculate domestic production, value added and environmental impacts induced by the focal industry in the domestic industries. It was also used to determine the induced imports by product group.

The environmental impacts of imported products were calculated with LCA data. In a first step, a representative product mix from the LCA database was chosen for each imported product group and linked to the import volume. Approximately 400 product groups are distinguished. The environmental impacts of imported services were determined with data used in Jungbluth et al. (2011).

With regard to the investment effect, investment goods were included in the calculation of supply chain effects with the Swiss EE-IOT in the same way as mentioned above and also in the LCA data used to determine the environmental impacts of imported products.

The following Table 2.2 displays the elements of this approach.

Table 2.2: Elements of the IO-TRAIL approach (Source: own depiction)

	Results	
	Production and value added	**Environmental impacts**
Focal industry	Swiss EE-IOT	Swiss EE-IOT
Domestic suppliers	Swiss EE-IOT	Swiss EE-IOT
Suppliers in foreign countries	-	Products: LCA software Services: Data from Jungbluth et al. (2011)

The results of these calculations are total environmental impacts caused by the focal industry's production activities, distinguishing between the focal industry itself, Swiss industries from the supply chain and foreign industries from the supply chain. A further differentiation by supply chain stage (resource extraction industries and other industries, respectively) and source country is not possible.

2.2.3 Environmental impacts during the use-phase

Due to the importance of energy and water consumption and emissions during the use phase, the production perspective for selected products that are in demand by end customers and for which the environmental impacts of the use phase are considered relevant has been extended to include the use phase.

The use phase of products used by other industries (and not by private or public households) was not allocated to the manufacturer’s supply chain, but to the supply chain of the (industry) users of these products. The operating energy and emissions from the use of machines, for example, were included in the energy and mass flow of the industries using these machines. Electricity use during use phase was modelled with the Swiss electricity mix 2014 (“Versorgungsmix”, including electricity production in Switzerland and imports, see Messmer & Frischknecht 2016b).

Energy and water consumption, emissions to air, water and soil and land use were taken into account over the entire service life of products. While the industries’ environmental footprints, based on the Environmental IOT and Exiobase, depict the supply chains in 2007/2008, today's products were considered for calculating the environmental impacts of the use phase, taking into account data availability. In this way, the improvements in energy efficiency achieved in the last about 10 years are taken into account.

The industries for which the use phase has been taken into account are listed in Table 2.3.

Table 2.3: List of industries where the use phase of the products has been taken into account

Number	Industry name
23	Manufacture of coke, refined petroleum products
24 w/o 24.4	Chemicals and chemical products*
30, 31	Manufacture of office machinery and computers + Manufacture of electrical machinery and apparatus n.e.c.
32	Manufacture of radio, television and communication equipment and apparatus
40g	Gas supply
45 / 70, 97	Construction / real estate services*
50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel

* industries analysed in depth

The environmental impacts during the use phase of the products were calculated using life cycle assessment data. They were related to one year in order to be able to compare them with the environmental impacts of the annual production of the industry in question.

2.3 Data basis

2.3.1 Overview

To calculate environmental footprints with the approaches described above we used three databases:

- the environmentally extended IOT for Switzerland, developed in the framework of the NRP 69 project "Sustainable agri-food systems" (Nathani et al. 2016, Frischknecht et al. 2015)
- the EE-MRIOT Exiobase (Stadler et al. 2018) and
- the KBOB life cycle inventory data DQRv2:2016, based on ecoinvent data v2.2.

These databases are described in the following sections.

2.3.2 Environmentally extended IOT Switzerland 2008

To calculate environmental impacts within Switzerland, a Swiss EE-IOT was used that was recently developed in the framework of the NRP 69 project "Sustainable agri-food systems" (Nathani et al. 2016, Frischknecht et al. 2015). Compared to the official Swiss IOT, it is characterised by a larger number of industries (roughly 100 vs. 50), especially detailed with regard to the energy, transport, agriculture and food industries that are particularly relevant from an environmental perspective. Furthermore the quality of the data representing these industries was improved. The economic part of the IOT is complemented with roughly 100 environmental indicators (emissions of pollutants and resource uses) of industries and private households that can be aggregated to various midpoint and endpoint indicators (including the Swiss eco-points according to the ecological scarcity method 2013). The reference year of the Swiss EE-IOT is 2008. The industry classification follows NOGA 2002.

The Swiss EE-IOT distinguishes between the use of domestic and imported products in industries and final demand. Imported products are recorded both in monetary and physical units. This allows linking the Swiss EE-IOT both to Exiobase (monetary units) and to LCI data (physical units).

2.3.3 Environmentally extended multiregional Input-Output-Table Exiobase

Exiobase is a multiregional IOT that has been developed by European research consortiums in various projects. Compared to other MRIOTs (e.g. GTAP, WIOD, OECD) it is characterised by high sectoral detail and a large set of environmental indicators.

Exiobase contains data covering 44 countries, including the EU 27 countries, other OECD countries and large emerging countries and five aggregated world regions. 200 branches and product groups are distinguished, which is substantially more than other MRIOT databases offer. In total, Exiobase contains data on 417 environmental indicators that represent emissions and resource use by industries and private households. It covers the years 1995 to 2011. The previous version Exiobase 2 refers to the year 2007. Whereas Exiobase 3 has advantages with regard to time series and the quality of the environmental data, we found that its economic data (e.g. sectoral output) partly show significant deviations from official national accounting data and input-output tables. On the other hand the economic data in Exiobase 2 show smaller deviations from official data on average, especially with regard to Switzerland's main trading partners. Since our aim was to link Exiobase with the Swiss EE-IOT, we used Exiobase 2 for the economic data. Due to the more advanced representation of the environmental indicators, we used the environmental data from Exiobase 3.4. Both Exiobase versions show the same number of industries and product groups and a similar number of countries[5]. Therefore it was possible to combine the two data sets.

In this project data for the reference year 2007 were used to ensure compatibility between economic and environmental data and proximity to the reference year of the Swiss EE-IOT (2008). The industry classification of Exiobase follows NACE rev. 1.1, which is similar to the Swiss classification NOGA 2002.

2.3.4 KBOB life cycle inventory data DQRv2:2016

The data basis used to model the imports in the IO-TRAIL approach is the KBOB LCI data DQRv2:2016 (KBOB et al. 2016). These data are based on ecoinvent data version 2.2 (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 KBOB LCI data DQRv2:2016. In addition, data from the World Food Life Cycle Inventory Database (Nemecek et al. 2015) representing many of the imported food products were embedded in the KBOB Life Cycle Inventory data DQRv2. These data have been regionalised in a project on the environmental footprint of the consumption of Switzerland from 1996 to 2015 (Frischknecht et al. 2018a). In addition, a number of LCI data, in particular datasets representing power production and mining of minerals and metals have been adapted by including country-specific land and water flows (see Frischknecht et al. 2018b). Remaining gaps in the KBOB LCI data were filled with life cycle inventory data from the company's own LCA database (treeze Ltd. 2017).

2.3.5 Methodological assumptions and limitations

Estimating the environmental footprint of industries is a highly complex issue that requires large amounts of data. The main reasons for this level of complexity in-

[5] Exiobase 2 excludes Croatia.

clude the heterogeneity of industries comprising many different companies with individual supply chains, the complexity of supply chains in a global economy spanning across many industries and countries and the variety and industry- and country-specificity of emissions and resource uses induced by production activities and their environmental impacts.

The tools used in this project to trace these highly complex supply chains are sophisticated, but still come with certain methodological assumptions and limitations that are briefly summarised in the following.

With regard to the EE-MRIOT, the main assumption used in IO modelling is that the industries and product groups are assumed to be homogeneous. This means that each industry produces a homogeneous product mix that is delivered to all industries and final demand categories. Resource and emission intensities of industries are constant for all destinations of industry products. Since industries are the lowest level of aggregation in the IOT it is not possible to represent heterogeneity with regard to input and output structures or resource and emission intensities below the industry level (e.g. emission intensities of export-oriented companies vs. companies oriented towards the domestic market). Due to this homogeneity assumption, modelling with Exiobase generally assumes that the environmental footprint of the exports of a specific industry in a specific country equals the average environmental footprint of the exporting industry.

The use of an EE-MRIOT entails the monetary allocation principle as opposed to the physical allocation principle mostly used in LCA. This means that the environmental footprint of an industry in a supply chain is allocated to its upstream “customers” according to their monetary share in the industry’s output.

These assumptions also apply analogously to the IO part of the IO-TRAIL approach (Swiss EE-IOT).

The imports modelled with LCA data in the IO-TRAIL approach refer to typical products of the corresponding SITC category. These categories are the lowest level of aggregation. This means that the imports do not necessarily reflect the products actually imported by a particular industry, but the production mix in the corresponding SITC category to which the imported products of that industry belong.

2.3.6 Data quality and uncertainties

In recent years significant resources have been invested to improve EE-MRIOT and LCA databases that are able to cover the global supply chains, but the data are still prone to uncertainties. With regard to the Swiss EE-IOT the following uncertainties are relevant for the study at hand:

The Swiss IOT represents an estimation of the flows of goods and services in Switzerland. It is classified by the Swiss OFS as an experimental statistics, since certain basic statistics used in other European countries to build IO tables are missing in Switzerland. This especially holds for commodity statistics and for statistics on the intermediate inputs of companies. While the sum of intermediate inputs is based on the official production account, the intermediate inputs of industries in the Swiss IOT are estimates based on input structures of similar industries in other European countries. In the construction process of the Swiss IOT the input structures can be subject to adjustments if necessary to balance disequilibriums between product supply and demands. In the Swiss EE-IOT 2008 the data quality of food, energy and transport data have been improved and based on Swiss statistics (cf. Nathani et al. 2013, Nathani et al. 2016). Yet, it is still important in the context of this project to check the plausibility of the industry inputs before using them in the calculations, e.g. by comparing them to input structures in other countries.

With regard to imported goods, the total imports are well-founded on trade statistics (with larger uncertainties for services than for goods), but the allocation of imported products to using industries and final demand categories is uncertain. In the development of the Swiss EE-IOT 2008 (Nathani et al. 2016) we have used detailed data from the Swiss foreign trade statistics and correspondence tables between detailed import commodity codes and use categories from the OECD to distinguish between intermediate and final uses of imported goods. We have then applied the commonly used proportionality assumption to further distribute goods for intermediate use to using industries. Thus the use of imported goods by industries is an estimate with uncertainties.

The allocation of emissions and resource uses to industries is for a larger part well-based on environmental statistics, but partly based on auxiliary indicators such as monetary or physical output or employment.

The imports in the IO-TRAIL approach have been modelled with LCA data. The latest available, regionalised data from the KBOB LCI database DQRv2:2016 (KBOB et al. 2016) and the World Food Life Cycle Inventory Database (Nemecek et al. 2015) have been used for this purpose. However, regionalised data sets could only be used for the most important products in terms of volume from the main import countries. The remaining products and countries of origin were modelled using non-regionalized data sets. Since regionalisation mainly affects biodiversity loss and water consumption and these two indicators were calculated using the EE-MRIO approach, this has no major impact on the uncertainty of the results.

The composition of the aggregated import groups according to the SITC categories could have a larger impact. If the composition of the imported products of a specific industry deviates greatly from the composition of the respective SITC group, this can lead to distortions in the environmental intensity of the respective imported products. This uncertainty was minimized by comparing the results according to the IO-TRAIL method with the results according to the EE-MRIO approach and verifying the contributing direct suppliers and imports.

With regard to the EE-MRIOT Exiobase, to our knowledge the available information on global production activities and their environmental impacts has largely been used in several large-scale projects to construct the database. Yet the following data uncertainties remain and are relevant for this study:

The quality of data on economic output and gross value added differs between countries. While the data quality of values is rather high at the aggregate sectoral level, data uncertainties can be larger for sectorally disaggregated data. This is especially true for emerging and developing countries.

The uncertainties increase with regard to the quality of input-output tables that depict the flows of goods and services within countries. Even though data quality has increased over the past years there still exist large differences between countries regarding the timeliness, disaggregation level, quality and international comparability of input-output tables. Exiobase uses elaborate algorithms to integrate the existing data into a coherent framework while minimising information loss.

Regarding import and export data past analysis has shown that significant differences can exist between bilateral trade data that trade partners report. Empirical research projects have aimed at reconciling trade data and these reconciled data have been included in Exiobase but uncertainties still remain.

Regarding environmental data, the available international statistics on resource use and emissions have extensively been exploited in the construction of Exiobase. Yet uncertainties exist in the allocation of emissions and resource use to single industries, especially with regard to emerging and developing countries and the five rest-of-the-world regions in Exiobase, where emission intensities have partly been roughly estimated by using auxiliary indicators such as value added.

We have dealt with these uncertainties by

- checking the plausibility of the input structures of the eight Swiss industries analysed in detail and adjusting the input structures in two cases (‘chemical industry’ and ‘health and social work’),
- capping the environmental intensities of industries in the aggregated world regions to the maximum of countries included in the database. Our first results have shown that the aggregated world regions have a strong influence on results. Since the data uncertainties for environmental intensities are especially large for these regions, we have introduced the caps. Therefore the results may partly be underestimated.

Even though the data used in this study are probably the best available to analyse the environmental impacts of supply chains at the industry level, due to the high complexity of global supply chains and environmental impacts and the mentioned data uncertainties, the results of the calculations should be regarded as estimates for Swiss industries that help identify the possible hot spots in their supply chains. Yet, at the company level, the supply chains and their environmental impacts can differ strongly from the industry averages presented in this study. Therefore companies can use the results as hints for identifying environmental hot spots, but they still need to analyse their own supply chains in detail to be able to improve their environmental performance.

This project uses data for the reference year 2008, since this is the reference year for the most recent Swiss EE-IOT. Exiobase data with the reference year 2007 are used to match the Swiss data. The most recent reference year, for which Exiobase data are publicly available, is 2011. Such a time lag is not unusual for EE-IOTs due to the fact that large amounts of data need to be collected and processed into a common framework. The use of this reference year could have the following impact on the results:

- At the time of completion of this report the share of emerging countries (esp. China) in the Swiss industries' supply chains is probably larger than in 2008. Thus our results may underestimate the environmental footprints of Swiss industries if we assume that emerging countries have larger environmental footprints than developed countries.
- On the other hand technical progress may have reduced the environmental intensities of industries since 2008, thus leading to an overestimation of results and reducing the former effect.

The imports modelled with LCA data in the IO-TRAIL approach refer to the latest available data and generally reflect current practices. However, in the event of major changes in practice or decisive technical progress in recent years, the environmental impact could be under- or overestimated. This uncertainty lies within the general uncertainty range of the LCA data.

2.3.7 Data provision

The entire database described above is published on the treeze website and is available for further assessments at http://treeze.ch/projects/case-studies/lifestyles/environmental-footprints-of-switzerland-developments-from-1996-to-2015. The life cycle inventories are offered in the ecospold v1 (xml) format and the impact assessment methods are provided in the SimaPro csv format. They are licensed under a Creative Commons Attribution-ShareAlike 4.0 International License. In order to download the data, interested people are required to register and login. A detailed read-me with information on how to implement and use the data is available as well.

2.4 Environmental indicators

2.4.1 Greenhouse gas footprint

The climate change effect of greenhouse gases is expressed by the Global Warming Potential (GWP) according to the 4th Assessment Report of the Intergovernmental Panel on Climate Change (expressed in kg CO_2-equivalents according to IPCC

2007). 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 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.

2.4.2 Biodiversity footprint

Land use is one of the major causes of biodiversity and species loss. The indicator “potential species loss from land use” (Chaudhary et al. 2016) quantifies the damage potential of land use on biodiversity. The indicator quantifies the loss of species in amphibians, reptiles, birds, mammals and plants by the use of arable land, permanent crops, pasture, intensively used forest, extensively used forest and urban areas. The indicator weights endemic species higher than species that are common. Species loss is determined in relation to the biodiversity of the natural state of the area in the region concerned. The indicator aggregates the regional loss of commonly occurring species and the global loss of endemic species into “globally lost species”. By that, the indicator aggregates differing impact intensities into a common unit, similar to the unit “kg CO_2-equivalents” used to aggregate greenhouse gas emissions (see above). The biodiversity footprint is expressed in equivalents of potentially globally lost species per million species (micro PDF·a). The indicator covers only a small share of all endangered species listed on the “red list”. This indicator was recommended by the UNEP SETAC Life Cycle Initiative as best available indicator for the time being ("interim recommendation"; Chaudhary et al. 2015; Chaudhary et al. 2016; Frischknecht & Jolliet 2016).

2.4.3 Eutrophication footprint

The release of nitrogen into the environment causes a wide range of problems. The most obvious of these is marine eutrophication ("over-fertilization" of the Oceans):

The indicator used in this study quantifies the amount of nitrogen that potentially enters the oceans through the emission of nitrogen compounds in water, air and soil and thus may contribute to over-fertilization (Goedkoop et al. 2009). Nitrogen quantities are taken into account according to their marine eutrophication potential (kg N-equivalents).

2.4.4 Water footprint

The water footprint describes the extent to which a Swiss industry uses the global freshwater resources, taking into account the prevailing water scarcity in the production regions. The water footprint is quantified using the water scarcity indicator AWARE, recommended by the UNEP SETAC Life Cycle Initiative (Boulay et al. 2017). The AWARE indicator is based on the assumption that decreasing water availability in a region increases the likelihood that other users will be deprived in their access to water. The indicator quantifies the available water quantity per catchment area by subtracting the water requirements of humans and ecosystems from the amount of naturally available water.

2.4.5 Air pollution footprint

Air pollution and in particular fine particles have a major impact on human health and well-being. Thus the air pollution footprint is characterised with primary and secondary particles and the associated effects on human health, such as respiratory diseases (Goedkoop et al. 2009). The emissions of the particulate matter precursors NO_X, SO_2 and NH_3 are converted to kg PM_{10}-equivalents according to their potential to form particulate matter.

2.4.6 Environmental footprint (UBP-method 2013)

The method is based on Switzerland's legally or politically defined environmental goals (distance to target) and evaluates resource extraction (energy, primary resources, water, land), pollutant inputs into the air, water and soil, waste and noise (Frischknecht & Büsser Knöpfel 2013). The indirect additional climate change effects of stratospheric emissions from aircrafts are taken into account (see Section 2.4.1). The method is also called the Ecological Scarcity Method (UBP) and is used by numerous Swiss companies.

2.4.7 Normalisation

In order to illustrate the relevance of the environmental footprints of the selected industries, the share of their environmental footprints in the respective global environmental footprint was determined for each industry and expressed in parts per million (ppm). Additionally, the share of the gross production value of the selected industries in global gross production value was calculated. A comparison of the share in environmental footprints with the share in gross production value indicates whether the industry's environmental footprint intensities are above or below average.

2.5 Target values for industries based on planetary boundaries

2.5.1 Global limit values

Based on the planetary boundaries (Steffen et al. 2015), global limit values (or "budgets") for footprints are deduced. For determining those limit values the methodological approach from Dao et al. (2015) was adopted and applied to the environmental indicators analysed in this study. In addition, new and further findings from Steffen et al. (2015) were taken into account.

Limit values based on planetary boundaries are defined for the greenhouse gas, biodiversity, eutrophication and air pollution footprints. Planetary boundaries are usually defined on a global level[6]. Water availability and scarcity depends very much on the geographic location. Water shortage in one region cannot be compensated by excess water in another region. Thus we refrained from defining a planetary boundary for the water footprint.

According to the calculations of Dao et al. (2015), the global yearly limit for greenhouse gas emissions is 12.3 Gt CO_2-eq per year. For agricultural nitrogen losses, the global yearly limit equals to 47.6 Mt (Dao et al. 2015). For the biodiversity and the air pollution footprints, the global limits were set according to Frischknecht et al. (2018a):

For biodiversity, Steffen et al. (2015) propose to define the naturally occurring loss of species as an estimate and quantify the globally tolerable loss of species per year with less than 10 species per million species (with an uncertainty range of 10 to 100 species per million species). With a starting point in the year 500 as a reference state of unaffected nature[7], by 2008 some 15,000 species would have been lost naturally. This value was therefore used as limit value for comparison with long term potential global species loss due to land use.

For the air pollution footprint, determining a limit value based planetary boundary is also difficult, as the extent of the overall impact on human health depends heavily on where the particles or their precursors are emitted. The comparison of the current annual emissions of PM10 and the particulate matter precursors NOX, NH_3 and SO_2 in Switzerland with the amounts in compliance with Switzerland's Ordinance on Air

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[6] For more information about the concept of planetary boundaries, see https://www.stockholmresilience.org/research/planetary-boundaries/

[7] Beginning of large-scale deforestation and thus the man-made loss of biodiversity in Central Europe.

Pollution Control (OAPC; LRV 2009) (both converted into particulate matter equivalents) results in a reduction requirement of around 39%. As a conservative assumption, we can also apply this reduction requirement to foreign emissions and set the necessary global reduction at 39 %.

Table 2.4 shows an overview of the yearly emission budgets available for each indicator, the worldwide emissions during the year 2008 and the necessary reduction. The reference year 2008 was used to ensure compatibility with the Swiss EE-IOT (see Chapter 2.3.3).

Table 2.4: Yearly emission budgets, global emissions in the year 2008 and the necessary reduction at global level for each environmental indicator analysed

Environmental indicator	Unit	Limit value for global footprint [reference year]	Current global environmental footprint (2008)	Necessary reduction (global level)	Source
Greenhouse gas footprint	Mt CO_2-eq./a	12‘300	50‘800	76%	Dao et al. 2015
Biodiversity footprint	10^{-6} PDF*a/a	15‘000	88'901	83%	Steffen et al. 2015; Frischknecht et al. 2018a
Eutrophication footprint	Mt N/a	47.6	55.6	14%	Dao et al. 2015
Air pollution footprint	Mt PM_{10}-eq/a	65.3	106.3	39%	Frischknecht & Büsser Knöpfel 2013

2.5.2 Concepts deriving "One Planet" target values for industries

In order to be able to make a statement on the compatibility of the environmental footprint of a particular industry with the limits of the earth's carrying capacity, the budgets available have to be divided between the different industries and countries. Several different approaches are conceivable to do this. Sabag Muñoz and Gladek (2017) categorize the existing approaches into

1. Egalitarian approaches (equal share)
2. Approaches based on economic throughput
3. Approaches based on economic capacity and efficiency
4. Historical approaches (taking into account responsibility for previous impacts or the need for a continuous access for resources).

Similarly, Höhne et al. (2014) propose the categories of (1) Equality (2) Cost effectiveness (3) Capability and (4) Responsibility. Criteria like equality and responsibility suggest that there is no single and objectively “correct” way of allocating (Sabag Muñoz and Gladek 2017). Whatever allocation principle is chosen, the results on the need for reduction must be seen as a starting point for discussion, not as authoritative target values.

When choosing the allocation approach, it is important to take into account the perspective adopted. For example, the socially ideal principle of egalitarianism is currently impossible to implement in a company context (Sabag Muñoz & Gladek 2017).

In this project we focus on industries and aim at providing a science base to support companies in their process of setting environmental targets. Considering all feasible alternatives, the best way forward for companies would be to establish impact ceilings based on demand trends, sectoral performance and best practices, and costs of impact abatement. These impact ceilings and target settings should ideally be developed and determined under the stewardship of civil society organisations (Sabag Muñoz & Gladek 2017). An example of such a civil society organisation is the Science Based Target initiative[8], which helps companies to determine how much they must cut their greenhouse gas emissions, with the overall goal of keeping global temperature increase below 2º C. The Science Based Target initiative differs between two main approaches to allocate emissions at company level (CDP et al. 2017):

1. Convergence, where the emissions intensities of all companies from a given industry converge to that required by a global 2º C pathway by 2050; and
2. Contraction (related to intensities or absolute amounts), where all current sources of emissions reduce at the same rate disregarding cost, equity, or growth factors.

The convergence of emission intensity approach assumes that the emission intensity of all companies within a given industry converges towards the respective planetary boundary based intensity (e.g. 2º C carbon intensity) of that industry at a rate that ensures the sectoral budget is not exceeded. This method can only be used with emissions scenarios that disaggregate emissions at the sector level. So far, such emission scenarios have only been available for selected industries in the area of greenhouse gas emissions (see CDP et al. 2015).

The contraction approach can be applied to emission *intensities* or *absolute* emissions.

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[8] www.sciencebasedtargets.org, visited on 13.2.2018.

- The contraction of emission *intensity* approach assumes that all companies within the same level of disaggregation (i.e. industry, region or globally) reduce their emission intensity at a parallel rate that ensures the respective planetary boundary based budget (e.g. 2° C carbon budget (industry, region or global)) is not exceeded. The rate of contraction is a function of the emission budget and the expected level of activity for the sector or region concerned. Activity can be expressed using economic (e.g. value added) or physical (e.g. ton of product) indicators. The challenge with intensity approaches is effective modelling of the denominator (e.g. Euro GDP) to ensure the emission budget is not exceeded (CDP et al. 2015).

The contraction of *absolute* emissions assumes that all companies within the same level of disaggregation (i.e. sector, region or globally) reduce emissions at the same rate. The rate of contraction is purely a function of the overall reductions implied in the corresponding emissions scenario. Using this approach, all companies have to reduce their emissions by the same amount. The contraction of absolute emissions approach has been applied in this study and is used for allocating the above mentioned global budgets to the different industries. It corresponds to the grandfathering principle[9]: Industries with high initial (actual) environmental impacts will be allowed higher target values than industries with low initial environmental impacts. However within a given industry the individual companies are attributed the same target values in a given year.

2.5.3 Implementing the contraction approach

The contraction of absolute emissions approach was implemented as follows:

- First, the current absolute environmental footprints (i.e. including the whole supply chain, and the use phase in the sectors “construction” and “equipment trade”) of the Swiss industries were quantified.
- Then the industry-specific target values were determined by multiplying the respective relative global reduction requirement with the current absolute environmental footprint of each Swiss industry.

Specific Swiss reduction requirements are available for the greenhouse gas and the eutrophication footprints (see Table 2.5). For these two footprints the industry-specific target values were derived using a weighted average of the Swiss and the global reduction requirements. The weighting was based on the respective shares of domestic and foreign emissions, i.e. the industry specific reduction requirements are composed of the sum of the share of emissions occurring in Switzerland, multiplied

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9 It is argued that those who have been using a resource have a higher need to continue using it, basically creating inertia on existing use patterns (Sabag Muñoz & Gladek 2017).

with the specific Swiss reduction requirements and the share of emissions occurring abroad, multiplied with the relative global reduction requirements.

The industry's target values as well as their current environmental footprints were finally divided by the respective global environmental footprints (see also Section 2.4.7).

Table 2.5: Necessary reduction at global and Swiss level for each environmental indicator analysed

Environmental indicator	Unit	Necessary reduction (global level)	Necessary reduction (Swiss level)	Source
Greenhouse gas footprint	Mt CO_2-eq./a	76%	80%	Global: Dao et al. 2015; CH: Frischknecht & Büsser Knöpfel 2013
Biodiversity footprint	10^{-6} PDF*a/a	83%		Steffen et al. 2015; Frischknecht et al. (2018a)
Eutrophication footprint	Mt N/a	14%	34%	Global: Dao et al. 2015; CH: Frischknecht & Büsser Knöpfel 2013
Air pollution footprint	Mt PM_{10}-eq/a	39%		Frischknecht & Büsser Knöpfel 2013

The planetary boundaries concept was not applied on the water footprint. An alternative approach was followed, which acknowledges regional differences in water scarcity. For each industry, a ranking was established listing the countries which contribute most to the water footprint. For each country on this list, the share of renewable water resources currently being used was then specified. Countries with a high contribution to the water footprint and at the same time a high amount of renewable water resources already in use (close or higher than 20 %, which is the tolerable pressure on renewable water resources according to OECD (2003))are considered those where action on the water footprint is of high priority.

2.5.4 Uncertainties regarding planetary boundaries

The above described derivation of planetary boundaries for individual industries is associated with a number of uncertainties. The yearly global emission budgets used for defining the planetary boundaries refer to threshold values determined by science, based on a large agreement from the scientific community, but the uncertainty range still is large. This is due to due to a) the use of global data sets with medium accuracy in comparison with data generally used at country level, and b) the process of setting limits based on expert advices and/or policy decisions due to lack of other data (Dao et al. 2015).

As the global limit value used for Climate Change (based on Dao et al. 2015) reflects only a 50 % chance to stay below a 2°C increase by 2100 compared with pre-industrial level, the necessary reduction in greenhouse gas emissions should in reality be higher than calculated in this study. Furthermore since the limit value in Dao et al. (2015) was for the reference year of 2015 and has since then been exceeded, the world's remaining available greenhouse gas budget is continuously shrinking. In the long term only a complete decarbonisation of the energy supply seems to be in line with aiming at the 2°C goal and the aspirational goal of 1.5 °C, as agreed on in the Paris Agreement. For future calculations of global footprint limits we recommend to base on scenarios providing at least a 66 % probability of reaching a 2°C increase.

The planetary boundary for the biodiversity footprint is based on information on the maximum tolerable global species loss. This value shows an uncertainty range of 10 to 100 species per million species. In this study, the lower value of 10 species per million species was used in accordance with the precautionary principle.

Determining a planetary boundary for air pollution is difficult because the extent of the effects on human health depends heavily on where the particles or their precursors are emitted. In this study, the Swiss reduction requirement in accordance with the Ordinance on Air Pollution Control was applied across the board to foreign emissions. However, the level of the limit thus set is very uncertain and should be verified or determined more precisely through in-depth analysis.

Nitrogen surpluses are distributed unevenly around the globe. Whereas some regions (e.g. Europe) have large nitrogen excesses, other regions (e.g. Africa) lack nitrogen for food production. A global perspective, as adopted in this study, has limited significance, even though the different reduction targets of Switzerland compared to global reduction targets have been taken into account. As for air pollution, for sound statements a more comprehensive analysis taking into account regionalised impact factors would be necessary.

3 Results of industry screening

3.1 Results of industry screening

The aim of the industry screening was to generate an empirical basis for selecting eight industries for further detailed analyses.

In a first round we calculated the six environmental footprints described in Subchapter 2.4 for all industries of the Swiss EE-IOT. In order to also address trade companies, we additionally determined the environmental footprints of 4 traded consumer product groups (food, textiles, household equipment and vehicles). These comprise the direct environmental impacts of the respective trade subsector as well as the environmental footprints of domestic and imported products consumed by households, including the use phase in the cases of household equipment and vehicles[10].

The results obtained were the basis for the selection of the focus industries which are analysed in more detail (cf. Chapter 4). The selection was mainly based on the following criteria:

- Relevance of the environmental footprint: all industries were ranked according to each footprint. On the one hand in absolute terms, on the other hand in terms of intensities with respect to the gross value added of the industries. The top 5 placements of every industry were then counted;
- additional criteria with regard to the footprints such as the ratio of the emissions by the industry itself to the emissions within the supply chain or the share of emissions during the use phase;
- supplementary industry information such as the industry size in terms of gross value added and employment as well as their respective growth rates during the last decade;
- another aim of the selection process was to pick a good mix of industries covering industrial sectors as well as service sectors.

Certain industries that are less in the focus of this project were excluded from the selection process. The following Table 3.1 contains an overview of the industries excluded and the reasons for exclusion.

Based on the results of the screening and further criteria we proposed a selection of industries to be studied in detail which was subsequently narrowed down in the discussion with the FOEN.

Many agri-food industries were among the top-ranked industries in terms of environmental footprints. To allow for industry diversity in the project, only one food processing industry was selected (processed meat).

[10] In this project the environmental footprint of an industry is defined as the total environmental impacts caused by an industry's products from resource extraction to the factory (exit) gate. The use phase is considered in the case of end user products causing relevant environmental impacts.

Table 3.1: Overview of industries excluded in the selection process

Industry	Reason for exclusion
Agriculture	Large (direct) environmental footprints which are already addressed by national environmental policy. The environmental relevance of the supply chain as compared to the direct impacts of agriculture is rather low in comparison to other industries.
Manufacture of coke, refined petroleum products	The ratio of impacts within the supply chain to the impacts of the industry itself is rather low in comparison to other industries.
Pharmaceutical products	Poor representativeness in Exiobase due to aggregation with the chemical industry.
Electricity, gas, steam and hot water supply	The ratio of impacts within the supply chain to the impacts of the industry itself is rather low in comparison to other industries.
Sewage and refuse disposal, sanitation and similar activities	Disqualifies as „key industry“, as impacts are taken into account when assessing the footprints of other industries.

From the service sector several trade subsectors were selected:

- Food trade is the largest subsector of the trade sector and moreover it is also one of the highest ranked industries in terms of environmental footprints (top 5 placements in all footprint rankings).
- In textile trade, supply chain management is already being discussed and a great potential for improvement in terms of environmental impacts is expected.
- With regard to equipment trade, the use phase is important in terms of environmental footprints due to electricity consumption, which makes the industry interesting for the detailed analyses.

Real estate activities were selected in order to analyse them jointly with the construction sector, since the two industries are highly intertwined.

The final set of chosen industries is displayed in Table 3.2. The table also covers some of the information on which the selection was founded, in particular the ranks of the industries with regard to the environmental footprints.

Table 3.2: Results of Industry screening. * Values refer to wholesale and retail trade as a whole, not to trade subsectors

Industry		Gross value added Rank	Greenhouse gas footprint Rank	Biodiversity footprint Rank	Water foot-print Rank	Air pollution footprint Rank	Eutrophica-tion footprint Rank	Total Envi-ronmental footprint[11] Rank	Share of env. impacts in supply chain	Env. impacts in use phase?	Share in GDP	Share of em-ployment in SME
15.1	Processing of meat	39	16	3	13	6	3	16	99%	no	0.2%	69%
24 w/o 24.4	Chemical industry, w/o pharmaceutical industry	15	6	8	5	7	11	7	91%	no	1.2%	33%
29	Manufacturing of machin-ery and equipment	7	7	14	12	3	17	6	99%	yes[12]	2.3%	68%
45	Construction	3	1	6	3	1	10	2	70%	yes	5.1%	95%
70, 97	Real estate activities incl. private households	1	10	13	11	12	13	20	98%	yes	9.3%	-
85	Health and social work	4	4	7	6	5	9	14	96%	no	6.3%	68%

[11] rank 1: distributed electricity; rank 3: wholesale and retail trade

[12] machinery is used in other industries; thus use phase of this machinery is part of other industries‘ footprints

Industry		Gross value added Rank	Greenhouse gas footprint Rank	Biodiversity footprint Rank	Water foot-print Rank	Air pollution footprint Rank	Eutrophica-tion footprint Rank	Total Envi-ronmental footprint[11] Rank	Share of env. impacts in supply chain	Env. impacts in use phase?	Share in GDP	Share of em-ployment in SME
51-52	Food trade	16	3	1	1	2	1	6	-	no	14.9%*	97%*
51-52	Textiles trade	32	19	18	9	19	18	66	-	yes[13]	14.9%*	97%*
51-52	Equipment trade	42	36	40	36	34	46	58	-	yes	14.9%*	97%*

[13] Use phase of clothes can also contribute significantly to the environmental impacts. Energy and water use of washing machines is included in use phase of household devices.

3.2 Comparison with the results of the REFF-study

The results of the industry screening have been compared to the results of the REFF-study (Kissling-Näf et al. 2013) based on the greenhouse gas footprints[14]. On the one hand, the results of the REFF study were compared directly with the results of this study, and on the other hand with the results according to the EE-IOT 2008 (Frischknecht et al. 2015). This allowed us to estimate the effect of the use of Exiobase instead of LCA data for modelling the foreign supply chains. For both comparisons, the use phase has not been included for consistency reasons (use phase not included in REFFF-study).

The REFF-study aimed at identifying the central fields of action for increasing the resource efficiency in Switzerland by adopting different perspectives (Swiss final demand, Swiss economy as well as materials and goods categories). The main target group was policy makers, and the goal was to identify appropriate measures and instruments for increasing the resource efficiency in Switzerland and derive the need for adapting the legal basis if necessary.

The present study focuses on the environmental footprints of Swiss industries. The main target group are Swiss companies and industry associations, where the efficient use of resources should be promoted. The study aims at identifying the environmentally relevant Swiss industries by taking into account the whole supply chain. To this end, the Swiss industry as a whole and selected key industries are analysed in detail. The contributions of the individual stages of the value chain and individual countries/regions are identified.

The REFF-study is based on the EE-IOT 2005, which was developed by Jungbluth et al. (2011), and on life cycle assessment data (modelling imports and exports). In comparison to the EE-IOT 2005, the EE-IOT 2008 used in this study has been updated and substantially disaggregated. The Swiss EE-IOT 2008 was combined with Exiobase, an environmentally extended multi-regional IOT.

Nevertheless, both studies yield similar results. In terms of absolute greenhouse gas emissions, the most important industries remained unchanged: In both studies, the ‘chemical industry’ (for consistency reasons including pharmaceutical industry) causes most greenhouse gas emissions. In addition, both studies show the same industries in the top seven positions, albeit in slightly different order, namely: ‘chemical industry’, ‘transport’, ‘manufacture of food products, beverages and tobacco’, ‘construction services’, ‘electricity distribution’, ‘agriculture, hunting, forestry, fishing and farming’ and ‘wholesale and retail trade, repair’. Twelve of the fourteen

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14 In contrast to the Ecological Scarcity method, which was used in Kissling-Näf et al. 2013 and which has since been revised, the characterisation factors to calculate greenhouse gas emissions (global warming potentials) have remained largely unchanged.

most important industries in the REFF-study are also among the fourteen most important industries in this study. Not between the top fourteen industries in this study are ‘services of hotels and restaurants’ and ‘other non-metallic mineral products’.

The different ranking of the above mentioned industries is mainly explained by differences in their greenhouse gas emission intensity as their total economic output remained fairly stable. The emission intensity of ‘other non-metallic mineral products’, for example, decreased by 25 %. Both the emissions of the industry itself and its suppliers decreased by the percentage mentioned, but the large share of emissions occurs in the supply chain.

In general, the emissions intensities of the economic industries changed in both directions. For most industries, the emissions in the supply chain are far more important than the emissions of the industries themselves. The changes in the supply chain are partly due to the more detailed and regionalised modelling, but also due to the use of Exiobase for modelling the foreign supply chains.

4 Detailed results for selected industries

4.1 Overview

In this chapter the results of the detailed analysis of eight selected industries are presented. Each subchapter referring to an industry is structured as follows:

- brief introduction of the industry,
- economic impacts along the industry’s supply chain,
- environmental impacts along the industry’s supply chain presenting the environmental hotspots with regard to supply chain stages, industries, countries and the direct suppliers to be addressed by the industry. Apart from an overview for each footprint indicator, one selected indicator is analysed in depth;
- comparison with planetary boundaries and priorities for reduction measures,
- measures for reducing the industry’s environmental footprint.

Additional results for other than the selected environmental indicator are presented in detail in annex A and summarised in the industry chapters.

It should be noted that the industry results contain numerous double-counting between the industries, since almost every industry supplies products to almost every other industry. Therefore the industry footprints cannot be added up to determine the environmental footprint of the total economy.

In order to enable a comparison of the shares of the different supply chain stages between the industries examined, the supply chain is summarised in the following four value-added stages for the presentation of the results: 'raw material extraction', 'remaining upstream chains', 'direct suppliers' and 'industry itself'.

Resource extraction industries are defined as agriculture (NOGA 2002: 01), forestry (NOGA 2002: 02), fishery (NOGA 2002: 05) and mining and quarrying (NOGA 2002: 10 - 14). When direct suppliers belong to the resource extraction industries, they are recorded in the latter group, not as direct suppliers.

In a different perspective the environmental impacts are allocated to the direct suppliers. Thus each direct supplier is presented with its total (cradle to exit gate) environmental footprint. In this perspective the total environmental footprint of the focal industry comprises its direct environmental impacts and the environmental footprints of its direct suppliers. This perspective allows the companies from an industry to prioritise the suppliers that they should address for optimisation measures.

4.2 Production of chemical products

4.2.1 Introduction

The industry 'Production of chemical products'[15] excludes the pharmaceutical industry. The Swiss chemical industry is characterised by the production of specialty chemicals while the importance of environmentally intensive basic chemical production (e.g. of plastics, fertilisers) is rather low. It includes the following activities:

- Manufacture of basic chemicals (26 % of employed persons),
- Manufacture of pesticides and other agro-chemical products (6 % of employed persons),
- Manufacture of paints, varnishes and similar coatings, printing ink and mastics (15 % of employed persons),
- Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations (20 % of employed persons),
- Manufacture of other chemical products (31 % of employed persons),
- Manufacture of man-made fibres (2 % of employed persons).

The Swiss chemical industry employed 27'100 persons (FTE) in 2015. This corresponds to 0.7 % of the entire Swiss workforce. However, employment has declined between 2011 and 2015 (see Table 4.1).

[15] Code 20 according to NOGA 2008, code 24 excl. 24.4 according to NOGA 2002.

Table 4.1: Employment in the chemical industry (Source: FSO – STATENT)

Year	Employed persons (in FTE)	Share in total employment	Average annual growth rate	Average annual growth rate of Swiss workforce
2011	29'487	0.8%		
2015	27'100	0.7%	-2.1%	1.0%

4.2.2 Economic impact

The total value added induced by the Swiss chemical industry amounts to 20’339 Mio. CHF[16]. Figure 4.1 shows how it is distributed across the different supply chain stages. The industry itself contributes 31 % to the induced value added and a share of 17 % stems from its direct suppliers. While the largest share is generated by the supply chain stages ‘remaining upstream chains’ (45 %), the fraction of value added imputable to raw material extracting industries (7 %) is much smaller.

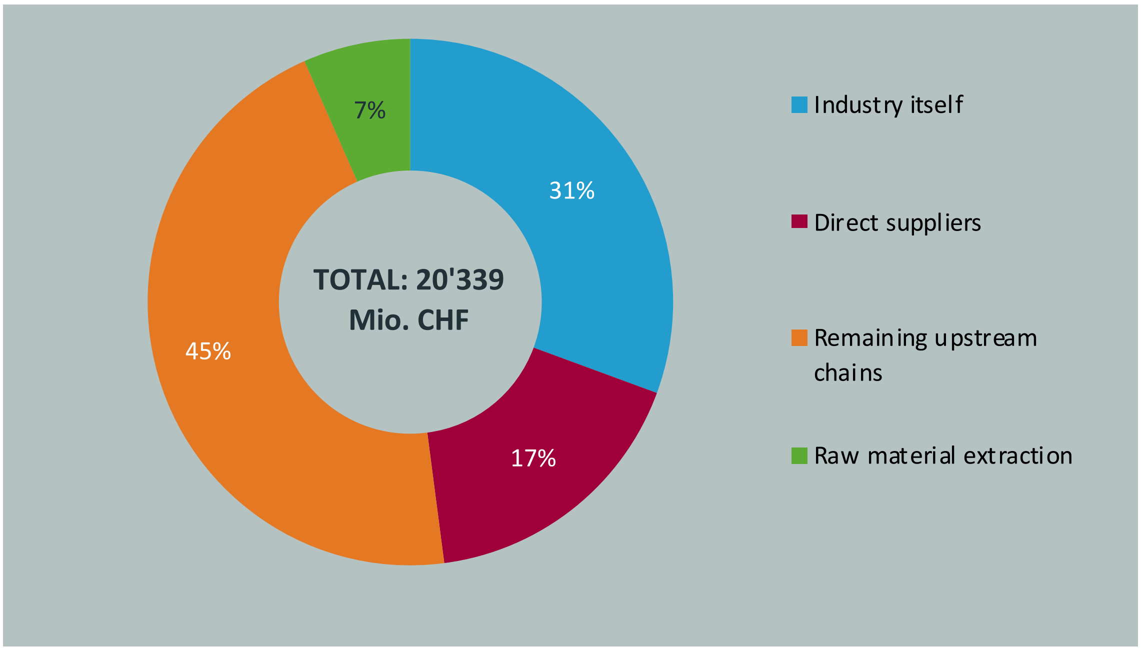

Figure 4.1: Total gross value added induced by the Swiss industry ‘Production of chemical products’, differentiated by supply chain stages (Source: Calculations Rütter Soceco)

[16] These and the following economic data refer to the year 2008.

In order to understand where - in geographical terms – the value added induced by the Swiss chemical industry is generated, Figure 4.2 shows the shares of induced value added differentiated by countries and supply chain stages.

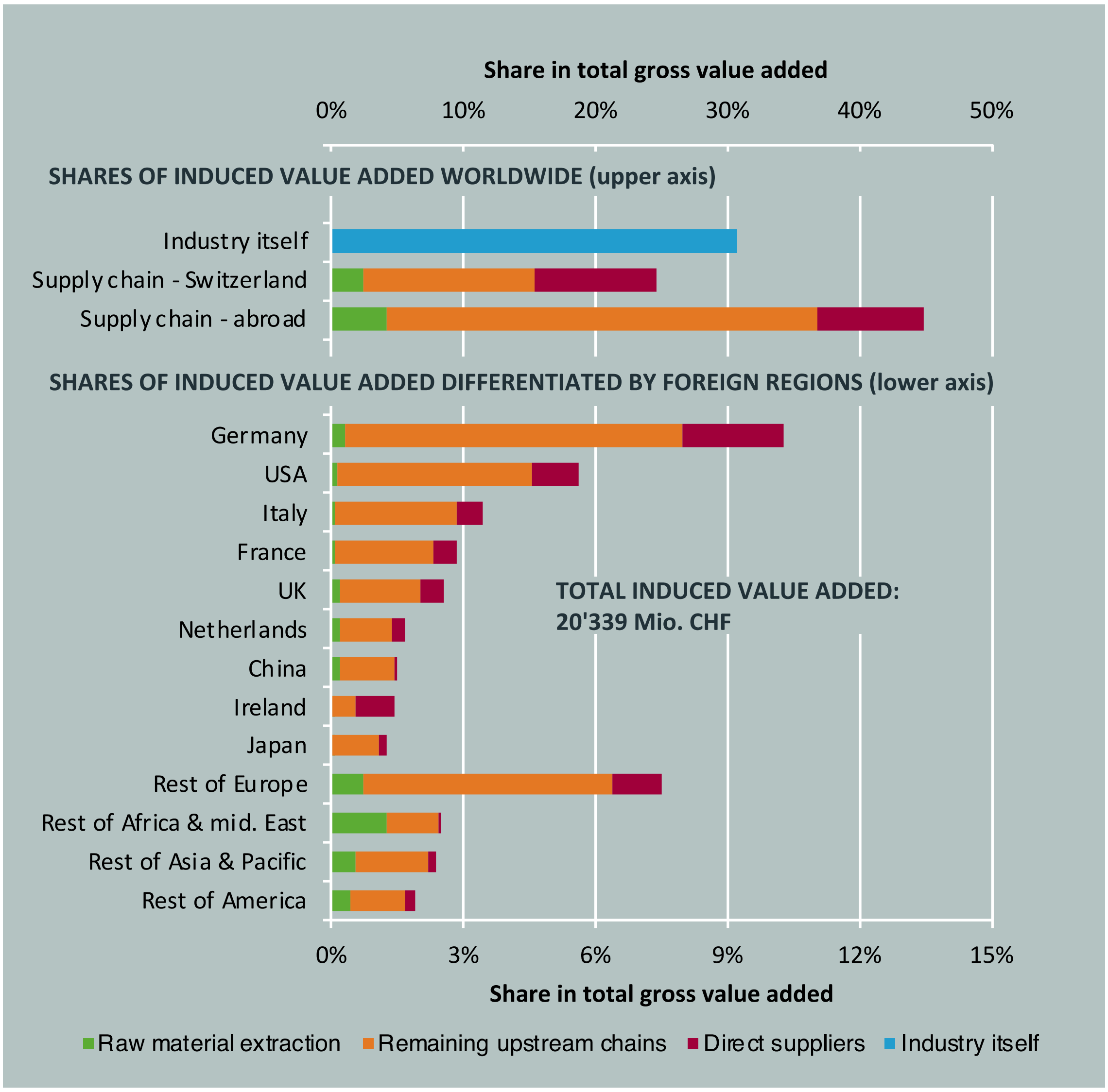

Figure 4.2: Total gross value added induced by the Swiss industry 'Production of chemical products', differentiated by supply chain stages and countries / regions (Source: Calculations Rütter Soceco)

The upper section of the figure displays the share of value added generated by the industry itself (31 %) as well as the shares generated within domestic (25 %) and foreign (44 %) parts of the supply chain. Thus more than half of the total value added is generated in Switzerland while the rest is created abroad.

Within the Swiss supply chain, the share of value added generated by direct suppliers is smaller than that of industries in the remaining upstream chains, whereas in the foreign supply chains the share of the direct suppliers is substantially lower. In addition, the share of value added induced in raw material extraction industries in foreign supply chains is slightly larger than in Swiss supply chains.

The lower part of Figure 4.2 displays the share of foreign countries in the total value added generated by the chemical industry (lower scale). Germany has the largest share in value added with 10 % and the US follow with more than 5 %. Other top ten countries are European countries, China and Japan. Countries outside the top ten account for 14 % of total value added. In terms of supply chain stages, it is noticeable that the largest portions of value added in raw material extraction industries are generated in Africa and the middle east, the rest of America and Asia, whereas there is almost no value added created in raw material extracting industries amongst the most European countries.

4.2.3 Environmental impacts

4.2.3.1 Overview

Table 4.2 contains an overview of the total environmental footprints caused by the Swiss chemical industry[17]. The footprints are reported in absolute terms and as intensities in relation to gross output as well as to gross value added of the industry itself. It should be noticed that the different footprints cannot be compared amongst each other since they are completely different measures with different units.

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[17] Environmental footprints are shown without the emissions occurring in the use phase. Although chemical emissions can have a significant impact on the environment, there is little detailed quantitative information on the sources and material loads of individual chemicals. For this reason, no reliable statement could be made about the environmental impacts in the use phase of the chemical industry and the use phase is therefore not presented.

Table 4.2: Environmental footprints caused by the Swiss chemical industry (Source: Calculations Rütter Soceco & Treeze)

Indicator	Unit	In absolute terms	Per M CHF gross output (only production)	Per M CHF gross value added (only production)
Greenhouse gas footprint	kt CO_2 eq	8'681	0.50	1.39
Biodiversity footprint	nano PDF*a	10'849	0.63	1.74
Water footprint	Mm3	3'663	0.21	0.59
Air pollution footprint	t PM10 eq	14'315	0.83	2.30
Eutrophication footprint	t N eq	8'825	0.51	1.42
Environmental footprint	G-eco Pt.	13'844	0.80	2.22
Gross output (industry itself)	M CHF	17'264		
Gross value added (industry itself)	M CHF	6'227		

Figure 4.3 displays the shares of supply chain stages in total impact as well as the share of the industry in the global impact for each footprint (and value added/gross production value for comparison reasons). It thus shows how much of the total environmental impact induced by the chemical industry stems from the industry itself, how much is caused in the supply chain and how relevant each indicator for the Swiss chemical industry is.

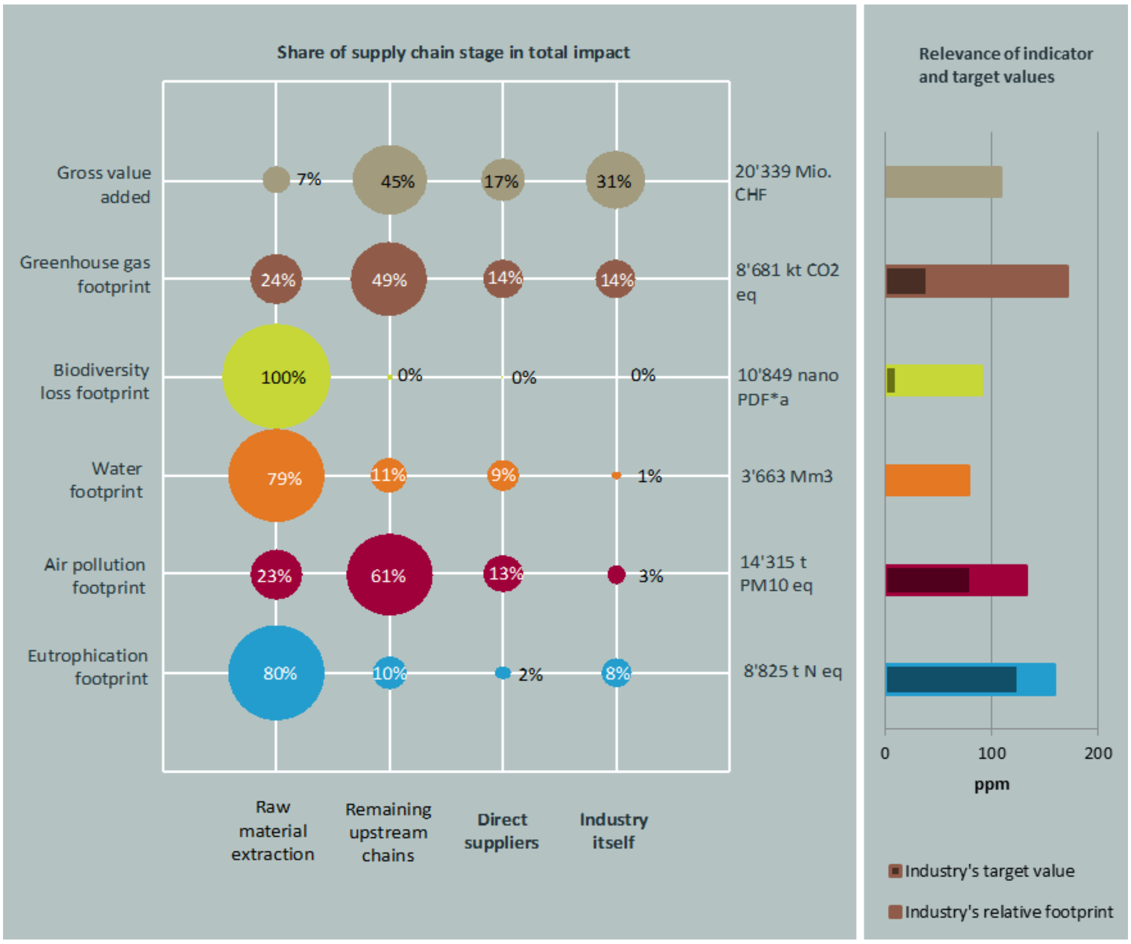

Figure 4.3: Environmental footprints caused by the Swiss industry ‘Production of chemical products’ by supply chain stages, share of the industry in global gross production value and global environmental footprints as well as the reduction necessary to comply with the planetary boundaries (Source: Calculations Rütter Soceco and treeze)

The results show a differentiated picture of the distribution of environmental impacts along the supply chain of the chemical industry. In most cases the chemical industry, generating 31 % of total value added, is responsible for a minor share of environmental impacts, whereas the major share occurs in its supply chain. The chemical industry contributes 14 % to the greenhouse gas footprint and 8 % to the eutrophication footprint. Its shares are negligible for the other footprints. Compared to the industry itself and other suppliers, raw material extraction dominates the results for the biodiversity, the water and the eutrophication footprint, whereas it plays a minor role for the greenhouse gas and the air pollution footprint with shares between 23 % and 24 %. The major share of the greenhouse gas and the air pollution footprints occurs in the upstream parts of the supply chain between raw material extraction and the direct suppliers.

The comparison of shares in value added and environmental footprints reveals that raw material extraction is especially resource and emission intensive, especially with regard to the biodiversity, water and eutrophication footprints. Regarding the greenhouse gas and the air emission footprint, the emission shares roughly mirror the value added shares of direct and intermediate suppliers, thus pointing to an average emission intensity in the supply chain. The chemical industry itself displays a below average emission intensity.

Most relevant for the chemical industry is the greenhouse gas footprint (see Figure 4.3; share of the respective footprint in the global footprints compared to the share of the gross production value of the chemical industry in the gross production of the entire global economy). Details on the necessary reduction in order to comply with the planetary boundaries can be found in section 4.2.4.

4.2.3.2 Focus on greenhouse gas footprint

The focus footprint chosen for the Swiss chemical industry is the greenhouse gas footprint, since it is one of the highest ranking footprints for this industry. As seen in Table 4.2 the global amount of greenhouse gas emissions induced by the chemical industry in Switzerland adds up to 8’681 kt CO_2 eq.

Figure 4.4 highlights which industries (aggregated over all countries) emit the greenhouse gases along the supply chain of the Swiss chemical industry. The largest emitter is the chemical industry itself with a share of 27 %, partly in its role as focal industry and partly in its role as direct supplier (from abroad). ‘Mining and quarrying’, supplying the chemical industry with inorganic raw materials and ‘electricity from fossil fuels’ follow with shares between 16 % and 18 %. The shares of other industries are significantly lower. Here basic metal production, public heat generation and other non-metallic minerals can be mentioned. Industries outside the top ten hold a share of almost 20 %.

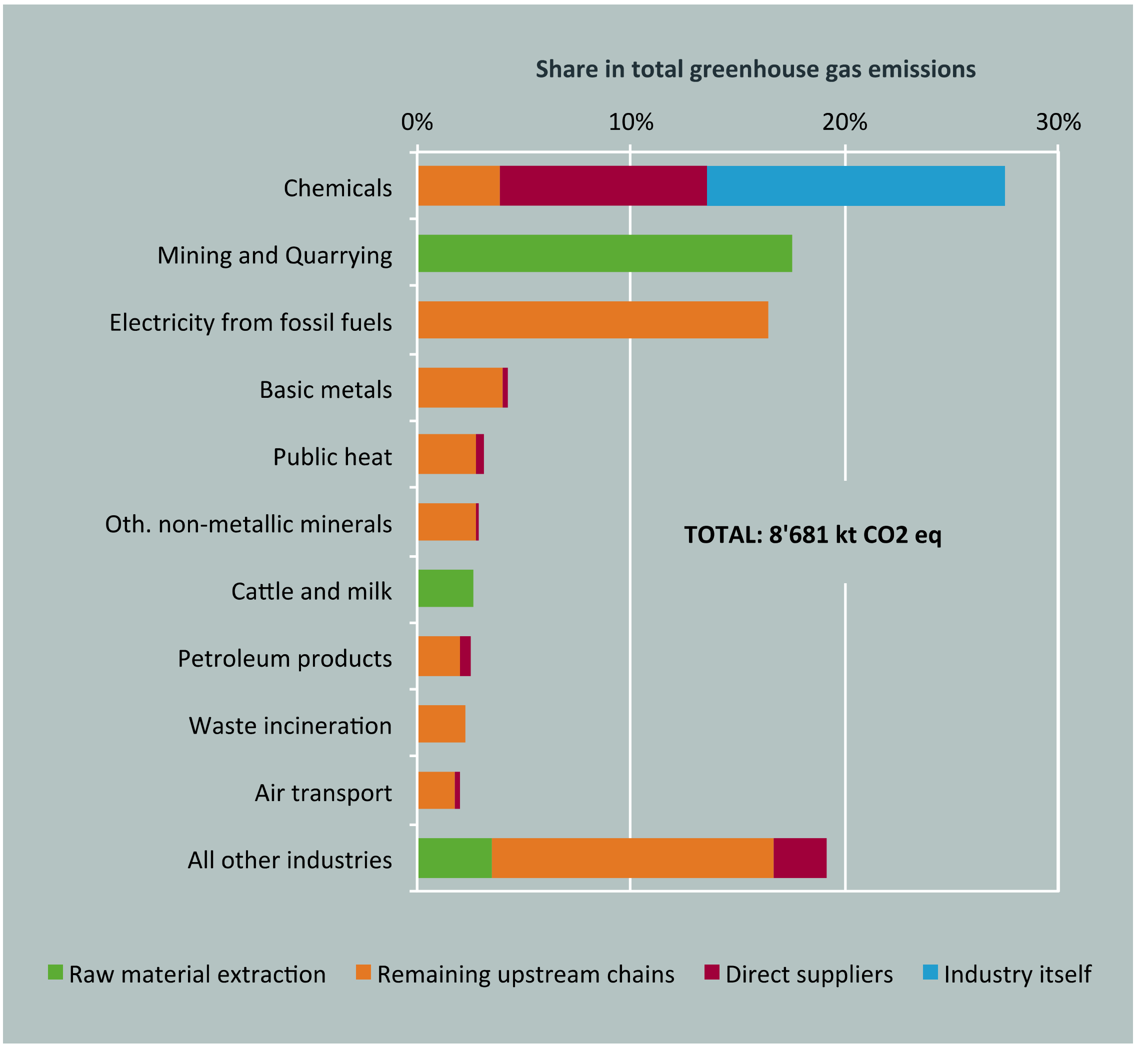

Figure 4.4: Greenhouse gas footprint caused by the industry 'Production of chemical products' by supply chain stage and supplying industries (Source: Calculations Rütter Soceco)

Figure 4.5 illustrates how the responsible companies are distributed across supply chain stages and countries. The diagram shows that 22 % of the footprint are due to emissions in Switzerland (14 % by the industry itself and the rest in the other supply chain stages).

Thus 78 % of the emissions take place abroad. The country differentiation of greenhouse gas emissions reveals China, Germany and the US to be the largest foreign polluters. In comparison to the value added distribution across countries (cf. Figure 4.2) China, Russia and India are ranked much higher when measuring in greenhouse gas emissions. This is due to the (in average) higher greenhouse gas emission intensities in those countries when compared to western countries such as Germany or the US. With regard to supply chain stages, the remaining upstream chains between raw material extraction and direct suppliers to the chemical industry are particularly important. Direct suppliers with significant greenhouse gas emissions are mainly located in Europe and the US, whereas raw material extraction is mainly located outside Europe.

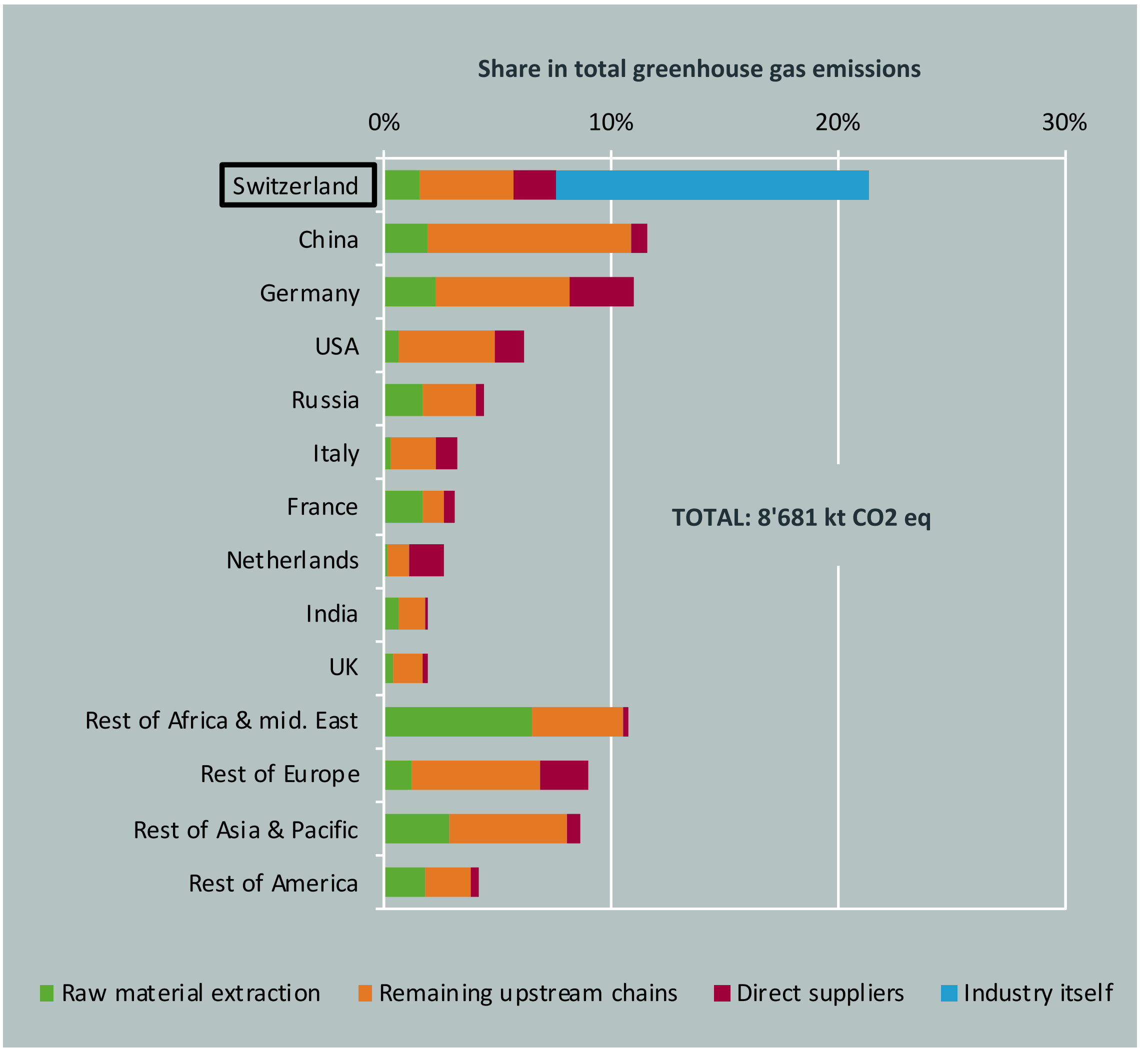

Figure 4.5: Greenhouse gas footprint caused by the Swiss industry ‘Production of chemical products’, differentiated by supply chain stage and source countries (Source: Calculations Rütter Soceco)

In a different perspective the greenhouse gas footprint is allocated to the direct suppliers in the sense that each supplying industry is allocated its total footprint. This allows companies to identify which of their suppliers they should access with which priority in order to optimise the environmental performance of their supply chain. The analysis presented in Figure 4.6 allocates the greenhouse gas emissions caused by the Swiss chemical industry within the supply chain to domestic and foreign direct suppliers. The direct emissions of the chemical industry itself are shown for reasons of comparison.

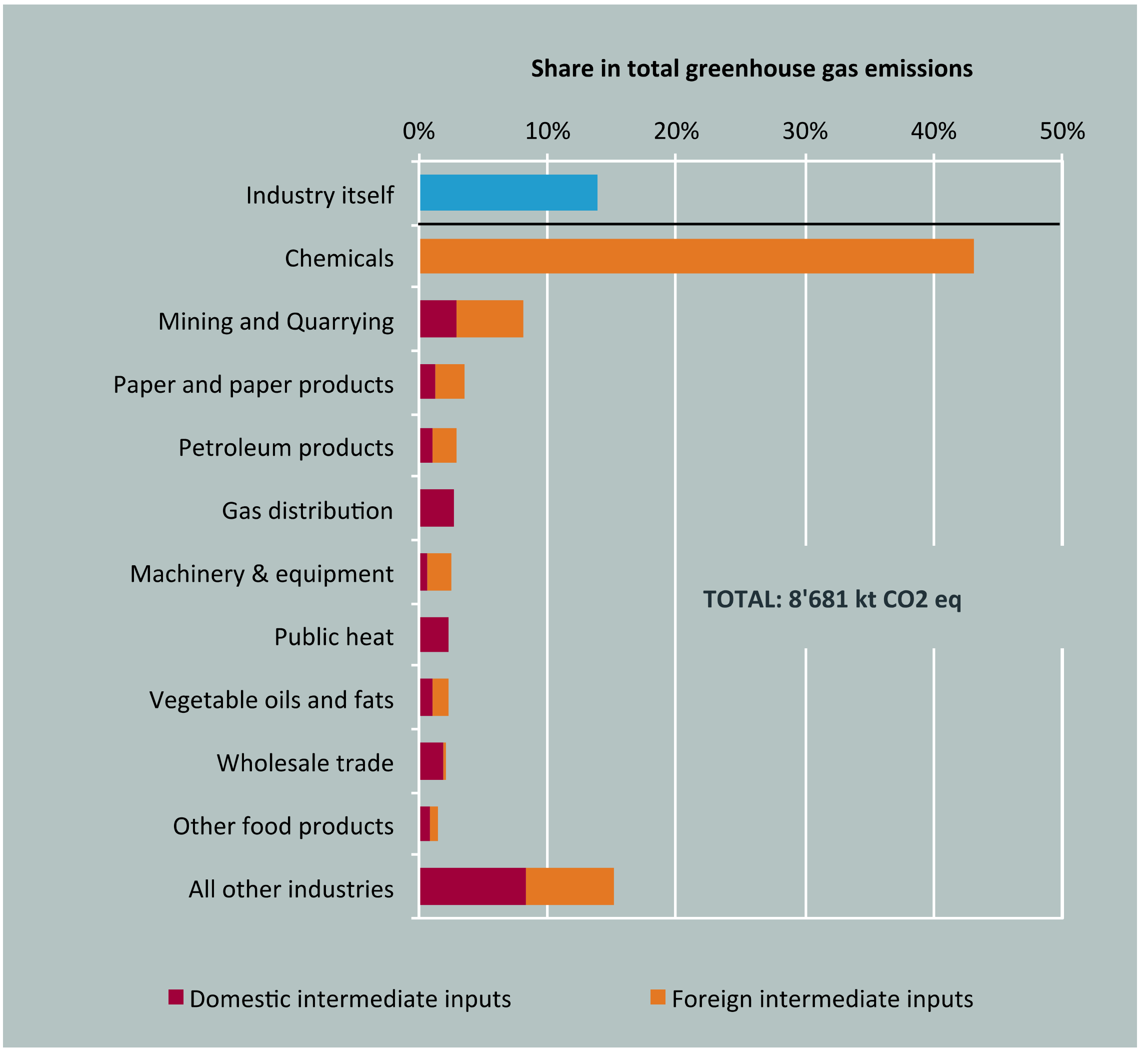

Figure 4.6: Greenhouse gas footprint caused by the direct suppliers of intermediate goods and services for the Swiss industry 'Production of chemical products' (Source: Calculations Rütter Soceco)

Over 40 % of the greenhouse gas emissions caused by the Swiss chemical industry within the supply chain are linked to intersectoral purchases of intermediate inputs from the chemical industry itself. Other important direct suppliers are 'mining and quarrying', paper and paper products supplying the chemical industry with raw and packaging materials, refineries supplying energy and raw materials for organic chemicals. Other suppliers are related to energy consumption, machinery and the food industry supplying products such as oils and fats, starch and sugar as inputs to the chemical industry.

4.2.3.3 Further environmental impacts

In the following the results for the other environmental impacts are briefly summarised. The respective figures can be found in the annex.

Regarding the air emission footprint, less than 10% of total emissions occur in Switzerland. Foreign emissions are spread across a large variety of countries with China, Germany and the USA responsible for the largest shares. The chemical industry, basic metal manufacturing and electricity generation from fossil fuels each cause roughly 15% of the total footprint, with the rest being distributed across a large number of industries. Biodiversity loss is mainly related to vegetal products used as raw materials in the chemical industry (e.g. oils, sugar and starches). Cattle farming induced by animal raw materials and by food supply to persons employed in the supply chain and forestry induced by the use of wood in buildings and other investment goods also play a role. Switzerland accounts for only 8 % of the total footprint. Tropical countries with a larger biomass loss potential (e.g. Brazil, Indonesia and the rest of Asia) have larger shares than for the other footprints. Approximately 50 % of the footprint occur outside the top ten countries. Thus the impact is spread across a variety of countries. The picture looks similar for the AWARE water footprint. Agriculture dominates, but chemicals account for 10% of the water footprint. With regard to country distribution, the water footprint is less concentrated than the other footprints, i.e. it spreads across a larger number of countries. Countries with extensive irrigation and/or high water scarcity (e.g. China, US, India, Italy and Spain) have the largest shares in the footprint (between 4 % and 15 %). In these countries even a low economic involvement in the supply chains can lead to large water footprints due to their large water footprint multipliers. The share of Switzerland is negligible with 2 %.

4.2.3.4 Environmental footprint according to the ecological scarcity method

The total environmental footprint according to the method of ecological scarcity (Frischknecht & Büsser Knöpfel 2013) of the industry ‘Production of chemical products’ is 13’587 billion eco-points. Nearly three quarters of it are caused by imported goods (Figure 4.7). The industry itself generates 15 % of its total footprint, with the main contributors being emissions of fossil CO_2 and nickel. Another 8 % and 5 %, respectively, stem from the remaining suppliers and direct suppliers in Switzerland.

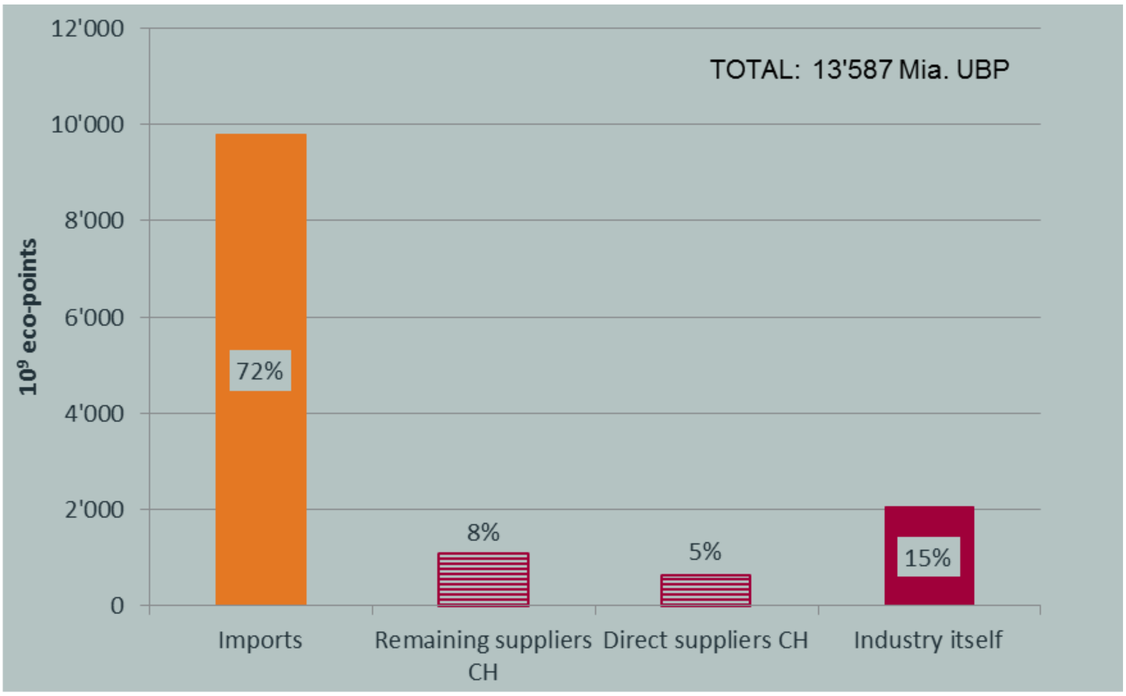

Figure 4.7: Environmental footprint in eco-points caused by the industry 'Production of chemical products' by supply chain stages and imports (Source: Calculations treeze)

Figure 4.8 shows the ten most important contributing direct suppliers to the total environmental impacts of the Swiss chemical industry. The ten largest contributors explain just about half of the total environmental footprint of the production of chemical products. Seven of them are imported precursor products. The three largest contributors are the import of other chemicals (20 %), organic chemicals (7 %) and 'Mining and quarrying' (6 %).

The footprint of the imported chemical products is determined by the raw material and energy requirements in their production. The most important contributors are different organic chemicals and agricultural raw materials (e.g. for starch production). The 'Mining and quarrying' industry provides for example lime based chemical additives, chemical raw materials and chemical active ingredients. About 60 % of the environmental footprint of this industry occurs within the country and stems mainly from its gravel resource requirements, from CO_2-emissions and gypsum requirements. The rest is due to its electricity use as well as from construction and disposal services. The environmental footprint of the electricity used (industry 'Electricity distribution') is caused by the production of Swiss and foreign nuclear power as well as imported electricity from coal power plants. Further impacts stem from other imported products (vegetable oils and fats, petroleum products, inorganic chemicals) as well as from oils and fats produced in Switzerland. For those as well as for the imported vegetable fats and oils, the main impacts occur during the cultivation of the oleaginous crops.

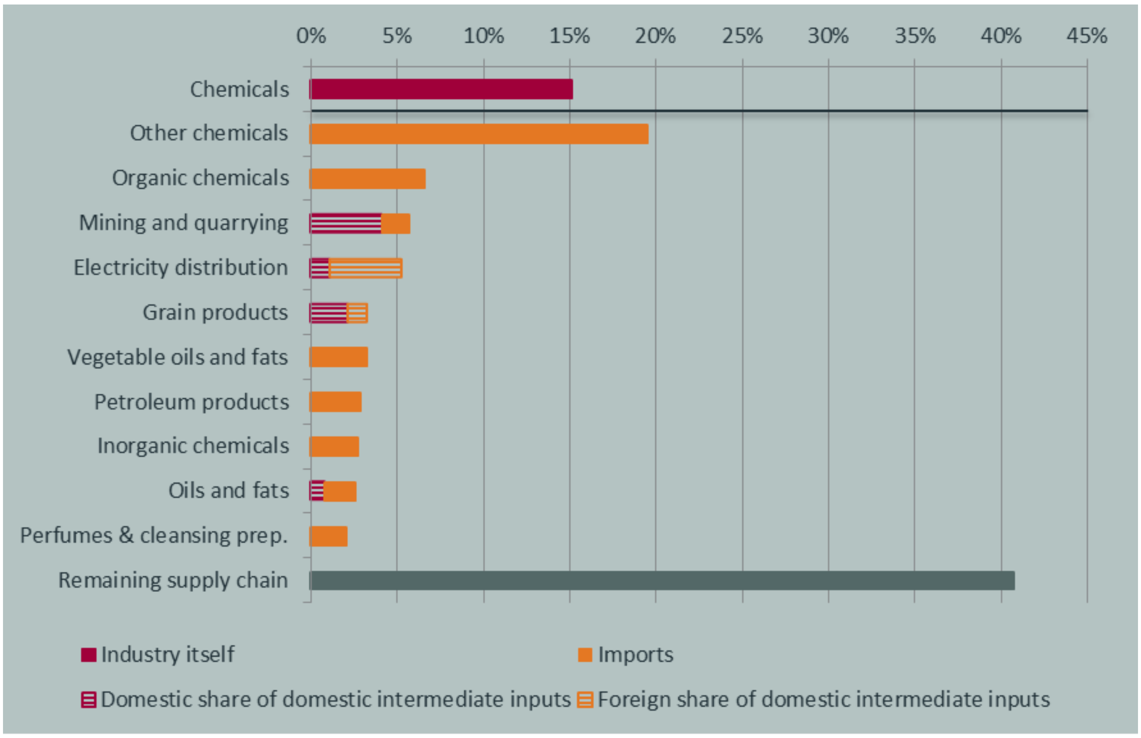

Figure 4.8: Environmental footprint caused by the direct suppliers of intermediate goods and services for the Swiss industry 'Production of chemical products'. Remaining supply chain = all other direct suppliers (Source: Calculations treeze)

4.2.3.5 Conclusion

Over 70 % of the greenhouse gas and the environmental footprint of the Swiss chemical industry are related to emissions occurring abroad. This is due to high purchases from the foreign chemical industry, which is the most important contributor to the greenhouse gas emissions and the total environmental impact of the Swiss chemical industry. Other important direct suppliers for both the greenhouse gas and the environmental footprint of the Swiss chemical industry are 'mining and quarrying' (delivering inorganic raw materials for the chemical industry), 'petroleum products' and 'vegetable oils and fats'.

For the greenhouse gas emissions, also 'paper and paper products' belong to the ten most important direct contributors, as well as heat supply ('gas distribution'; 'public heat'), 'machinery & equipment', 'wholesale trade' and 'other food products'. On the other hand, the electricity use, 'fertilizers' and 'grain products' are only among the ten most important direct suppliers for the total environmental footprint.

For both the greenhouse gas and the total environmental footprint the industry itself causes about one seventh of the total emissions over the whole supply chain.

4.2.4 Comparison with the planetary boundaries

Figure 4.9 shows the share of the environmental footprints of the Swiss industry 'Production of chemical products' in the respective global environmental footprints as well as the relative reduction needs. The Swiss chemical industry contributes most to the greenhouse gas footprint. The second largest contribution is to the eutrophication footprint, followed by the contributions to the air pollution and biodiversity loss footprints. For the latter, the industry's share in the global environmental impact is below its share in global gross production value.

The biodiversity and the greenhouse gas footprint have the highest relative reduction needs. Taking into account the share of industry in the global impact and the relative need for reduction, the greenhouse gas footprint is identified as priority field of action for the Swiss chemical industry. In second place comes the biodiversity footprint.

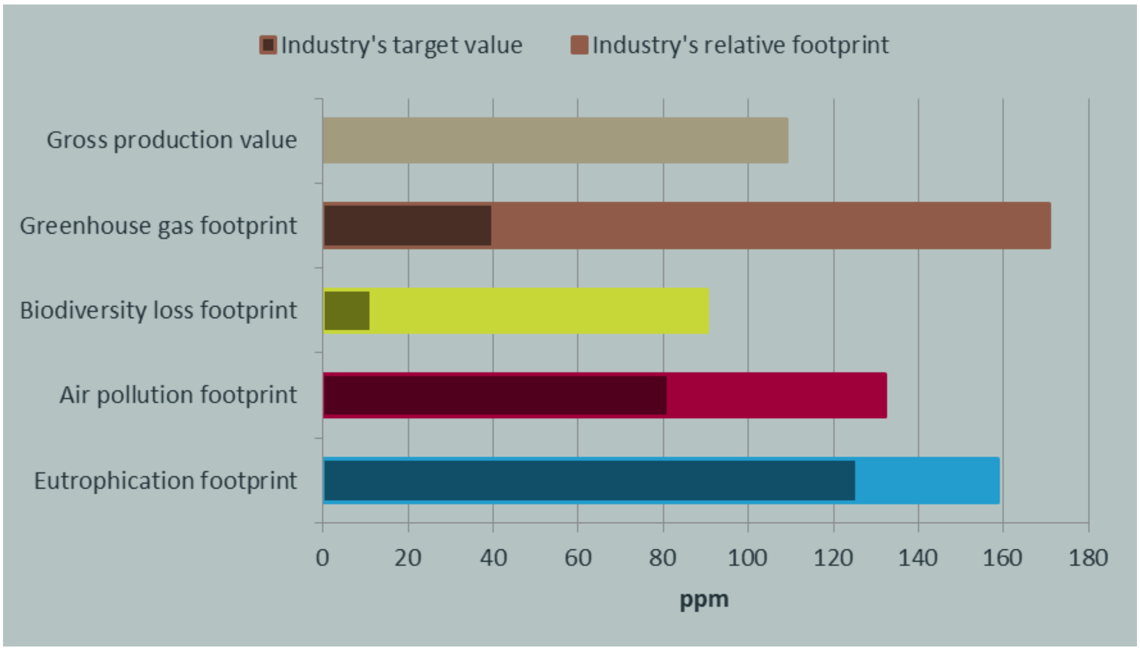

Figure 4.9: Share of environmental footprints caused by the Swiss industry 'Production of chemical products' in global environmental footprints and respective planetary boundaries (Source: Calculations treeze)

Table 4.3 shows the water footprint of the Swiss chemical industry, differentiated by country, and the share of renewable water supply used in the respective country. 12 % of the water footprint of the Swiss chemical industry occurs in India, where 37 % of the renewable water supply is already used. The tolerable amount of sustainably usable water is also exceeded in Italy and Spain, where 7 % and 4 %, respectively, of the water footprint of the Swiss chemical industry stem from. In China, where 15 % of the water footprint of the Swiss chemical industry takes place, the sustainably useable share of 20 % of the renewable water supply is almost reached.

Therefore India, China, Italy and Spain are the countries with a need for action regarding the water footprint of the Swiss chemical industry. Another 9 % of the water footprint of the Swiss chemical industry stems from the United States, where in a national average already 16 % of the renewable water supply are used. As especially in large countries, regional differences in water availability can be high, imports from this country should also be monitored for their impact on the water footprint.

Table 4.3: Water footprint of the Swiss chemical industry differentiated after country and share of renewable water supply used in the respective countries

Country	Share of renewable water supply used	Water footprint of chemical industry [Mm^3]	Share of total water footprint of the chemical industry
China	20%	536	15%
India	37%	446	12%
United States	16%	336	9%
Italy	24%	247	7%
Spain	29%	149	4%
Switzerland	5%	61	2%
Turkey	17%	30	1%
France	15%	20	1%
Greece	13%	20	1%
Australia	5%	19	1%
Remaining countries and unspecified regions		1799	49%

4.2.5 Measures for reducing environmental impacts

4.2.5.1 Focal areas for measures

For the chemical industry, most of the environmental impacts are related to imported products. But also the emissions from the industry itself are not negligible. Therefore, effective measures for reducing the environmental impacts of the chemical industry should focus on those two areas:

- For the imported goods a sustainable supply chain management is crucial. Therefore, different possibilities exist (see e.g. Jungmichel et al. 2017):

- Integration into purchasing: environmental issues are included in framework agreements or a supplier code. Specific ecological requirements can be taken into account in purchasing criteria and specifications. Compliance can be checked by presenting certificates or by audits of suppliers.
- Cooperation with suppliers: knowledge transfer and capacity building among suppliers worldwide (e.g. on the subject of energy efficiency). Environmental topics can be anchored in regular target discussions with suppliers or joint projects can be implemented to identify suitable solutions for improvements. The exchange also allows better coordination of processes with the supplier. Furthermore, own experiences, e.g. from energy efficiency measures in the context of the use of environmental management systems, can be passed on to suppliers in order to initiate improvements there. The qualification can take place either through own training programs or with the help of existing knowledge platforms.
- Supply Chain Structure: targeted development of transparent supply chains that meet high ecological standards. This measure covers the entire supply chain. One possibility is direct procurement from raw material producers. This creates greater transparency regarding the origin of materials and existing local environmental standards, which in turn enables the implementation of targeted measures to improve the environmental performance of the raw material producer. In order to avoid that eventual higher purchase prices become an obstacle to the procurement of products from sustainable sources, it makes sense to build up sustainable supply chains step by step and at the same time to sensitize customers to these products.
- Product structure (use of more sustainable product components): This area of action also covers the entire value chain. Product design changes can be an important lever for reducing environmental impacts in the supply chain. This concerns above all the replacement of critical raw materials by more environmentally friendly alternatives, e.g. the use of recycled material. Changes to product design can also help to avoid or at least reduce the scope of problematic processes from an environmental perspective. This field of measures has a high innovation potential both for the procuring company and the (pre-)suppliers. The prerequisites are that sustainable alternatives for product components are available and that companies are able to achieve more sustainable product designs through their research and development activities.

- For the direct emissions from industry itself, especially the reduction of fossil CO_2- and nickel emissions are central. Besides, also the emissions of halogenated hydrocarbons could play a certain role:

  - CO_2-emissions: Enhancement of the energy efficiency of buildings and production facilities, replacement of fossil fuels by fuels or electricity from renewable sources, waste heat recovery
  - Nickel-emissions to water: Use best available technique (BAT) for production and waste water treatment
  - Halogenated hydrocarbons: use of alternative refrigerants (see e.g. https://www.responsible-care.ch/unser-ziel-ist-es-bei-roche-alle-klimaschaedigenden-kaeltemittel-zu-ersetzen/)
- Beside the above mentioned measures, also measures addressing the 'Mining and quarrying' industry, 'paper and paper products' are important. For both industries, their impact is mainly related to the energy supply and the induced CO_2-emissions. Reducing these impacts requires the same measures as for the CO_2-emissions of the chemical industry itself: a sustainable energy supply from renewable sources as well as the enhancement of the energy efficiency of buildings and production facilities.

4.2.5.2 Monitoring parameters

The development of the environmental impacts of the chemical industry could be monitored with the following indicators:

- Amount of CO_2, nickel and halogenated hydrocarbons emitted per t of product
- Amount of purchased inputs per CHF revenue
- Share of known players in the supply chain
- Share of purchased inputs sustainably produced (according to agreements with producer, certification schemes, collaboration with producer etc.)
- Amount of electricity used per t of product and share of renewable electricity
- Amount of fossil fuels used per t of product

4.2.5.3 Instruments and guidelines

The following instruments help in finding and implementing appropriate measures to reduce the environmental impacts in the production of chemical products:

- Existing initiatives of the chemical industry:
  - Responsible Care'-Program (RC): voluntary initiative of the globally active chemical industry with the aim of continuously improving performance in the areas of safety, health and environmental protection. Further information: https://www.responsible-care.ch/
  - Chemie[3] - Nachhaltigkeitsinitiative der deutschen Chemie: Joint sustainability initiative of VCI, IG BCE and BAVC with the aim of anchoring

the principle of sustainability as a guiding principle in the chemical industry. Inter alia with a guide to sustainable supply chain management especially designed for small and medium-sized companies in the chemical industry (https://www.chemiehoch3.de/de/home/die-initiative/news/nachhaltigkeit-in-der-lieferkette-chemie3-leitfaden-bietet-orientierung.html)
Further information: https://www.chemiehoch3.de/de/home.html

  - Portal of the International Councils of Chemical Associations (ICCA): https://www.icca-chem.org/energy-climate/

- Sustainable supply chain management: Environmental management systems:
  - Initiative "Together for Sustainability": https://tfs-initiative.com/
  - Environmental management scheme of the European Union EMAS: www.emas.de
  - ISO 14001 ff. (https://www.iso.org/iso-14001-environmental-management.html) and ISO 50001 (https://www.iso.org/iso-50001-energy-management.html)
- Energy reduction measures
  - Guidelines Chemicals Sector of Carbon Trust: https://www.carbontrust.com/resources/guides/sector-based-advice/chemicals/
- Guidelines to industry-specific best available technique standards:
  - European Commission Best Available Techniques (BAT) and Best Available Techniques Reference Documents (BREF) Guides: http://eippcb.jrc.ec.europa.eu/reference/
  - Environmental, health and safety guidelines of the World Bank: https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/policies-standards/ehs-guidelines

5 Synthesis

5.1 Economic impact

The analysis of economic impacts demonstrates how supply chains span across industries and countries for all analysed industries. Significant shares of total value added are induced in foreign countries. However the ratios of direct value added of the focal industries, of value added induced in Switzerland and abroad are very industry-specific and difficult to generalise. For most industries raw material extraction accounts for minor shares of induced value added. The results indicate the complexity of supply chains and hint to which suppliers in which industries and countries companies can address to manage their supply chains and to optimise their environmental performance.

5.2 Environmental footprints

The environmental footprints of the industries analysed are influenced by the size of the industries and by their environmental intensities. Table 5.1 gives an overview of the environmental footprints of all the eight industries that were analysed in detail and their share in the global footprints.

The environmental footprints of the industries are highly industry specific and difficult to generalise. The food related industries meat production and food trade cause significant environmental impacts with regard to almost all indicators, especially if measured by their environmental intensity per unit of value added. They cause particularly high eutrophication and biodiversity loss footprints. The industry 'Food trade' has the highest shares of its footprints in the global impacts (150 to 1400 ppm). This shows the high environmental intensity and relevance of food products.

Other industries clearly have their hotspots in greenhouse gas emissions and air pollution, especially real estate services, machinery and household equipment trade. 'Real estate services' is also an industry with relatively high shares in the global impacts (55 to 500 ppm). Its high greenhouse gas and air pollution footprints are due to its high needs in (fossil) energy in manufacturing building materials and during the use phase of the buildings.

For textiles trade the water and the greenhouse gas footprint are especially important. The chemical industry displays no clear focus, while the health and social work industry as a service industry is characterised by relatively lower but still substantial footprints.

Table 5.1: Overview of absolute environmental footprints and share of Swiss industries (incl. supply chain) in global footprints and global gross production value for the industries analysed in detail (Source: calculations Rütter Soceco & treeze)

NOGA	Industry	Gross value added	Gross prod. value	Greenhouse gas footprint		Biodiversity footprint		Water footprint	Air pollution footprint		Eutrophication footprint		Total Environmental footprint
		M CHF	ppm	kt CO_2 eq	ppm	nano PDF*a	ppm	Mm^3	t PM_{10} eq	ppm	t N eq	ppm	G-eco Pt.
15.1	Processing of meat	1'163	22	4'419	87	11'301	94	1'361	16'635	154	21'865	393	11'039
24 w/o 24.4	Chemical industry, w/o pharmaceutical industry	6'227	109	8'681	171	10'849	90	3'663	14'315	132	8'825	159	13'844
29	Manufacturing of machinery and equipment	12'462	233	10'031	197	5'602	47	2'348	23'090	213	4'859	87	13'853
70, 97	Real estate activities incl. private households	50’064	191	24’286	478	6’631	55	3’707	28’254	261	7’173	129	26’605
85	Health and social work	33'959	167	8'290	163	9'302	78	3'229	15'345	142	12'119	218	12'887
51-52	Food trade	10'066	154	15'681	309	76'519	638	25'587	48'734	450	76'578	1377	50'469
51-52	Textiles trade	2'730	41	4'890	96	4'441	37	5'829	11'582	107	3'492	63	3'932
51-52	Household equipment trade	2'257	40	3’908	77	1’398	12	1’376	8’319	77	1’447	26	5’966

With regard to the relevance of supply chain stages, the biodiversity, the water and the eutrophication footprints are dominated by raw material extraction and production, respectively. For the greenhouse gas and the air pollution footprint also other supply chain stages can be important, usually the intermediate suppliers between raw material extraction and direct suppliers. The effect of the industry itself is mostly small, if not negligible. The chemical industry has the highest share of own industrial emissions with 14 % of greenhouse gas emissions over the entire supply chain.

For many industries, most of the environmental impacts occur abroad. Exceptions are the 'meat production' industry, where a substantial share of its environmental impacts occurs in Switzerland and the industries 'real estate services' and 'household devices trade' that exhibit significant impacts in the use phase. The geographical proximity of environmental impact and triggering industry should simplify the introduction of improvement measures. It is more difficult for industries where a large part of the environmental impacts occur in far-off countries. An aggravating factor is that small demand for supply chain inputs in countries with high environmental intensities can strongly influence the overall environmental impact of the supply chain. For these industries, key data on their own supply chain and sustainable supply chain management are central.

5.3 Comparison with the planetary boundaries

The priority of the individual environmental indicators for the recommendation of reduction measures was determined on the basis of a combination of information on global reduction requirements and the share of the respective industry in the global impact. Across all eight focal industries, the greenhouse gas footprint proved to be the environmental impact with the highest priority for reduction measures. Except for the 'Meat production' and the 'Food trade' industries, the greenhouse gas footprint has the highest or second highest share in the global emissions for all industries analysed. Combined with the second highest global reduction requirements, mitigation measures regarding greenhouse gas emissions should have a high priority for all Swiss industries. For the two food-related industries ('Meat production' and 'Food trade'), the biodiversity loss footprint was the indicator with the highest need for action. Even though the share of the biodiversity footprints of the Swiss industries in the global impact is not that high (rank 3 to 4), the high reduction requirement leads to a high priority of this indicator for food-related industries. This is explained by the high relevance of agriculture for the biodiversity loss. For other industries with a high need in food or other agricultural products ('Production of chemical products' and 'Health and social work' industries), the reduction of the biodiversity loss has the second highest priority (after the greenhouse gas footprint).

The share of the industries' air pollution footprint in the global emissions is often similar to the share of the greenhouse gas footprint. This is most likely because similar processes contribute to both indicators (combustion of fossil fuels). As the global reduction need for the air pollution footprint is assumed to be lower than for the greenhouse gas footprint, this indicator has overall a lower priority for reduction measures. Furthermore, a reduction in greenhouse gas emissions will likely lead to a reduced air pollution footprint.

The indicator with – over all industries – the lowest priority for reduction measures is the eutrophication footprint. The reason for this is the low global reduction need for eutrophication. However, the Swiss reduction requirement for eutrophication is considerably higher than the global one. Given that for industries related with food products (Food trade', 'Meat production' and 'Health and social work'), their share in the global emissions is highest for eutrophication, reduction measures regarding eutrophication are particularly relevant for agriculture.

5.4 Measures for reducing environmental impacts

The measures aimed at reducing the environmental impact of Swiss companies can be categorised into two groups: On the one hand, there are measures within Switzerland to comply with the objectives of Swiss environmental policy and Swiss obligations; on the other hand, there are further measures being taken in the supply chain which often affect foreign companies. The results of this study show that in all industries, most of the environmental impacts do not occur in the industry itself, but in its supply chain. Measures to reduce the environmental impact of Swiss industries should therefore imperatively include the supply chains, regardless of whether the companies concerned are located in Switzerland or abroad.

As a first step, transparency over the supply chain should be created as far as possible. The main aim is to target those parts of the supply chain that are relevant from an environmental point of view. This knowledge allows the identification of hotspots in the supply chain and the development of targeted measures adapted to the respective manufacturer or raw material producer. At the end, supply chains that meet high ecological standards can be specifically developed. This can also include a simplification of the supply chain or a reduction in the number of suppliers.

For implementing environmental improvements in the supply chains, there are various options. Specific environmental requirements can be taken into account in purchasing criteria and specifications. For this purpose, framework agreements or supplier codes can be concluded, or compliance can be checked by presenting certificates or by audits of suppliers. Cooperation with suppliers can lead to knowledge transfer and capacity building among suppliers worldwide.

The products themselves are also an important area of action. Through longer lifespans, lower material consumption or the use of more sustainable product components product design changes can be an important lever for reducing environmental impacts in the supply chain. This field of measures has a high innovation potential both for the procuring company and the (pre-)suppliers and is especially relevant for industries with high impacts during the use phase.

For industries related with food production or food trade, agriculture is the most important stage to be addressed. Reducing food waste has major leverage effects.

A crucial area affecting all industries is energy supply. In order to reduce greenhouse gas emissions below the limits of the earth's carrying capacity, it is essential to replace fossil fuels with renewable energy sources at all stages of the supply chain and in the respective industry itself. This should be accompanied by measures to increase the energy efficiency. This applies not only to production but also to the use phase. The use phase can play a very large role in the environmental impact of a product (e.g. in buildings, but also in electrical appliances). Suitable production methods with the aim of minimising environmental impacts during the use phase can make major contributions to the compliance with the planetary boundaries.

6 Conclusions and outlook

6.1 Results

Most of the environmental impacts of Swiss industries occur in their supply chain, often abroad. To reduce the environmental impacts, Swiss industries should therefore include their supply chains and e.g. implement multilateral action plans.

Specific knowledge of the own supply chain is essential for identifying individual environmental hotspots and developing measures. Companies can use the information gained in this study as a starting point for analysing their environmental hotspots.

Specific life cycle assessments can help to identify environmental hotspots in supply chains of individual companies and to monitor the effectiveness of improvement measures. However, large differences in environmental intensities require high geographical resolution of supply chain information.

Exiobase delivers high country and industry resolution and extensive environmental data. The data used in this study have global coverage and make it possible to address selected thematic environmental footprints. However, the global capture of Swiss supply chains requires large amounts of data. Uncertainties exist primarily due to the uncertainties in the basic data and the evaluation for individual industries is partly at the limit of the available data resolution. Plausibility checks and a 'critical' use of the results are therefore very important. The use of two different methods for calculating the environmental impacts made detailed plausibility checks possible, but was also very time-consuming.

6.2 Outlook

The integration of a sustainable supply chain management in the corporate environmental management and environmental reporting of Swiss companies should be further promoted and advanced.

As a further step, policy measures (e.g. border compensation levies on greenhouse gas emissions) should be examined. For facilitating the identification of hotspots regarding water scarcity and biodiversity loss, automated tools, where the relevant data is readily provided, should be developed.

On the part of the data basis, the data quality in the economic and the environmental part of MRIOT should further be improved. The inclusion of a wider range of pollutants and resources in the EE-MRIOT would lead to a more comprehensive data base for environmental analyses and e.g. allow assessing further environmental impacts.

Furthermore, improved and more regionalised Life Cycle Inventory data on production could further enhance the accuracy of the results obtained.

References

Beton A., Dias D., Farrant L., Gibon T., Guern Y. L., Desaxce M., Perwueltz A. and Boufateh I. (2014) Environmental Improvement Potential of textiles (IMPRO Textiles). Joint Research Centre (JRC), Luxembourg.

Böni H. and Hischier R. (2018) Weiter- und Wiederverwendung von elektrischen und elektronischen Geräten. Ökologische und ökonomische Analyse. Schlussbericht. Empa, St. Gallen.

Boulay A.-M., Bare J., Benini L., Berger M., Lathuillière M., Manzardo A., Margni M., Motoshita M., Núñez M., Pastor A. V., Ridoutt B., Oki T., Worbe S. and Pfister S. (2017) The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on Available WAter REmaining (AWARE). In: The International Journal of Life Cycle Assessment, pp. 1-11, 10.1007/s11367-017-1333-8.

Bundesrat S. (2017) Massnahmen an der Quelle zur Reduktion der Mikroverunreinigungen in den Gewässern. Bericht des Bundesrates in Erfüllung des Postulats 12.3090 Hêche vom 7. März 2012, Bern.

CDP, WRI and WWF (2015) SECTORAL DECARBONIZATION APPROACH (SDA): A method for setting corporate emission reduction targets in line with climate science, retrieved from: www.sciencebasedtargets.org/downloads.

CDP, United Nations Global Compact, WRI and WWF (2017) Science-based Target Setting Manual. 4/4/2017, Version 3.0. Carbon Disclosure Project, United Nations Global Compact, Word Resources Institute, World Wide Fund for Nature, Geneva.

Chaudhary A., Verones F., de Baan L. and Hellweg S. (2015) Quantifying Land Use Impacts on Biodiversity: Combining Species–Area Models and Vulnerability Indicators. In: Environmental Science & Technology, 49(16), pp. 9987-9995.

Chaudhary A., Pfister S. and Hellweg S. (2016) Spatially Explicit Analysis of Biodiversity Loss due to Global Agriculture, Pasture and Forest Land Use from a Producer and Consumer Perspective. In: Environmental Science & Technology, 50, pp. 3928–3936.

COSO and WBCSD (2018) Enterprise Risk Management. Applying enterprise risk management to environmental, social and governance-related risks. Preliminary Draft. Committee of Sponsoring Organizations of the Treadway Commission, World Business Council for Sustainable Development.

Dao H., Friot D., Peduzzi P., Bruno C., Andrea D. B. and Stefan S. (2015) Environmental limits and Swiss footprints based on Planetary Boundaries. UNEP/GRID-Geneva & University of Geneva, commissioned by the Swiss Federal Office for the Environment (FOEN), Geneva, Switzerland.

Daub C.-H., Winistörfer H. and Weber M.-C. (2016) Umweltziele von Unternehmen in der Schweiz. Fachhochschule Nordwestschweiz / Zürcher Hochschule für Angewandte Wissenschaften, Olten / Winterthur.

Droz H. and Hellweg P. D. S. (2018) Analyse der Umweltwirkung der MEM-Industrie. ETH Zürich, Zürich.

ecoinvent Centre (2010) ecoinvent data v2.2, ecoinvent reports No. 1-25. Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland, retrieved from: www.ecoinvent.org.

European Commission (2011) A renewed EU strategy 2011-14 for Corporate Social Responsibility COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, Brussels, Belgium, retrieved from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0681:FIN:EN:PDF.

European Commission (2014) DIRECTIVE 2014/95/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups. In: L 330/1 (ed. Commission E.), Brussels.

Frischknecht R. and Büsser Knöpfel S. (2013) Swiss Eco-Factors 2013 according to the Ecological Scarcity Method. Methodological fundamentals and their application in Switzerland. Environmental studies no. 1330. Federal Office for the Environment, Bern, retrieved from: http://www.bafu.admin.ch/publikationen/publikation/01750/index.html?lang=en.

Frischknecht R., Nathani C., Stolz P., Wyss F. and Itten R. (2015) Extension of a Disaggregated Input-Output Table with Environmental Data for the Year 2008. treeze Ltd / Rütter Soceco AG, commissioned by the Swiss Federal Office for the Environment (FOEN), Uster / Rüschlikon, Switzerland.

Frischknecht R. and Jolliet O. (ed.) (2016) Global Guidance on Environmental Life Cycle Impact Assessment Indicators, Volume 1. United Nations Environment Programme, UNEP, Paris.

Frischknecht R., Messmer A., Stolz P. and Tuchschmid M. (2016) mobitool - Grundlagenbericht. Hintergrund, Methodik & Emissionsfaktoren. Schweizerische Bundesbahnen SBB, Bundesamt für Energie BFE, Swisscom, Öbu, Bern, retrieved from: http://www.mobitool.ch/typo_static/fileadmin/tools/mobitool-Hintergrundbericht.pdf.

Frischknecht R., Nathani C., Alig M., Stolz P., Tschümperlin L. and Hellmüller P. (2018a) Umwelt-Fussabdrücke der Schweiz: Zeitlicher Verlauf 1996-2015. treeze Ltd / Rütter Soceco AG, im Auftrag des Bundesamts für Umwelt (BAFU), Uster / Rüschlikon.

Frischknecht R., Nathani C., Alig M., Stolz P., Tschümperlin L. and Hellmüller P. (2018b) Umwelt-Fussabdrücke der Schweiz: Zeitlicher Verlauf 1996-2015 - Technischer Bericht. treeze Ltd / Rütter Soceco AG, commissioned by the Swiss Federal Office for the Environment (FOEN), Uster / Rüschlikon.

Fuglestvedt J. S., Shine K. P., Berntsen T., Cook J., Lee D. S., Stenke A., Skeie R. B., Velders G. J. M. and Waitz I. A. (2010) Transport impacts on atmosphere and climate: Metrics. In: Atmospheric Environment, 44(2010), pp. 4648–4677.

Goedkoop M., Heijungs R., Huijbregts M. A. J., De Schryver A., Struijs J. and van Zelm R. (2009) ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition. Report I: Characterisation, NL, retrieved from: lcia-recipe.net/.

Höhne N., den Elzen M. and Escalante D. (2014) Regional GHG Reduction Targets Based on Effort Sharing: A Comparison of Studies. In: Climate Policy, 14(1), pp. 122-147.

IPCC (2007) The IPCC fourth Assessment Report - Technical Summary. Cambridge University Press., Cambridge.

Jungbluth N., Nathani C., Stucki M. and Leuenberger M. (2011) Environmental impacts of Swiss consumption and production: a combination of input-output analysis with life cycle assessment. Environmental studies no. 1111. ESU-services Ltd. & Rütter + Partner, commissioned by the Swiss Federal Office for the Environment (FOEN), Bern, CH, retrieved from: www.esu-services.ch/projects/ioa/ or www.umwelt-schweiz.ch.

Jungmichel N., Schampel C. and Weiss D. (2017) Umweltatlas Lieferketten - Umweltwirkungen und Hot-Spots in der Lieferkette. adelphi / Systain, Berlin / Hamburg.

KBOB, eco-bau and IPB (2016) KBOB Ökobilanzdatenbestand DQRv2:2016; Grundlage für die KBOB-Empfehlung 2009/1:2016: Ökobilanzdaten im Baubereich, Stand 2016. Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren c/o BBL Bundesamt für Bauten und Logistik, retrieved from: www.ecoinvent.org.

Kissling-Näf I., Bernath K., Seyler C., Fussen D., Jungbluth N. and Stucki M. (2013) RessourcenEFFizienz Schweiz REFF; Grundlagenbericht zur Ressourceneffizienz und Rohstoffnutzung. Ernst Basler & Partner, ESU-services GmbH, Zürich.

Lee D. S., Pitari G., Grewe V., Gierens K., Penner J. E., Petzold A., Prather M. J., Schumann U., Bais A., Berntsen T., Iachetti D., Lim L. L. and Sausen R. (2010) Transport impacts on atmosphere and climate: Aviation. In: J Atmosenv, 2010(44), pp. 4678–4734, 10.1016/j.atmosenv.2009.06.005, retrieved from: http://ac.els-cdn.com/S1352231009004956/1-s2.0-S1352231009004956-main.pdf?_tid=2127a67595d8edf6c516e912c49c4240&acdnat=1333532417_ad6f8409ad87089beac3d618cce3f283.

LRV (2009) Luftreinhalte-Verordnung vom 16. Dezember 1985 (LRV): (Stand am 1.1.2009). 814.318.142.1. Schweizerischer Bundesrat, retrieved from: www.admin.ch/ch/d/sr/c814_318_142_1.html.

Messmer A. and Frischknecht R. (2016a) Life Cycle Inventories of Air Transport Services. treeze Ltd., Uster.

Messmer A. and Frischknecht R. (2016b) Umweltbilanz Strommix Schweiz 2014. treeze Ltd., Uster.

Nathani C., Stolz P., Tribaldos T., Schmid C., Schneider M., Frischknecht R., Itten R., Wyss F. and Kopainsky B. (2016) Estimation of a Swiss environmentally extended input-output table with a disaggregated agri-food sector. Rütter Soceco AG / treeze Ltd. / Flury & Giuliani, Rüschlikon / Uster / Zürich.

Nemecek T., Bengoa X., Lansche J., Mouron P., Riedener E., Rossi V. and Humbert S. (2015) Methodological Guidelines for the Life Cycle Inventory of Agricultural Products. Quantis and Agroscope, Lausanne and Zurich, Switzerland.

Sabag Muñoz O. and Gladek E. (2017) One planet approaches. Methodology mapping and pathways forward. Metabolic, Amsterdam.

Steffen W., Richardson K., Rockström J., Cornell S. E., Fetzer I., Bennett E. M., Biggs R., Carpenter S. R., de Vries W., de Wit C. A., Folke C., Gerten D., Heinke J., Mace G. M., Persson L. M., Ramanathan V., Reyers B. and Sörlin S. (2015) Planetary boundaries: Guiding human development on a changing planet. In: Science, 347(6223), pp. 736-747.

treeze Ltd. (2017) Life cycle inventory database: datasets compliant with ecoinvent protocol v2 and provided in EcoSpold v1 data format. treeze Ltd., Uster, CH, retrieved from: www.treeze.ch.

United Nations (2015) Resolution adopted by the General Assembly on 25 September 2015: Transforming our world: the 2030 Agenda for Sustainable Development. United Nations General Assembly, New York, USA.

A Annex

A.1 Chemical industry

A.1.1 Biodiversity loss footprint

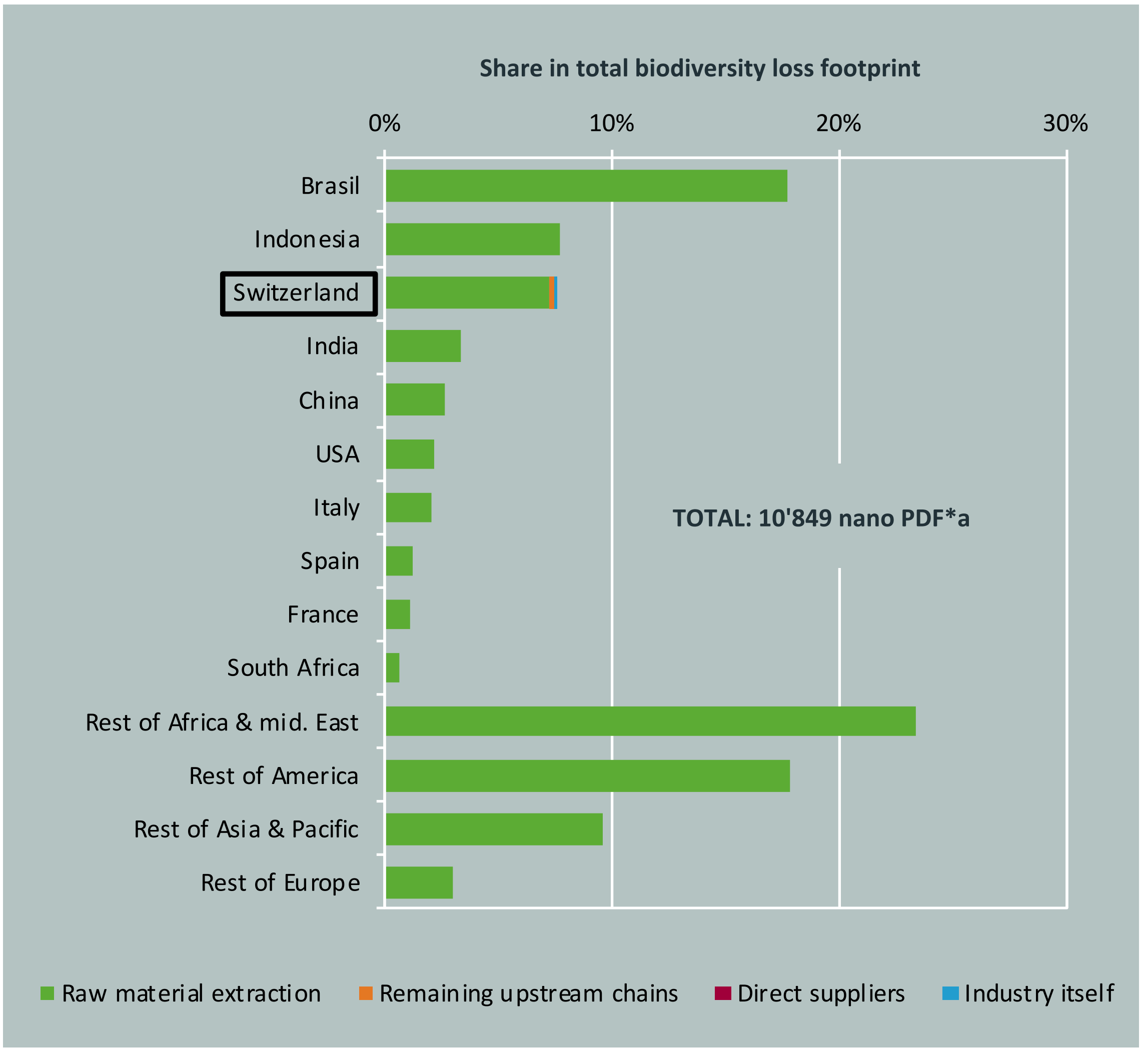

Fig. A.1.1.1: Biodiversity loss footprint caused by the Swiss industry 'Production of chemical products', differentiated by supply chain stage and source countries (Source: Calculations Rütter Soceco)

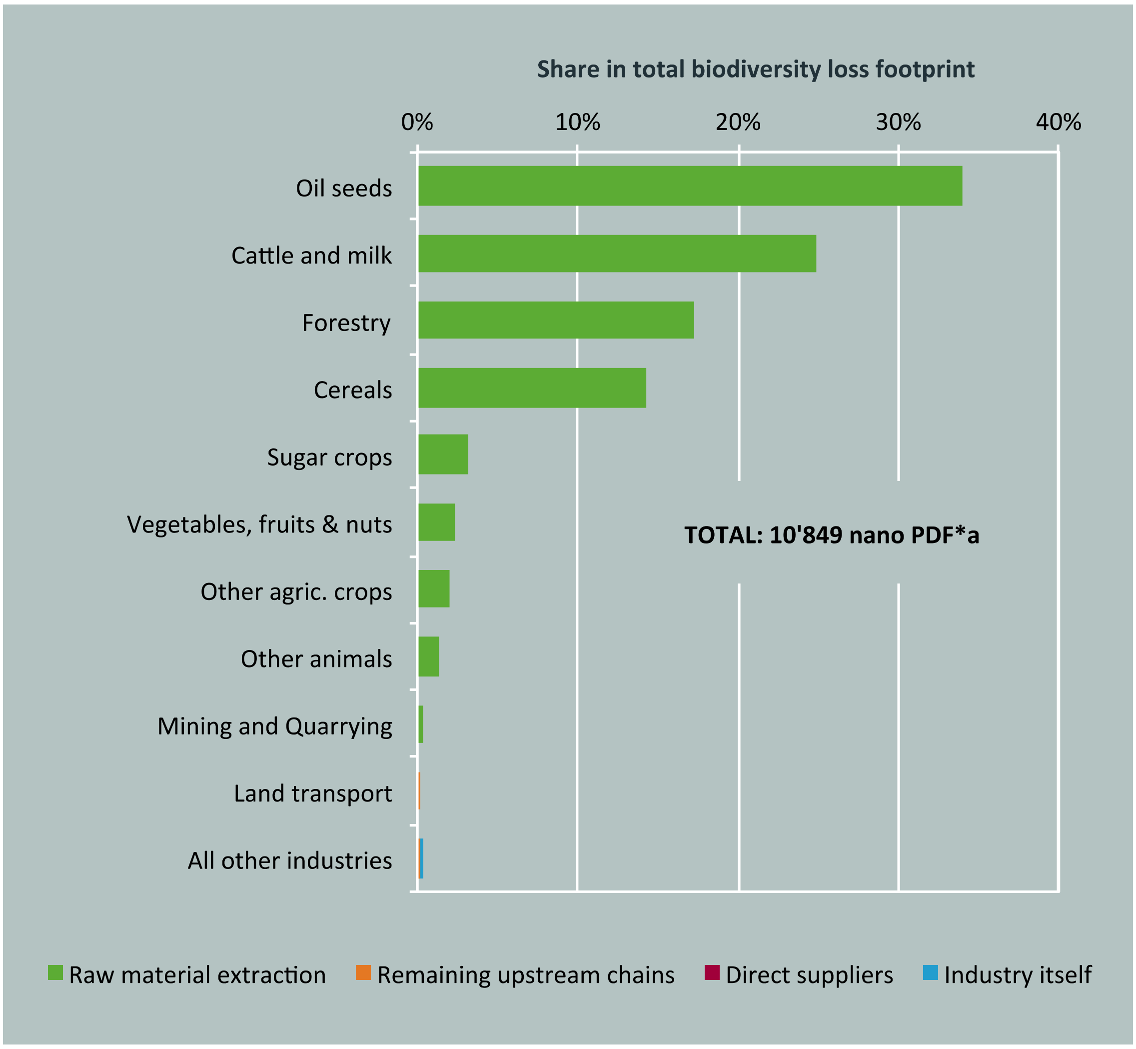

Fig. A.1.1.2: Biodiversity loss footprint caused by the industry 'Production of chemical products' by supply chain stage and industry (Source: Calculations Rütter Soceco)

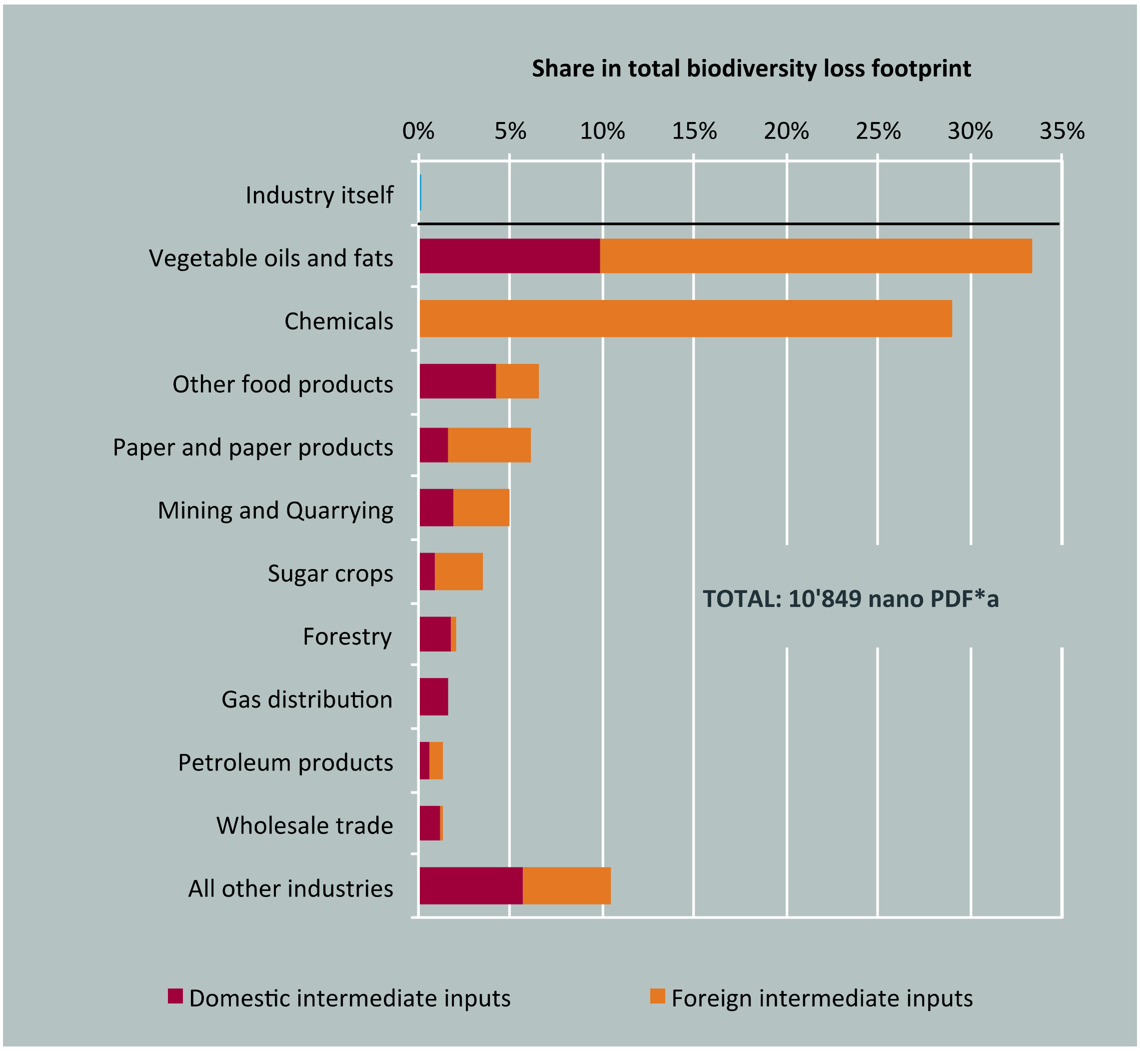

Fig. A.1.1.3: Biodiverstiy loss footprint allocated to the direct suppliers of intermediate goods and services for the Swiss industry 'Production of chemical products' (Source: Calculations Rütter Soceco)

A.1.2 Water footprint

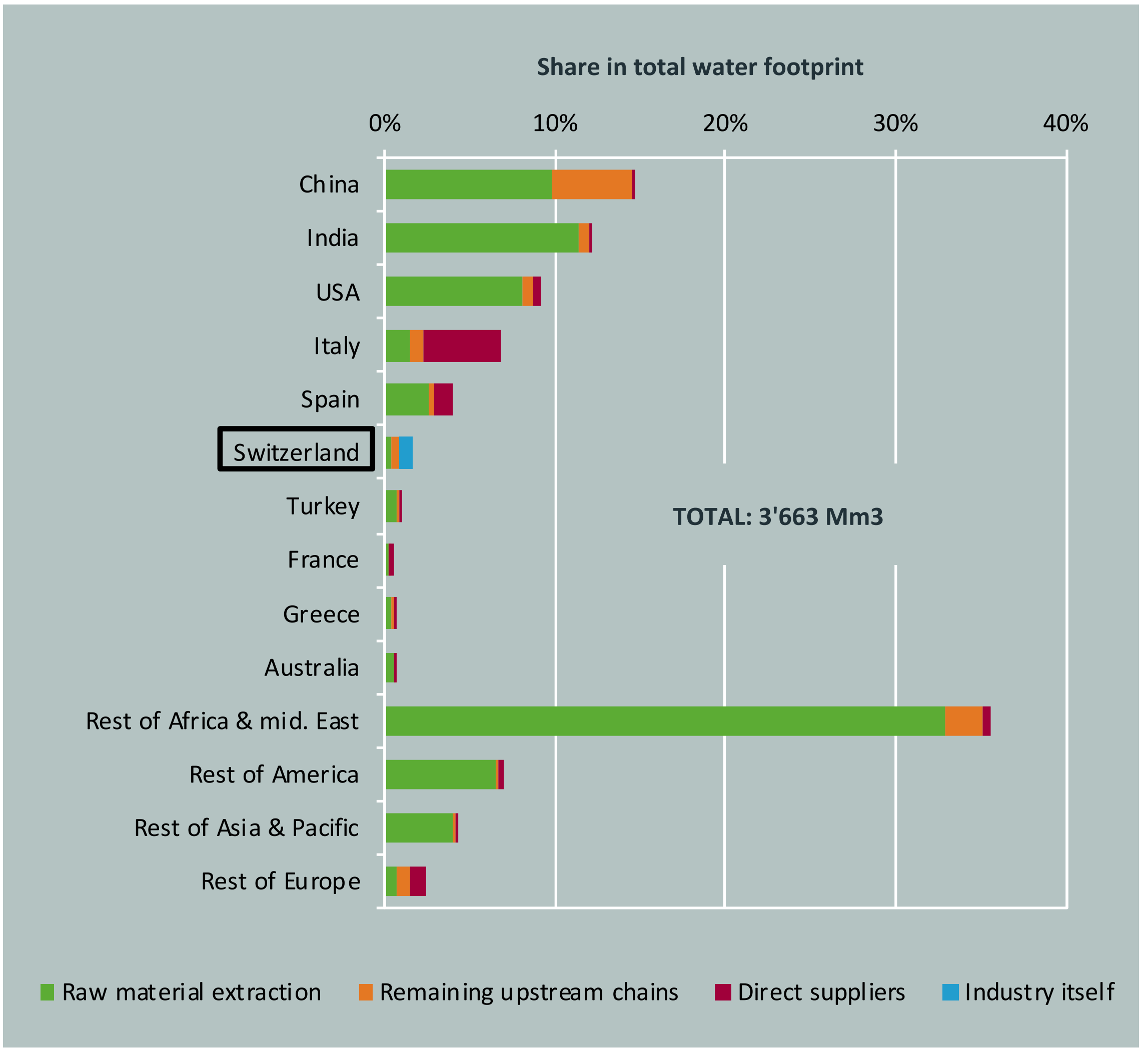

Fig. A.1.2.1: Water footprint caused by the Swiss industry 'Production of chemical products', differentiated by supply chain stage and source countries (Source: Calculations Rütter Soceco)

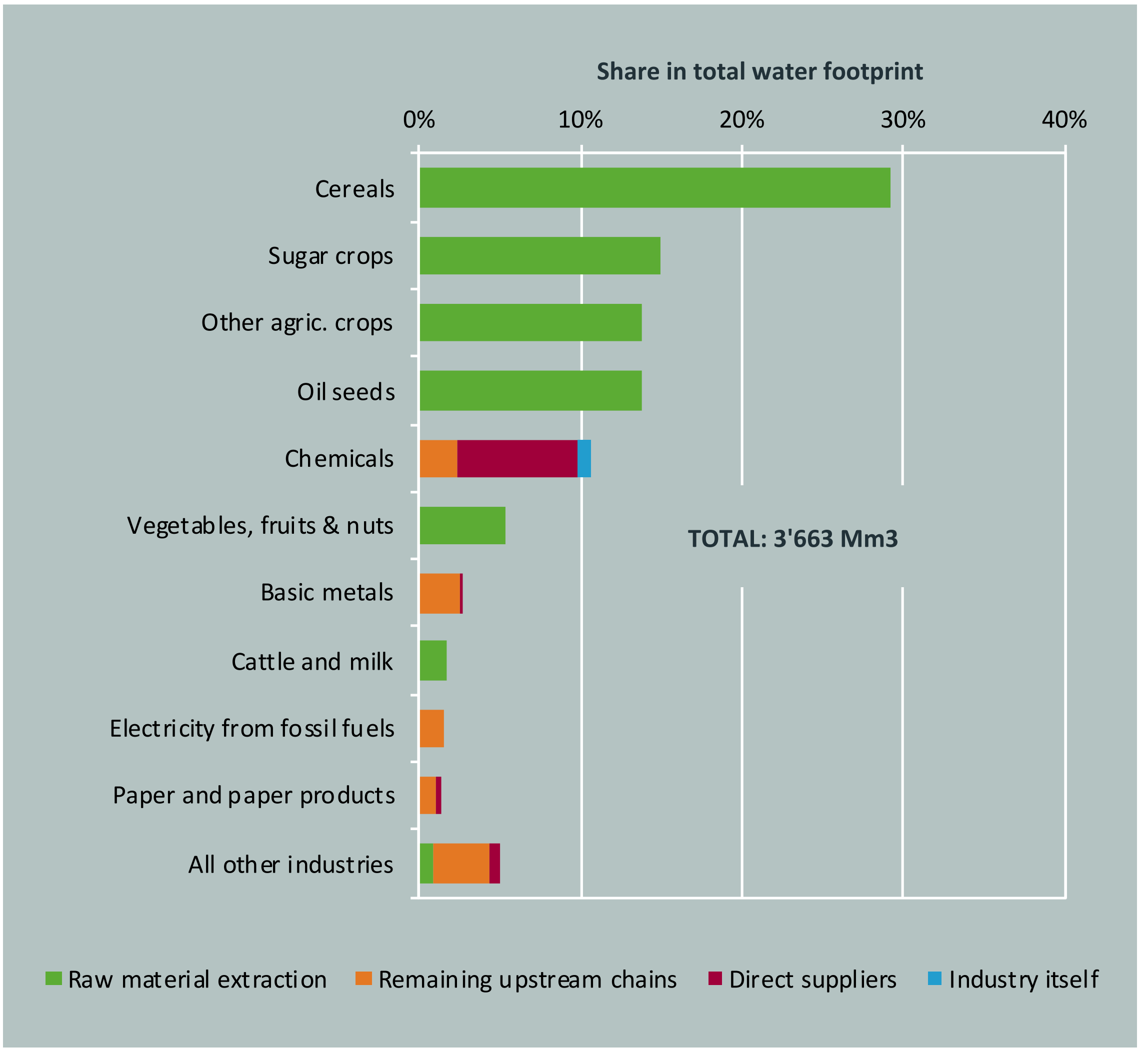

Fig. A.1.2.2: Water footprint caused by the industry 'Production of chemical products' by supply chain stage and industry (Source: Calculations Rütter Soceco)

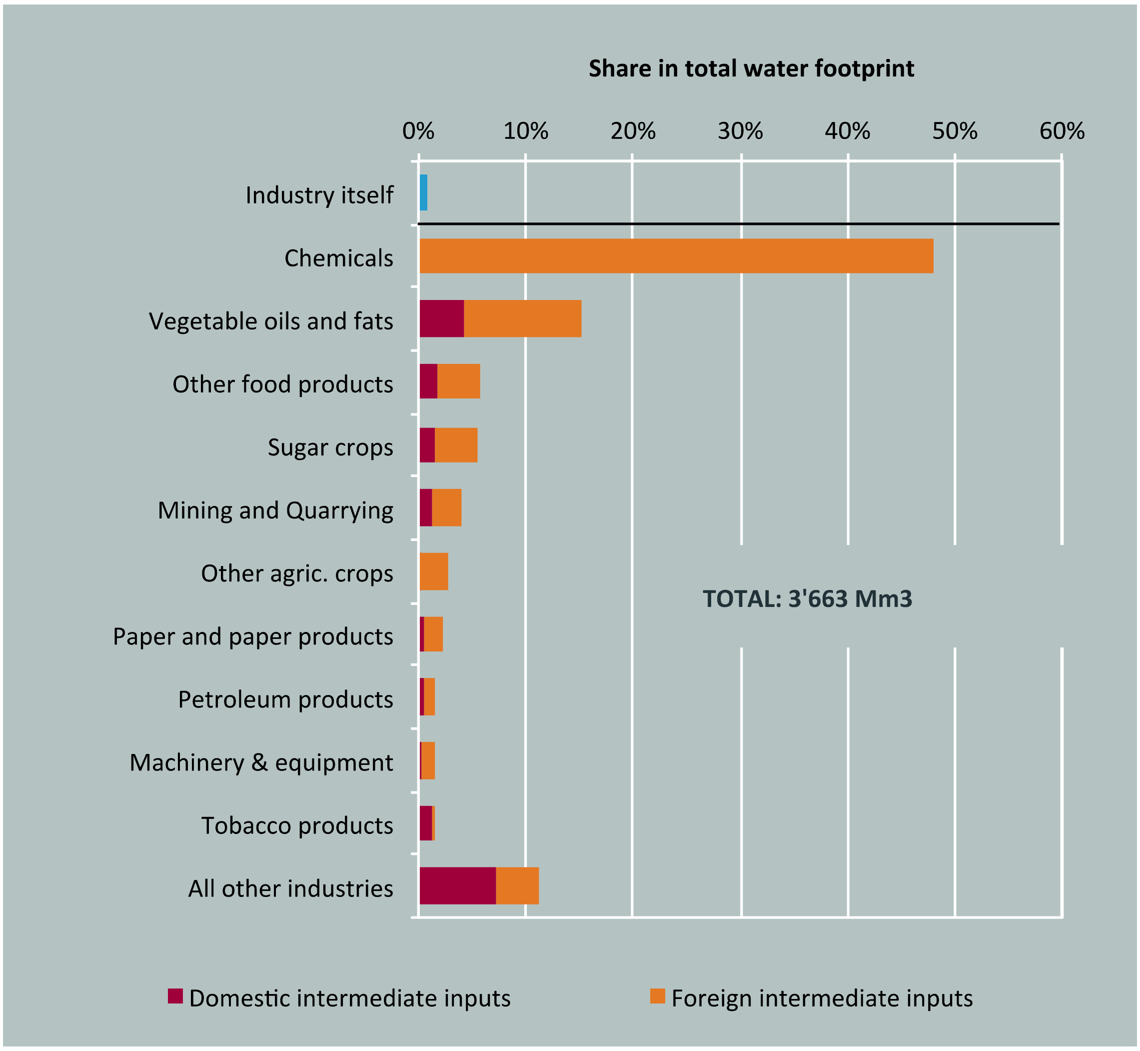

Fig. A.1.2.3: Water footprint allocated to the direct suppliers of intermediate goods and services for the Swiss industry 'Production of chemical products' (Source: Calculations Rütter Soceco)

A.1.3 Air pollution footprint

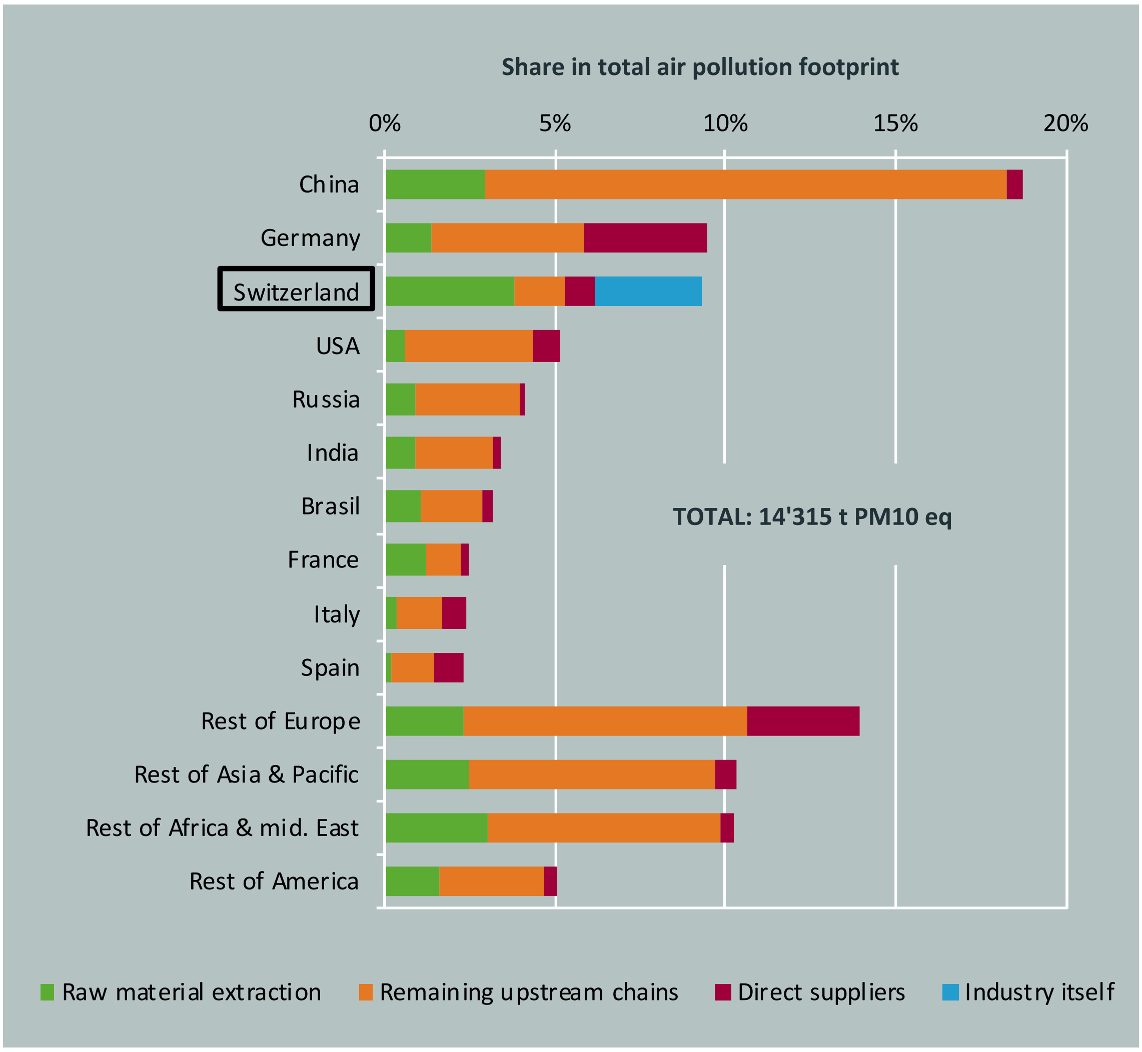

Fig. A.1.3.1: Air pollution footprint caused by the Swiss industry 'Production of chemical products', differentiated by supply chain stage and source countries (Source: Calculations Rütter Soceco

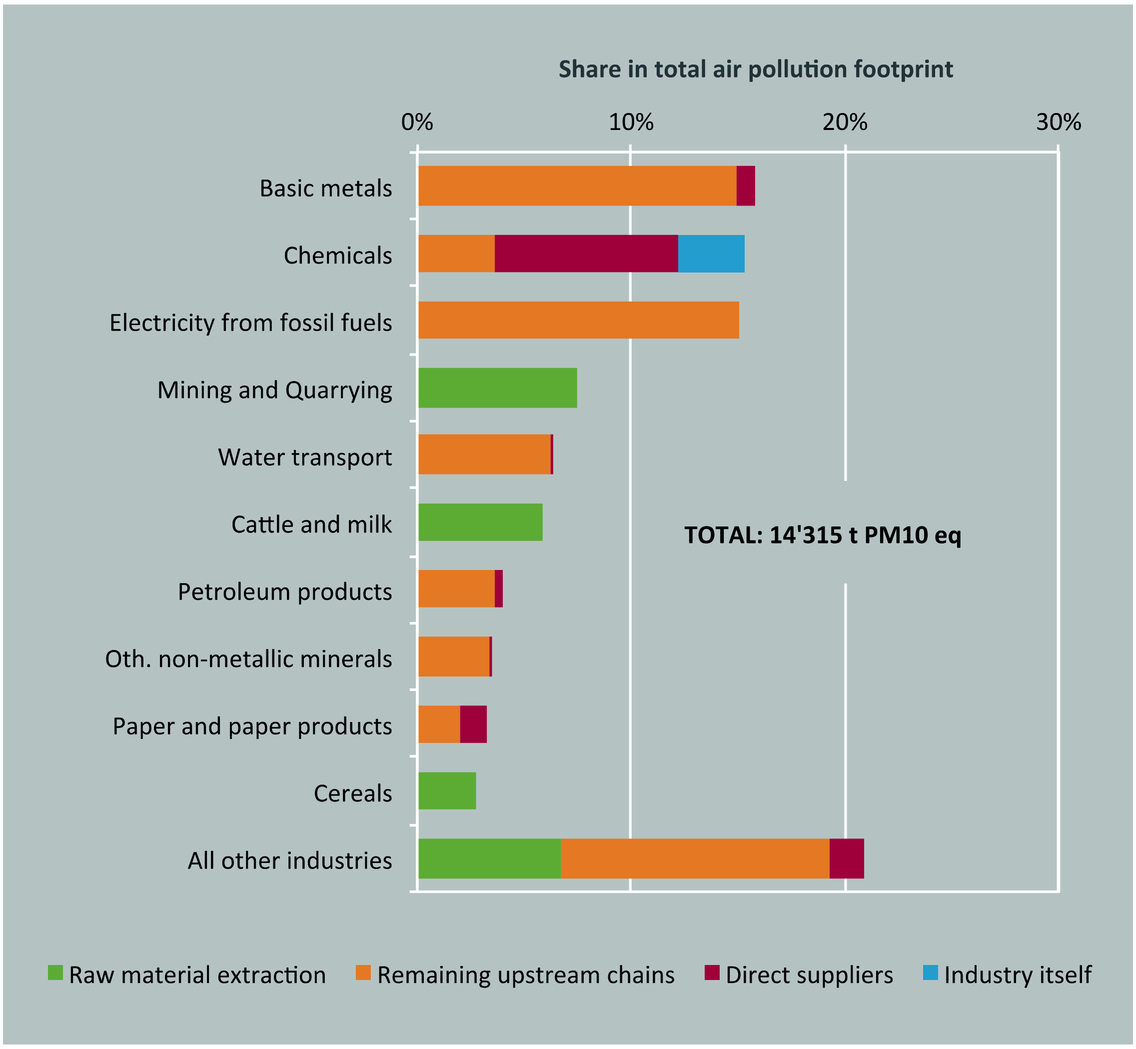

Fig. A.1.3.2: Air pollution footprint caused by the industry 'Production of chemical products' by supply chain stage and industry (Source: Calculations Rütter Soceco)

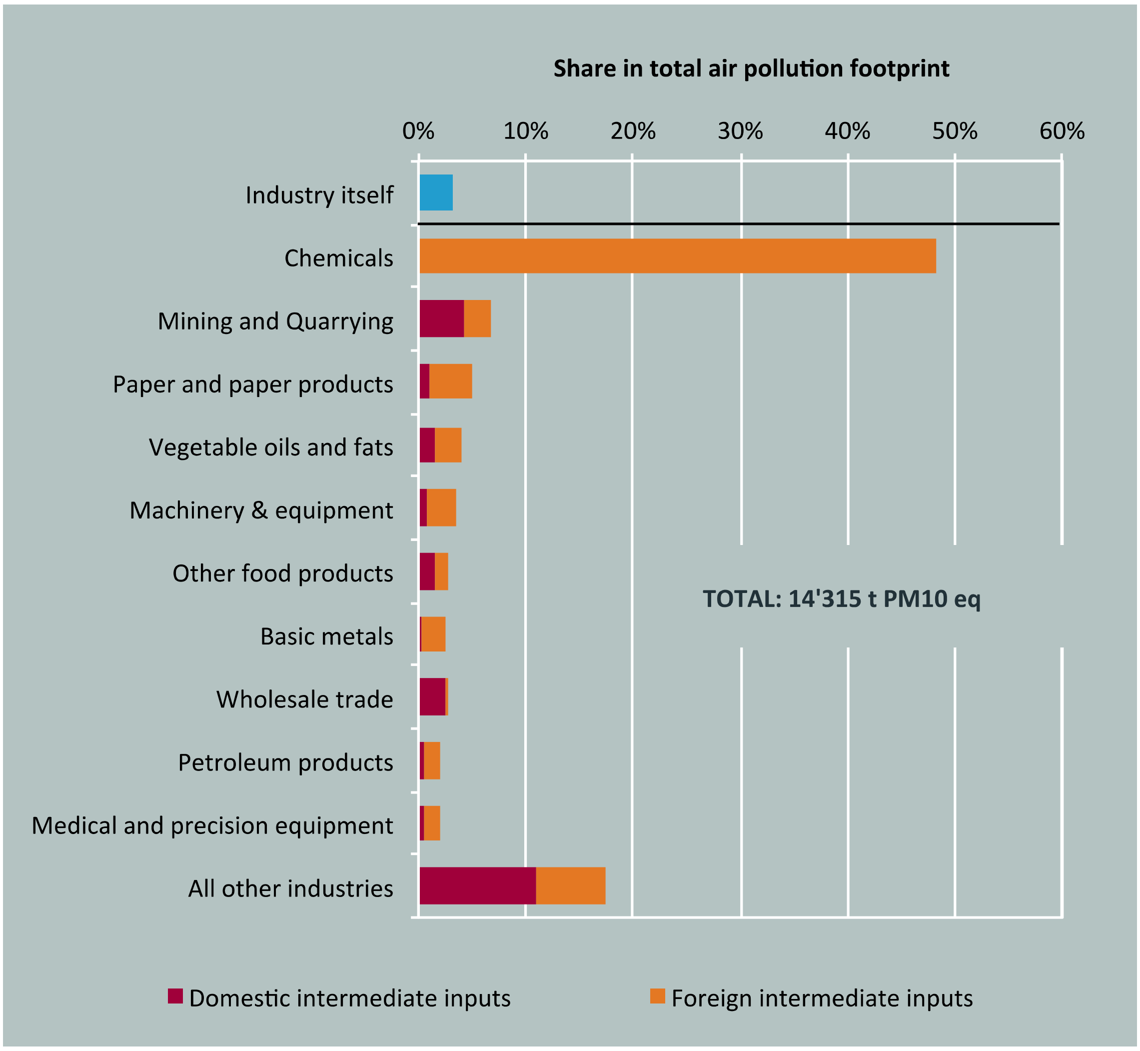

Fig. A.1.3.3: Air pollution footprint allocated to the direct suppliers of intermediate goods and services for the Swiss industry 'Production of chemical products' (Source: Calculations Rütter Soceco)

A.1.4 Eutrophication footprint

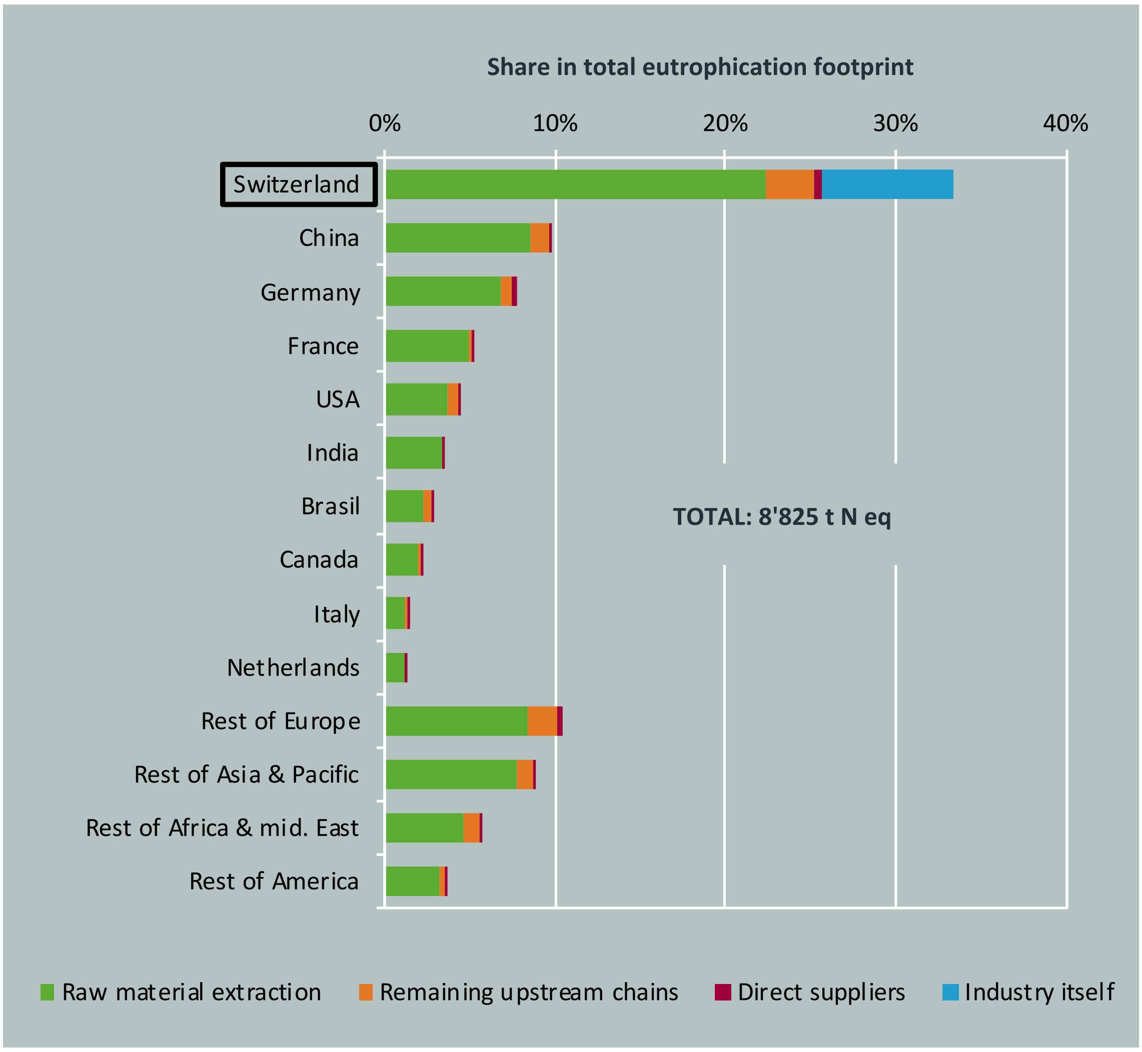

Fig. A.1.4.1: Eutrophication footprint caused by the Swiss industry 'Production of chemical products', differentiated by supply chain stage and source countries (Source: Calculations Rütter Soceco)

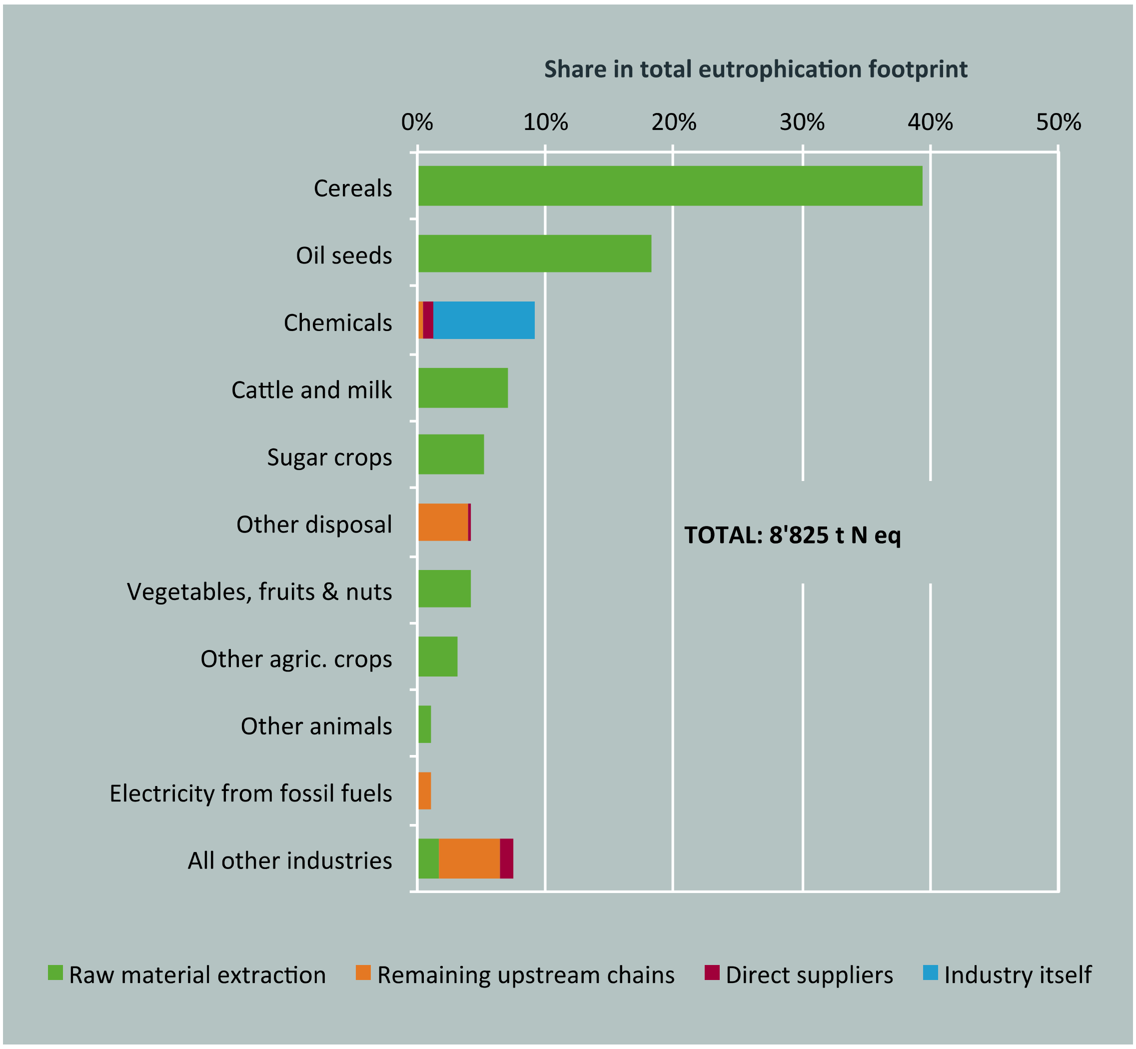

Fig. A.1.4.2: Eutrophication footprint caused by the industry ‘Production of chemical products’ by supply chain stage and industry (Source: Calculations Rütter Soceco)

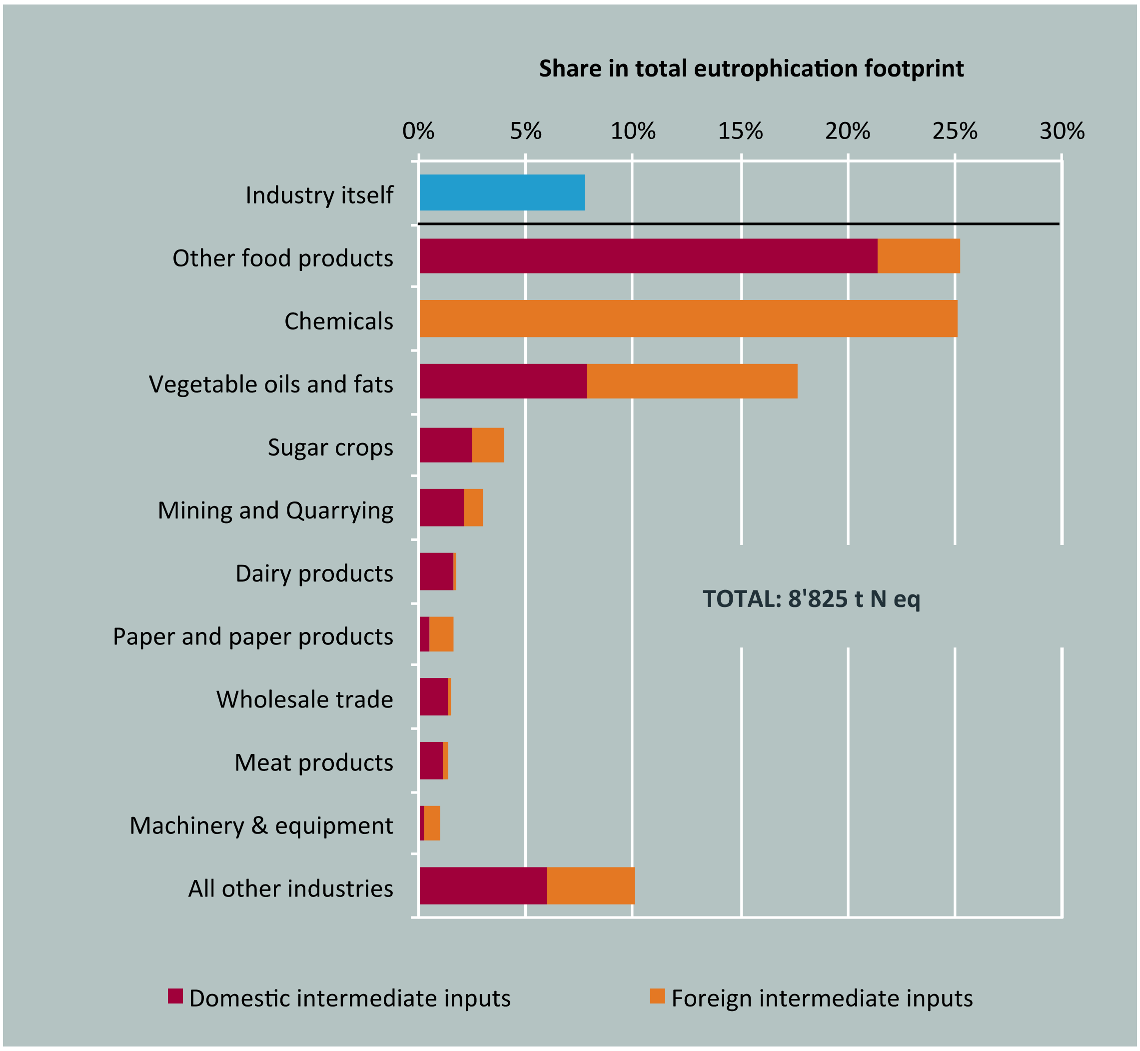

Fig. A.1.4.3: Eutrophication footprint allocated to the direct suppliers of intermediate goods and services for the Swiss industry 'Production of chemical products' (Source: Calculations Rütter Soceco)