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Greenhouse gas footprint of Swiss consumption

A comparison of calculation approaches

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Contents

1. Background and goal of this paper

The calculation of consumption-related environmental footprints of countries has become more important in recent years and many countries and international organizations such as the OECD and the EU are calculating such footprints (cf. e.g. CBS 2019, Eurostat 2018, OECD, 2016). Different approaches have been developed and applied for these calculations. We can distinguish approaches based on environmentally extended input-output models, methods based on environmental life cycle assessment (LCA) and methods combining both approaches.

The different approaches use different methods and data sources and therefore come to different results. The aim of this paper is to identify the methodological and empirical differences between the approaches outlined above and their strengths and weaknesses, to understand the reasons for the differences in outcomes. Four methods are empirically compared for the case of greenhouse gas emissions caused by Swiss consumption and production. In addition, we examine whether a combination of these methods would be useful, how this could be done and what advantages and challenges this would have.

The following approaches have been used to estimate the greenhouse gas footprint of Swiss consumption and are included in the comparison:

- a combination of national environmental statistics with trade and LCA data (TRAIL), used by Frischknecht et al. 2018,
- a combination of a single-country environmentally extended input-output table (EE-IOT) with trade and LCA data (IO-TRAIL), applied by Jungbluth et al. (2011), Frischknecht et al. (2015) and Nathani et al. (2016),
- a combination of a single-country EE-IOT with environmental impact factors of imported products from a European EE-IOT (FSO 2018), called FSO approach in the following,
- environmentally extended multiregional input-output tables (EE-MRIOT).

Another possible approach would be the direct combination of (physical) final consumption data with LCA data. This approach is not considered in this paper.

The paper is structured as follows: In chapter two the different methodological approaches are briefly presented. They are compared from a methodological point of view in chapter three. Chapter four contains the results of the calculation of the Swiss greenhouse gas footprint[1] with each method and conclusions are drawn and recommendations given in chapter five.

[1] We use here the term of “Greenhouse gas footprint” since we also include other greenhouse gases than CO_2._Some authors use the term “Carbon footprint” for a mere CO_2 footprint, while many use it for consumption based greenhouse gases.

2. Overview of footprint calculation approaches

In the following the concept of a consumption-based environmental footprint is illustrated and the four calculation approaches included in the comparison are described and compared from a methodological point of view.

2.1 The environmental footprint of consumption

The responsibility of a country for its environmental impacts can be regarded from two[2] perspectives, the production perspective and the consumption perspective.

- In the production perspective, a country is responsible for its domestic environmental impacts, be they induced by domestic final demand or by exports (green-framed cell in Table 1). This perspective is applied in the context of the UN framework convention on climate change and in the national greenhouse gas inventories.
- In the consumption perspective, a country is responsible for the environmental impacts that are caused by its domestic final consumption[3] (consumption of private households, non-profit institutions serving households and government). These include domestic impacts and impacts caused abroad by imports into the country (red-framed cell in Table 1). Environmental impacts caused by exported products are not included.

In both perspectives, the direct environmental impacts of households are included.

Table 1: Schematic of production and consumption based environmental impacts

	Environmental impacts induced by …		
Location of environmental impacts	**(domestic) final consumption**	**exports**	**Total environmental impacts**
Domestic environmental impacts			**Production perspective**
Environmental impacts abroad			
Total environmental impacts	**Consumption perspective**		

Source: own depiction

The consumption based environmental impacts consists of

- the direct impacts of private households and
- the total impacts induced by domestic final consumption of goods and services across their complete product life cycles, stretching from raw material extraction to waste disposal. The depreciation of capital goods in the product life cycles should also be accounted for, since it is causally linked to production and finally consumption. The induced impacts include domestic environmental impacts and the respective impacts induced by imported goods in foreign countries.

From an environmental accounting point of view, the system boundary between the home country and foreign countries should follow the residence principle that is used in national accounting and that ensures coherence between economic activities and environmental impacts.

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[2] Other perspectives could include e.g. an investors perspective etc.

[3] Following the wording of national accounting, we distinguish between final consumption, domestic final demand, that in addition to final consumption includes gross capital formation and final demand that in addition to domestic final demand also includes exports.

LCA data as well as environmentally extended input output tables usually contain data on resource extraction and emissions of pollutants. Environmental impact category indicators and their characterisation factors are used to quantify environmental impacts such as greenhouse gas emissions or biodiversity losses caused by land use. This important step is identical for all approaches and not described in the following sections.

2.2 TRAIL method

The TRAIL[4] method combines national environmental statistics with trade data and LCA data to calculate the consumption based environmental impacts of a country. The environmental impacts are calculated as

- domestic environmental impacts plus
- environmental impacts induced by imports minus
- environmental impacts induced by exports.

Domestic environmental impacts are quantified using adequate environmental statistics and accounts. Environmental impacts induced by imports and exports are calculated with two approaches, distinguishing between goods and services. Foreign trade with goods is calculated by combining data from the foreign trade statistics in physical units with LCA data. Foreign trade data are aggregated into product groups and for each product group representative products are selected, for which a (global) supply chain from resource extraction to the Swiss border is constructed with LCA data.

The environmental impacts of imports and exports of services can also be calculated with LCA data, although data availability is lower than for goods. Alternatively, they can be estimated with an input-output based approach, e.g. with a domestic EE-IOT assuming that service provision abroad cause the same specific environmental impacts as domestic service provision.

2.3 IO-TRAIL method

The IO-TRAIL method combines a domestic EE-IOT with trade data and LCA data. The domestic EE-IOT distinguishes between the use of domestic and of imported products. The use of imported goods is measured in physical units, whereas the use of imported services is measured in monetary units. The domestic part of the EE-IOT is extended by environmental data expressing the direct environmental impacts of industries and private households. The imported goods in physical units are linked to LCAs like in the TRAIL method. Imported services can either be calculated with LCA data, if possible and available, or by assuming that foreign services have the same environmental impact intensities as domestic services that can be calculated with the IO-TRAIL method.

The scheme of the EE-IOT is shown in Figure 1:

From the EE-IOT the following data are derived:

- A vector of domestic final consumption by product group,
- the Leontief-inverse,
- a coefficient matrix of imported goods in physical units per (monetary) unit of output[5], calculated by dividing imports by gross outputs of the importing industries,
- a coefficient matrix of imported services in monetary units per monetary unit of output, calculated by dividing service imports by gross outputs of the importing industries,
- a domestic environmental coefficient matrix, calculated by dividing environmental impact by (monetary) output.

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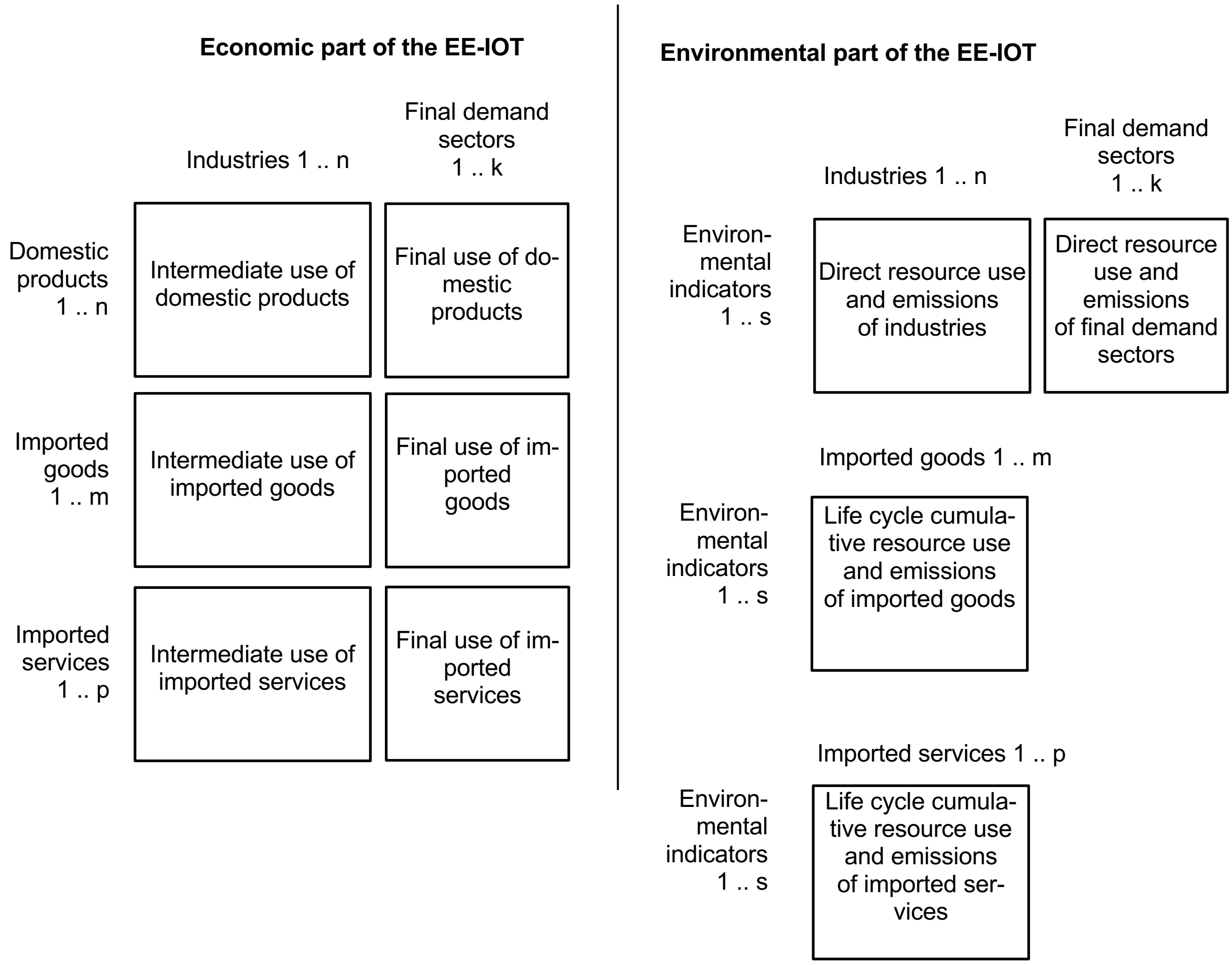
[4] TRAIL: Environmental statistics, TRAde Information and LCA data

[5] output, in German: Bruttoproduktionswert

- The total environmental impacts of imported products can be expressed as a matrix of impact factors relating the total impact over the life cycle of the product to the physical import value.

Figure 1: Scheme of the Swiss EE-IOT



Source: own depiction

Starting with the domestic final consumption vector, the calculation includes the following steps:

- Calculation of total domestic production by industry, induced by domestic final consumption, by multiplying the Leontief inverse with the domestic final consumption vector,
- Calculation of total imports of goods by product group, induced by domestic final consumption, by multiplying total domestic production with the coefficient matrix of imported goods,
- Calculation of total imports of services by product group, induced by domestic final consumption, by multiplying total domestic production with the coefficient matrix of imported services,
- Calculation of total domestic environmental impacts by industry, by multiplying total output by industry with the domestic environmental coefficient matrix, and calculation of the direct domestic environmental impacts of households
- Calculation of total environmental impacts related to imported goods by imported product group, by multiplying physical imports by product group with the matrix of import-related impact factors,
- Calculation of total environmental impacts related to imported services with the following sub-steps:
  - Multiplication of induced services with the Leontief inverse to yield total (domestic) output
  - Multiplication of total services-induced output with the coefficient matrix of imported goods to yield total services-induced imports of goods,

- Multiplication of total services-induced output with the coefficient matrix of imported services to yield total services-induced imports of services,
- Calculation of domestic environmental impacts and environmental impacts induced by imported goods and services according to the above-mentioned steps. The calculation contains an iterative element, that can be stopped when the additional impacts are lower than a defined threshold value.

2.4 FSO method

The Swiss Federal Statistical Office (FSO) has calculated the development of the Swiss greenhouse gas footprint by combining the Swiss EE-IOT with import-related emission factors derived from an EE-IOT for the EU (FSO 2018). This approach makes use of the following data:

- A Swiss EE-IOT with the Swiss IOT extended by greenhouse gas emissions of industries and households. The economic part of the IOT does not distinguish between domestic and imported products;
- direct greenhouse gas emission intensities by industry for Switzerland,
- cumulative greenhouse gas emission intensities by product group for EU exports, summing up emissions across the product life cycles,
- adjustment factors for nine world regions reflecting the relation of their aggregate emission intensities to the aggregate emission intensity of the EU. The aggregate emission intensities are defined as CO2 emissions divided by GDP.

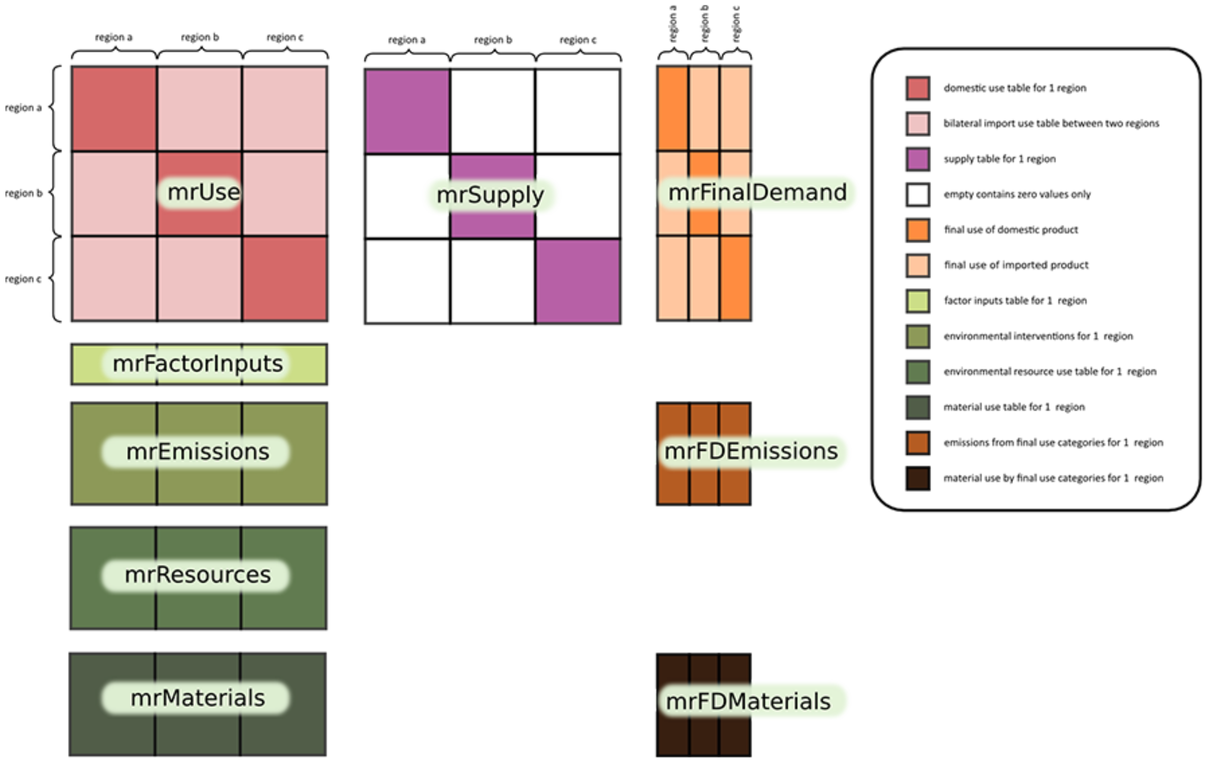
The greenhouse gas footprint is then calculated as follows:

- Total use by product group, induced by domestic final consumption is calculated by multiplying the domestic final consumption vector with the Leontief inverse that is derived from the EE-IOT.
- Total use by product group is allocated to the region of origin, i.e. Switzerland and nine world regions (Africa, Asia, Europe, Japan, Middle East, North America, Oceania, Russia and South America). The share of foreign world regions in total use is determined from foreign trade data.
- For each product group and each region of origin greenhouse gas emission intensities are estimated. They are based on the emission intensities of EU exports calculated with a single-country EE-IOT for the EU. The EU emission intensities are adjusted to the regions of origin by multiplying them with the above-mentioned adjustment factors.

2.5 EE-MRIO method

The use of environmentally extended input-output analysis is a well-established method for calculating a country's consumption footprint (cf. e.g. Hertwich, Peters 2009). Various EE-MRIOT have been constructed to depict the global supply chains and the environmental impacts of production in the various countries (e.g. the OECD ICIO database, World Input-Output Database WIOD, GTAP, Exiobase). EE-MRIOT consist of multiregional input-output tables and environmental extensions. A multiregional input-output table consists of several national input-output tables linked via trade flows at the level of industries and product groups. It depicts the flows of goods and services from every industry in every country to every industry and final demand category in every country. The environmental extensions contain data on the direct resource extractions and emissions of industries and households. The following Figure 2 displays the structure of an EE-MRIOT.

Figure 2: Structure of an EE-MRIOT



Source: http://www.exiobase.eu

The available EE-MRIOTs differ with regard to the number of countries, the level of industry aggregation, the number of environmental extensions and the coverage of environmental impacts. They allow to calculate the total (economic) output and the cumulative environmental impacts by country and industry induced by final demand in a specific country. The calculation includes the following steps:

- The calculation starts with domestic final demand of a country.
- Total output by country and industry is derived by multiplying the Leontief inverse of the MRIOT with domestic final demand.
- Multiplying total output by country and industry with the country and industry specific environmental impact coefficients and adding the direct environmental impacts of households in the initial country yields total environmental impacts by country and industry, induced by final consumption in the initial country.

3. Methodological comparison of approaches

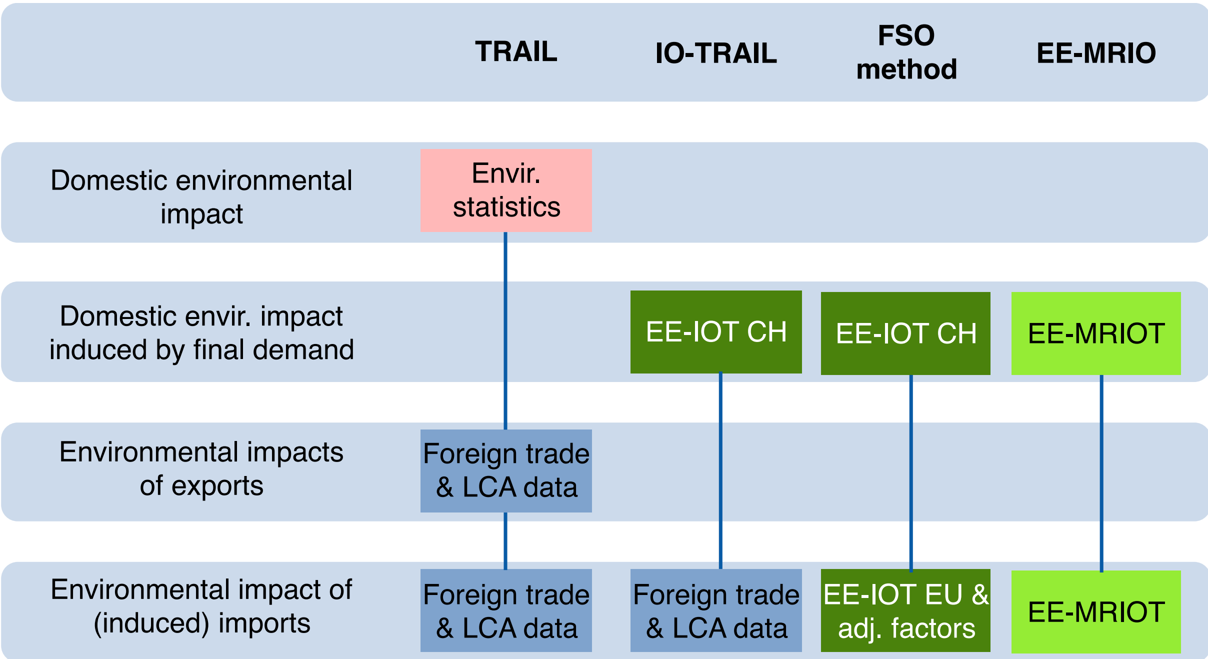
3.1 Overview

In this chapter the four approaches are compared from a methodological point of view. The calculation methods are compared in Subchapter 3.2, the system boundaries in Subchapter 4.2.1 and the databases and data sources in Subchapter 4.2.2. Strengths and weaknesses of the four approaches are discussed in Subchapter 3.3.

3.2 Calculation methods

The following figure compares the methodological elements used by the different approaches. The TRAIL method combines environmental statistics for the domestic environmental impacts with foreign trade and LCA data to quantify the environmental impacts of imports and exports. The IO-TRAIL approach links a Swiss EE-IOT for domestic environmental impacts with foreign trade and LCA data to quantify the environmental impacts of imports. The FSO method works with data based on a Swiss EE-IOT for domestic environmental impacts and with data based on an EE-IOT for the EU and adjustment factors for the environmental impacts of imports from different world regions. The EE-MRIO approach finally uses an EE-MRIOT as a unified framework for calculating domestic environmental impacts as well as environmental impacts in foreign countries.

Figure 3: Methodological elements used by the different calculation approaches[6]



Source: own depiction

The TRAIL method calculates the consumption based environmental impacts in a different way compared to input-output based approaches (cf. Table 2). It adds direct environmental impacts of private households, direct environmental impacts of domestic industries, cumulative environmental impacts of imported products in foreign countries and then deducts cumulative environmental impacts of exported products, arriving at consumption based environmental impacts. By contrast, IO-based methods calculate domestic environmental impacts and environmental impacts in foreign countries induced by domestic final demand and add direct environmental impacts of private households, arriving at consumption based environmental impacts.

The methods also differ with regard to the units. The TRAIL method calculates in physical units (except for imports of services), while the IO-based FSO and EE-MRIO methods work with monetary units. The IO-TRAIL method combines monetary with physical units.

[6] Environmental statistics are used in all approaches as a database and include a transformation to the residence principle.

Table 2 : Calculation methods of the TRAIL method vs. IO-based methods

Emissions ... / induced by ...	Domestic final demand	Exports	Total
by private households	IO-based methods		TRAIL
by domestic industries	IO-based methods		TRAIL
by foreign industries	IO-based methods		TRAIL
Total		TRAIL	TRAIL

Source: own depiction

The approaches also differ in the simplifying assumptions that they make (cf. Table 3) and that may lead to distorted results. The TRAIL approach links imported and exported product groups from the trade statistics with LCA data of best suitable products and product groups and thus assumes that the chosen products and product groups are representative for the product groups traded in reality. In order to allocate export-induced environmental impacts to domestic and foreign sources of impacts, the method assumes that the relation between domestic impacts and import-induced impacts is also representative for export-induced impacts.

The IO-TRAIL method shares the first assumption (representativeness of product LCAs) with the TRAIL method. In addition, it includes the so-called homogeneity assumption of IO analysis, meaning that industries of the IOT are homogeneous. Thus, all outputs of an industry are produced with the same input structure and environmental impact intensity, while in reality industries produce a set of heterogeneous products, that are sold to target industries (within the country and abroad) with varying relations. This assumption is also shared by the other IO-related approaches, the SFSO and the EE-MRIO approach.

Another IO related assumption is the proportionality assumption of import use. In the construction of IO tables, the use of products by industries and final demand sectors is determined first, before distinguishing between the use of domestic and imported products. In some cases, the use of imported products is estimated by making the assumption, that for each imported product group the distribution across industries and final demand sectors is proportional to the distribution of total use of this product group. In other words, the distribution of imported products equals the distribution of domestic products used in the industries. In reality the distribution of the use of imported products may differ from the distribution of the use of domestic products. In this case the import proportionality assumption may distort the actual supply chains of industries and final demand sectors and thus also their induced environmental impacts. This assumption can be relaxed when using additional information from trade statistics

The IO-TRAIL approach comes with an additional import-related assumption, since it includes a transition from monetary to physical units. With regard to goods, the import matrix of the IOT needs to be converted from monetary to physical units that can be linked to LCA data. Due to missing data this conversion entails the assumption that import prices of a specific imported product group are identical across the using industries and final demand sectors. This assumption may distort the supply chains measured in physical units.

Table 3 : Overview of simplifying assumptions between approaches

	TRAIL	IO-TRAIL	FSO method	EE-MRIO (OECD)
LCA process chains representative for imported / exported product groups	Yes	Yes (imports)	–	–
Relation of domestic / foreign emissions applicable for exports	Yes	–	–	–
IO: homogeneity assumption	–	Yes	Yes	Yes
Imports: proportionality assumption reg. use	–	No	Yes	No
Imports: Use of physical imports proportional to use of monetary imports	–	Yes	–	–
Emission intensity of non-EU-imports estimated with GDP-based correction factors	–	No	Yes	No
Environmental intensities of production same in source regions	Partly	Partly	Partly	No

Orange cells: "Yes" and "partly"

Source: own depiction

The FSO approach includes a specific assumption due to its specific way to estimate emission intensities of imports from non-EU countries. These emission intensities are estimated from EU-related emission intensities by including correction factors that reflect the relation of GDP-based emission intensities of non-EU countries or world regions to the respective average emission intensities of EU countries. (cf. subchapter 2.4). This assumption introduces a distortion into the calculation of environmental impacts induced by imports from non-EU countries.

The final assumption is due to the fact that production systems, supply chains and emission intensities of the same product group may differ across countries and world regions. LCA databases often include data for a significant amount of products, but often lack detail with regard to these regional differences. They often refer to specific countries or regional or world average production systems / process / supply chains. The LCA data used in the TRAIL and IO-TRAIL approaches include regional differentiation of import countries' power generation technology mixes and partly of agricultural systems (focusing on regionalised land use and water use data) but assume identical production systems for most other product groups. The FSO approach distinguishes between different non-EU source countries for imports, but currently only with a simplified approach.

3.3 Strengths and limitations

After having presented the approaches we compare the strengths and limitations of the approaches. We organise the comparison along the following criteria:

- Modelling accuracy,
- Economic and environmental comprehensiveness,
- Modelling flexibility,
- Analytical options,
- Data availability and calculation costs.

3.3.1 Modelling accuracy

In reality the supply chains of the products consumed in a country are highly complex and product-specific. The better the approaches are able to capture the complexity and specificity of the real supply chains, the better the quality of the results. Complexity and specificity can relate to the following dimensions, that should ideally be taken into account in environmental footprint calculations.

- *Aggregation level of activities in supply chains*: Supply chains can be depicted at different levels of detail, from detailed processes in dedicated enterprises via generic average technologies to aggregated industries comprising different activities. The higher the level of detail, the better the results. Increasing the level of detail often entails a trade-off with comprehensiveness (cf. below).
- *Technology standards*: Industrial (and commercial) processes can adhere to different technology standards. Ideally the effective technology levels are depicted.
- *Regional specifics of processes*: The same activities in different regions may be characterised by different technology standards, process input combinations and environmental intensities.
- *Regional specifics of supply chains*: The inputs used by enterprises may be sourced from different suppliers in different countries, that usually are characterised by different environmental intensities.
- *Temporal specificity*: Various factors influence the environmental impacts of economic activities over time, e.g. technological change or environmental regulations. In order to track the development of environmental footprints over time it is necessary to capture the technical characteristics of activities and their environmental intensity for the reference period of interest.
- *Quality of data*: This criterion relates to the quality of the data used in modelling supply chains, meaning how well they depict the economic activities they intend to describe.
- *Allocation principle*: The criterion “allocation principle” refers to the principle according to which downstream environmental impacts are allocated to the following processes. The allocation principle is linked to the units, in which the supply chains are modelled. We can distinguish physical and monetary allocation principles. LCA-based methods, that set up supply chains in physical units, usually follow a physical allocation principle, but are flexible to choose between both allocation principles. IO-based methods, that represent supply chains in monetary units, follow a monetary allocation principle. In most cases the physical allocation principle should be preferred.

The performance of the compared approaches with regard to these criteria is evaluated in the following.

TRAIL method

In the TRAIL method the aggregation level of imported and exported product groups is relevant for the quality of the results. Basically, the aggregation level depends on LCA data availability and the resources invested in linking foreign trade and LCA data. In its application to Switzerland, approximately 400 product groups are distinguished, leading to a rather high level of detail. LCA data often include generic (often European) technology data, while different technology standards and temporal and regional specificities are often not available. But the flexibility of the approach allows to generate data that are missing but relevant for the results (cf. below). The TRAIL method uses the physical allocation principle.

IO-TRAIL method

For the IO-TRAIL method the aggregation level of the IOT is also relevant. In the application to Switzerland, an IOT with a rather high level of detail is used, distinguishing approximately 100 industries. Information on domestic technology standards is implicitly included in the EE-IOT. Information on foreign technology standards and other regional specificities are – similar to the TRAIL approach – hardly available, but important missing information can be modelled due to the flexibility of the approach. The IO-TRAIL method is based on the monetary allocation principle for domestic activities and on the physical allocation principle for imported products.

FSO method

In the FSO approach the aggregation level is linked to that of the Swiss IOT, which is rather high, since some environmentally relevant industries in the energy and transport sector are aggregated. It allows to capture the development of economic structures and emission intensities over time by using time series data. Regarding regional specifics and technology standards, on the one hand these are implicitly included in the Eurostat data for the EU countries. On the other hand, a major assumption is that Swiss imports from EU countries are produced under EU-average conditions, which could cause an aggregation error in the results, if the conditions in countries effectively exporting to Switzerland significantly deviate from these average conditions. Regarding imports from non-EU countries, their greenhouse gas emission intensities are roughly estimated with GDP-based ratios. The FSO method uses the monetary allocation principle.

MRIO method

The aggregation level of data used in the MRIO approach strongly depends on the database used. The number of industries lies between 34 industries in the OECD database, 35 industries in the WIOD database and 200 industries resp. product groups in Exiobase. Technology standards, regional and temporal specificities are implicitly included in the EE-MRIOT. Since the EE-MRIOT are estimations based on publicly available statistics, their data quality depends upon the quality of the compilation method and the data used. The MRIO approach uses the monetary allocation principle.

3.3.2 Comprehensiveness

Comprehensiveness can refer to economic and to environmental comprehensiveness.

Economic comprehensiveness means that all economic activities induced nationally and globally by final consumption in a country should be considered in the calculation of environmental footprints. This refers on the one hand to the goods and services that make up final consumption. On the other hand, it refers to the supply chains induced by final consumption that should ideally be fully included. In reality it is often necessary to reduce complexity by focusing on the most important economic activities in final consumption as well as supply chains.

Comprehensiveness also infers that the use of investment goods is included in the supply chains. Production of goods and services makes use of capital goods, that, in contrast with intermediate goods, are not immediately used up in production. They need to be replaced periodically. It is therefore necessary to allocate the use of capital goods to production by some sort of depreciation factor (e.g. based on their economic lifetime) and include this depreciation into the supply chain.

Regarding *environmental comprehensiveness* it is useful to include all relevant environmental impacts into the calculation of environmental footprints in order to have the complete picture. Decisions taken on the basis of non-comprehensive environmental indicators have the risk of shifting environmental impacts to environmental problems/issues that have not been measured. Including all relevant environmental impacts can imply assessing a group of environmental indicators or analysing an aggregated indicator that weights various partial indicators.

- If a partial footprint such as the greenhouse gas footprint is analysed, all relevant factors influencing the footprint should ideally be included into the analysis (e.g. in the case of the greenhouse gas footprint all Kyoto-substances contributing to climate change).
- Furthermore, it is beneficial if a method can also be applied for other environmental issues than climate change (e.g. biodiversity, water scarcity, eutrophication etc.). The number of environmental indicators, that are supported by resource extraction and emission data in a calculation method, can be used as a coarse criterion for comparing the environmental comprehensiveness.

The performance of the compared approaches with regard to these criteria is evaluated in the following. All approaches are economically comprehensive with regard to domestic activities, but they differ with regard to foreign activities.

TRAIL method

Regarding the comprehensiveness of foreign economic activities, the TRAIL method relies on LCA data that focus on the relevant processes but are not able to comprehensively include all economic activities. LCA data allow including investment goods in the supply chains and this has been done in the application to the Swiss consumption footprints.

The comprehensiveness of the environmental data depends upon the scope of the domestic environmental statistics and that of the data included in the LCA data. The data sources used allow including a wide range of environmental indicators.

IO-TRAIL method

The performance of the IO-TRAIL method with regard to economic comprehensiveness is similar to that of the TRAIL method, since the data sources are similar.

FSO method

The FSO approach can be considered to be comprehensive with regard to economic activities. The performance of the FSO approach partly depends on the comprehensiveness of the EE-IOT for the EU, that we assume to include imports from non-EU countries into the EU. The investment effect has not been included in the FSO approach, but this would in principle be possible by using or estimating investment matrices for Switzerland and the EU.

The environmental comprehensiveness of the approach depends on the range of environmental indicators that can be linked to the input-output tables. The FSO's application to Switzerland currently focuses on greenhouse gases.

MRIO method

Since multiregional input-output tables in principle include all economic activities, the approach can be considered to be comprehensive from an economic point of view. Empirical weaknesses or gaps may occur for countries with gaps in the economic accounts or foreign trade data.

The environmental comprehensiveness of the approach again depends on the range of environmental indicators that are included in the EE-MRIOT. Here the available databases differ widely, with few indicators in the OECD and the WIOD databases and more than 100 indicators in Exiobase.

3.3.3 Modelling flexibility

Modelling flexibility refers to the possibility of adapting the supply chain modelling to improve the depiction/mapping of reality.

In principle, both the IO-based and the LCA-based approaches are able to adapt their supply chains and the environmental intensities of the activities included in the supply chains. In reality LCA-based methods (TRAIL and IO-TRAIL) are easier to adapt, since they can rely on extensive process databases and focus on physical interrelations. The adaptation of IO-based approaches is more data- and time-consuming since input-output tables are based on statistical data. Inputs, outputs and environmental intensities of (additional) industries need to be newly estimated from the available sources. While it is possible to extend national IOT with reasonable resources, the adaptation of an EE-MRIOT is highly time-consuming and seldomly done in the context of footprint calculations. Usually EE-MRIOT are used as they are.

3.3.4 Analytical options

The compared approaches can also be distinguished with regard to their analytical options, meaning the questions that can be answered with these approaches. The following table summarises the analytical options of the compared approaches.

Table 4: Analytical options of the compared approaches

	Methods			
Research question	**TRAIL**	**IO-TRAIL**	**FSO method**	**EE-MRIO**
Level of footprint for a single period	Yes	Yes	Yes	Yes
Contribution of final demand categories to footprint	No	Yes	Yes	Yes
Contribution of industries and product groups to footprint	Domestic: no Foreign: by imported product group	Domestic: yes Foreign: by imported product group	Domestic: yes Foreign: by imported product group	Domestic: yes Foreign: yes
Contribution of regions to footprint	Allocation to domestic and foreign env. impacts: with simplifying assumptions Differentiation of regions in impacts abroad (partly, for water and biodiversity footprints)	Partly (water and biodiversity footprints)	Yes (macro regions, with simplifying assumptions)	Yes (countries and regions)
Temporal development of footprint	Domestic: yes Foreign: yes for level and structure of imports Emission intensity of imports: possible for selected product groups with specific modelling, depending on availability of time series in LCA data	Domestic: possible, depending on time series of EE-IOT Foreign: cf. TRAIL method	Yes	Currently yes; Future: depending on regular availability of EE-MRIOT

Source : own depiction

3.3.5 Data availability and costs of calculation

TRAIL method

The TRAIL method relies on environmental statistics, foreign trade data and on LCA data. Environmental statistics are often available annually, partly at specific intervals. Foreign trade data are available annually. LCA data are organised in dedicated databases. Their content relies on data that have been specifically collected for environmental life cycle assessments and have been shared by their authors with the LCA community. The scope of processes and products included in the databases are therefore partly random. In general, LCA databases have extensive data on energy technologies, raw and basic materials, transport and waste management services. The coverage of complex industrial products and services other than those mentioned is usually less extended.

For calculating the environmental footprint, it is necessary to collect the required data from environmental and foreign trade statistics and to link the imported and exported product groups with sufficiently representative products for which LCA data are available. Repeating a footprint calculation can benefit from previous allocations of LCA data to foreign trade data. Therefore, the costs of calculating footprints are rather low compared to the efforts and costs of other approaches (once the LCA data are available).

IO-TRAIL method

The IO-TRAIL method differs from the TRAIL method in that it additionally needs a national input-output table. The environmental data (domestic resource use and emissions) need to be allocated to the industries and households represented in the IOT. The IOT needs to distinguish between domestic and imported products. For this, the use of imported products by industries and final demand categories needs to be estimated in physical units and included into the IOT. Imports in physical units can then be linked to LCA data. Compared to the TRAIL method, this method requires more data. The import matrix needs to be estimated for each new reference year, while the resources needed to set up the matrix of environmental extensions depends on the available data. Currently, the Swiss environmental accounts published by the SFSO include data on energy carriers and air emissions. Additional indicators need to be additionally allocated to industries and households with the help of existing data sources. The allocation of LCA data to foreign trade data only needs to be changed if better and more recent LCA data are available. Overall, the calculation costs of the IO-TRAIL depend on the scope of the analysis but are generally higher than for the TRAIL method.

FSO method

The FSO method makes use of the following data sets: a national EE-IOT linked with foreign trade data on the regional origin of imports, environmental multipliers for imported products provided by Eurostat and aggregated GDP and environmental data for non-EU countries and world regions. All these data are publicly available or can be calculated with publicly available data. The scope of analysis with regard to time and environmental indicators is therefore restricted to the data, that are available in the national and environmental accounts published by FSO and Eurostat.

MRIO method

The MRIO method makes use of an environmentally extended multiregional input-output table for each reference year analysed. The yearly EE-MRIOT are not published by national statistical offices but are estimated in dedicated projects by international organisations and research teams. Therefore, the scope of data included in these EE-MRIOT with regard to sectoral and regional disaggregation, time series and environmental extensions strongly differs and it is partly unclear if and how often the data will be updated. The OECD is periodically updating their set of MRIOTs but only offers a small set of environmental extensions. The WIOD database offers a larger set of environmental extensions, but the updating policy is uncertain. The Exiobase database has the largest scope with regard to industry disaggregation, time series and environmental extensions, but also here updating depends on the ability to secure new funding.

The development of a new EE-MRIOT is highly resource-consuming and thus costly. If the required database is available, the costs of calculating environmental footprints are relatively low.

3.3.6 Summary of strengths and limitations

The following table gives an indicative overview of strengths and limitations of the approaches compared, indicating positive factors with green and negative factors with red. Factors in between are characterised with yellow and unclear factors with grey colour. The comparison criteria listed in the table do not necessarily have equal weights. This should be considered in an aggregate evaluation of the different methods.

Table 5: Overview of strengths and limitations

	Methods			
Comparison criterion	**TRAIL**	**IO-TRAIL**	**FSO method**	**EE-MRIO**
Modelling accuracy				
Aggregation level of activities	Domestic: n.a. Imports: low	Domestic: medium Imports: low	Domestic: high Imports: high	WIOD / OECD: high Exiobase: low
Data uncertainty	Mainly from linking of foreign trade and LCA data	Physical import matrix Linking of foreign trade and LCA data	EU-average conditions for Swiss imports from EU GDP-based multipliers for non-EU imports	Global trade flows Allocation of global env. impacts to industries
Allocation principle	Physical	Physical / monetary	Monetary	Monetary
Technology standards	Domestic: yes Foreign: partly possible with dedicated modelling; depends on data availability	Domestic: yes Foreign: see TRAIL method	Domestic: yes Foreign: possible; partly with simplifying assumptions	Domestic: yes Foreign: yes
Regional specifics	Partly possible with dedicated modelling; depends on data availability	see TRAIL method	With simplifying assumptions	Yes
Comprehensiveness				
Economic comprehensiveness	Medium	Medium	High	High
Environmental comprehensiveness (Adaptability to other environmental indicators)	High	High	Low	WIOD / OECD: low Exiobase: high
Modelling flexibility	High	Medium	Low	Low
Analytical options				
Footprint for a single period	Yes	Yes	Yes	Yes
Contribution of final demand categories to total footprint	No	Yes	Yes	Yes
Contribution of industries and product groups to total footprint	Domestic: no Foreign: by imported product group	Domestic: yes Foreign: by imported product group	Domestic: yes Foreign: by imported product group	Domestic: yes Foreign: yes
Contribution of regions to total footprint	GHG: no Other: Partly (water and biodiversity footprints)	GHG: no Other: Partly (water and biodiversity footprints)	GHG: Yes (macro regions, with simplifying assumptions)	Yes (countries and regions)
Temporal development of footprint	Yes	If time series of EE-IOTs are available	Yes	If time series of EE-MRIOTs are available
Data availability				
Data sources publicly available	Yes	Depending on domestic EE-IOT project	Yes	Depending on dedicated EE-MRIO projects

	Methods			
Comparison criterion	**TRAIL**	**IO-TRAIL**	**FSO method**	**EE-MRIO**
Frequency of updates	Regular	Irregular	Regular	Irregular
Additional calculation costs				
Database setup	Medium	High	Low	Low, if EE-MRIO is available
Initial calculation	Medium	Medium	Low	Low
Updates	Low	Medium	Low	Low

GHG: greenhouse gases

Source : own depiction

The comparison reveals that the main strengths of the TRAIL method are its high level of detail, the physical allocation principle and its high modelling flexibility allowing to include relevant effects by adapting the supply chain modelling. Calculations of footprint time series are possible at relatively low costs. Limitations are the consideration of different technology standards, regional specificities and temporal dynamics and fewer analytical options.

The main advantage of the IO-TRAIL method compared to the TRAIL method is the inclusion of a national EE-IOT for calculating domestic environmental impacts. This opens additional analytical options allowing to identify drivers of environmental footprints. The main disadvantages are higher calculation costs, especially for footprint time series.

The FSO approach is innovative in the sense that it combines a Swiss EE-IOT with EE-IOT based data for the European Union as the most important trade partner of Switzerland. It makes use of publicly available data and allows to calculate time series of the greenhouse gas footprint with low resources. Its major limitation stems from the hypothesis that the greenhouse gas footprint of Swiss imports can be adequately estimated by using the greenhouse gas footprint of EU-average exports and GDP-based emission multipliers.

The major advantage of the EE-MRIO approach is its economic comprehensiveness that completely covers the global supply chains. For some EE-MRIO databases the other side of this coin is the low level of sectoral detail and the small number of environmental extensions. The Exiobase database is an exception with a high level of sectoral detail. A major disadvantage of this approach is the homogeneity assumption that could lead to aggregation errors.

4. Comparison of results for the Swiss greenhouse gas footprint

4.1 Introduction

In this chapter the results for the Swiss consumption-based greenhouse gas footprint calculated according to approaches presented in Chapter 2, i.e. the TRAIL approach, the IO-TRAIL approach, the FSO approach and the EE-MRIO approach are described and discussed. The approaches are compared for the reference year 2008, the only year covered by all approaches. For the TRAIL approach and the FSO approach, the results are compared for the time period between 2008 and 2015.

The following data sets were used for the calculations:

- TRAIL: data base developed in Frischknecht et al. (2018),
- IO-TRAIL: Swiss EE-IOT 2008 with disaggregated and improved data for the energy, the transport and the food sectors, developed by Nathani et al. (2016),

- FSO approach: Swiss IOT 2011 back-casted to 2008 and extended with GHG emission data from the Swiss air emission accounts (FSO 2018)[7]
- EE-MRIO approach: OECD intercountry IOT for the year 2008, extended with country and industry specific GHG emission data that were taken from various sources, since the OECD only used energy related CO_2 emissions:
  - Energy related CO_2 emissions were sourced from the OECD (Yamano, 2018)
  - Non-energy related CO_2 emissions were taken from the air emission extensions of the WIOD database (2013 version)
  - CH_4 and N_2O emissions also stem mainly from the WIOD database.
  - GHG emissions of Switzerland were taken from the Swiss EE-IOT.

Apart from the methodological differences laid out in chapter 3, differences exist with regard to the concrete data bases used for the calculations, that may hamper the comparability of results. Before presenting and comparing the results of the calculations in subchapter 4.3, we provide an overview of these data-oriented differences, that may disappear in future updates of the respective data bases.

4.2 Comparison of the used data bases

4.2.1 Differences regarding system boundaries

Apart from the methodological differences described in Subchapter 3.2 above, the compared approaches also differ with regard to system boundaries, especially in their current application on Switzerland. Table 6 contains an overview of these differences.

The first difference refers to the *concept of foreign trade*. In 2014 the Swiss Statistical Office has implemented the European System of Accounts (ESA 2010), which in particular changes the concept of foreign trade from a country-of-production concept to a country-of-origin concept (Fischer/Pfammatter 2013). This change led to significantly larger values for imports and exports of goods and services. The TRAIL and the FSO approaches work with trade data from after the SNA revision while the IO-TRAIL and the EE-MRIO approach work with trade data from before the SNA revision. This difference affects the levels of imports and exports and thus their induced environmental impacts but much less the net trade related environmental impacts.

The second difference refers to the *concept of foreign trade with electricity*. The IO-TRAIL, FSO and EE-MRIO approach make use of the data from foreign trade statistics. The TRAIL approach uses a kind of a net approach, using the statistical information published by Pronovo AG (swissgrid 2016) about the amounts and technologies supplying electricity to Swiss customers.

The third difference concerns the so-called *investment effect*. Supply chains not only include transactions of intermediate inputs but also of investment goods. While intermediate inputs are used up during production activities, investment goods are replaced discontinuously and their contribution to production is measured by capital depreciation. While the use of investment goods in supply chains is usually taken into account in LCA, this is usually not the case in input-output analysis, where the use of investment goods is part of final demand, but not included in the supply chains. It is however in principle possible to capture the investment effect also with input-output analysis. This can be done by including the depreciation of investment goods in the inter-industry matrix, if a depreciation matrix is available that allocates depreciation in all industries to product groups. Accordingly, depreciation is deducted from the investment vectors in final demand. After deduction, the investment vectors reflect net investment.

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[7] In the meantime, the FSO has updated its calculations based on the Swiss IOT 2014 with backcasting to the year 2000, including all Kyoto greenhouse gases. These data were not available at the beginning of the work at hand.

Among the compared approaches, the investment effect is currently taken into account[8] in the TRAIL approach and the IO-TRAIL approach. It is possible to exclude the investment effect in the latter approach. The investment effect is not included in the FSO and the EE-MRIO approach. By excluding the investment effect, i.e. excluding capital depreciation and investment for replacement, the environmental impacts of exports are underestimated and hence those of domestic final demand are overestimated.

Table 6 : Comparison of system boundaries in the four approaches analysed

	TRAIL	IO-TRAIL	FSO method	EE-MRIO (OECD)
Foreign trade data	After Swiss NA revision 2014	Before Swiss NA revision 2014	After Swiss NA revision 2014	Before Swiss NA revision 2014
Foreign trade with electricity	Net concept	Gross concept	Gross concept	Gross concept
Investment effect	Yes (LCA)	Yes (IOT) / No	No	No
Inclusion of precious metals				
Non-monetary gold (and silver)	No / (Yes)	No	No	No
Other PM: imports & exports	No / (Yes)	No	Yes	Probably no
Other PM: domestic use	No / (Yes)	No	No	Yes

Orange cells highlight deviation from TRAIL approach

Source: own depiction

In Switzerland *precious metals* are responsible for a large part of traded environmental impacts. But they are mainly used for the purpose of value storage and also introduce a large amount of temporal variation into the greenhouse gas footprint. It therefore may be reasonable to exclude precious metals from the analysis or to record the respective footprint separately. It is therefore important to specify in which way the precious metals are included in the calculations in order to compare the results. Since the Swiss NA revision 2014 imports and exports of non-monetary gold (NMG) are included in the Swiss foreign trade statistics. The TRAIL method allows to include non-monetary gold as an option. In the main calculation it is not included but reported separately. The NMG is not included in the other approaches due to the database they are using[9]. Regarding other precious metals, platinum group metals and silver are especially important. In the TRAIL method these are excluded in the default calculation, but their environmental impacts are calculated separately. The IO-TRAIL approach does not include other precious metals. The FSO method does include imports and exports of other precious metals, but not their domestic use. This is due to the fact that domestic use of precious metals is recorded in the Swiss NA as net addition of valuables and this final demand category is excluded from the FSO calculations. The EE-MRIO approach with the OECD MRIOT on the other hand includes domestic use of other precious metals, but not their impacts of imports and exports, since precious metals, that are not used domestically, can be considered as reexports and these are eliminated in the construction of the OECD multiregional IOT.

[8] taken into account in the sense that depreciation of investment goods is part of each industry's production function and allocated to supplying industries

[9] It is in principal possible to include NMG in the FSO method.

4.2.2 Comparison of data sources

The comparison of results can also be hampered by differences in the databases used. The following Table 7 presents an overview of differences in databases. The IO-based approaches differ with regard to the Swiss IOT used in their data base. The IO-TRAIL approach uses a disaggregated IOT for the year 2008, that distinguishes roughly 100 industries and product groups and in which data and granularity representing the energy, transport and food sectors have been improved. The FSO approach uses a more recent Swiss IOT for the year 2011, that was back-casted to the year 2008[10]. This IOT distinguishes 63 industries and product groups and does not include the improvements mentioned above. The EE-MRIO approach with an OECD MRIOT refers to the period around 2010 and is based on the standard Swiss IOT for 2010. It is the most highly aggregated IOT with only 34 industries and product groups and does not include improved and refined data for the food, energy and transport sectors. Regarding the foreign trade data, the TRAIL and the FSO approaches use data from after the SNA revision 2014, while the other two approaches use data from before the SNA revision 2014.

All approaches use the same statistical data for Swiss greenhouse gas emissions: the emission accounts (AEA) published by FSO, which are calculated according to the methods developed by Eurostat based on the UN System of Environmental and Economic Accounting (SEEA). One final difference with regard to CO_2 emissions needs to be mentioned. The TRAIL and the IO-TRAIL approaches consider a higher greenhouse gas potential of CO_2 emitted by airplanes (1.95 kg CO_2 eq per kg CO_2 from kerosene burned in airplanes) taking into account indirect effects of short-term climate forcers and induced clouds caused by stratospheric emissions. Neither the other two approaches nor the UN framework convention on climate change and the national greenhouse gas inventories do consider this higher warming potential.

Table 7 : Differences regarding data (bases) of the compared approaches

	TRAIL	IO-TRAIL	FSO method	EE-MRIO (OECD)
IOT CH	–	Disaggregated IOT 2008 (NOGA 2002)	IOT 2011 backcasted (NOGA 2008)	Standard IOT 2008 (NOGA 2002)
IOT CH: Improved data for energy, transport and food sectors	–	Yes	No	No
Number of industries / product groups (Domestic / Imports / Exports)	D: – I: 440 E: 440	D: 103 I: 440 E: 103	D: 63 I: 63 E: 63	D: 34 I: 34 E: 34
Foreign trade data	After Swiss NA revision 2014	Before Swiss NA revision 2014	After Swiss NA revision 2014	Before Swiss NA revision 2014
GHG potential of air transport CO2 in stratosphere (in kg CO2 eq / kg CO2)	1.95	1.95	1	1

Orange cells highlight deviation from TRAIL approach

Source : own depiction

[10] For an updated calculation the FSO uses the Swiss IOT 2014 that was backcasted up to the year 2000 and includes six greenhouse gases (FSO 2019). This updated calculation was published after the calculation for this paper had been made and therefore the updated results of the FSO calculations could not be included in the paper at hand.

4.3 Comparison of results

In order to make the results of the four methods as comparable as possible, the following choices were made:

- Only CO_2, CH_4 and N_2O emissions are considered in the comparison since the results for the FSO approach were only available for these three greenhouse gases[11].
- For CO_2-emissions of air transport the additional GHG potential of indirect effects of airplane emissions in the stratosphere are disregarded. Thus, CO_2-emissions of air transport have a CO_2-eq factor of 1 kg CO_2-eq per kg CO_2. This was done for the calculation and comparison of the results for 2008. In the time series results (cf. section 4.3.2) the higher GHG potential of air transport emissions are included.
- With regard to the investment effect, it is included in the TRAIL approach and it is not included in the FSO and the EE-MRIO approaches. In the IO-TRAIL approach it can be switched on and off. It is therefore switched on for comparison with the TRAIL approach and off for comparison with the other two approaches.
- Imports and exports of precious metals contribute substantially to the Swiss greenhouse gas footprint, especially since non-monetary gold[12] has been included in Swiss foreign trade statistics. Foreign trade with precious metals strongly fluctuates over time and thus also contributes to strong fluctuation of the Swiss greenhouse gas footprint. Therefore trade with precious metals has by and large been excluded in the use of the TRAIL approach for calculating time series of the Swiss greenhouse gas footprint (Frischknecht et al. 2018). It has also largely been excluded in the FSO approach by using a version of the Swiss IOT 2011 where non-monetary gold has been excluded and by excluding net acquisition of valuables as a final demand sector. In the IO-TRAIL approach, non-monetary gold is also excluded[13] and net acquisition of valuables, that contains net imports of precious metals, is disregarded.

Since the approaches were applied at different points in time, they also differ with regard to the underlying national account data. In 2014 the Swiss national accounts underwent a major revision due to the implementation of the ESA 2010, which has in particular affected foreign trade. Whereas the TRAIL approach and the FSO approach are aligned to national accounts after the revision, the Swiss IOTs used for the IO-TRAIL and the EE-MRIO approach are aligned to national accounts data from before the 2014 revision.

4.3.1 Development of greenhouse gas emissions between 2008 and 2015

The TRAIL and the FSO approaches allow to calculate the development of the Swiss greenhouse footprint over a time period. Figure 4 displays the results of these approaches for the development of the Swiss domestic greenhouse gas emissions between 2008 and 2015. The differences between the two approaches are mainly due to the inclusion of the higher GHG potential of airplane emissions in the TRAIL approach. Apart from that, both approaches use the same data from the FSO air emission accounts.

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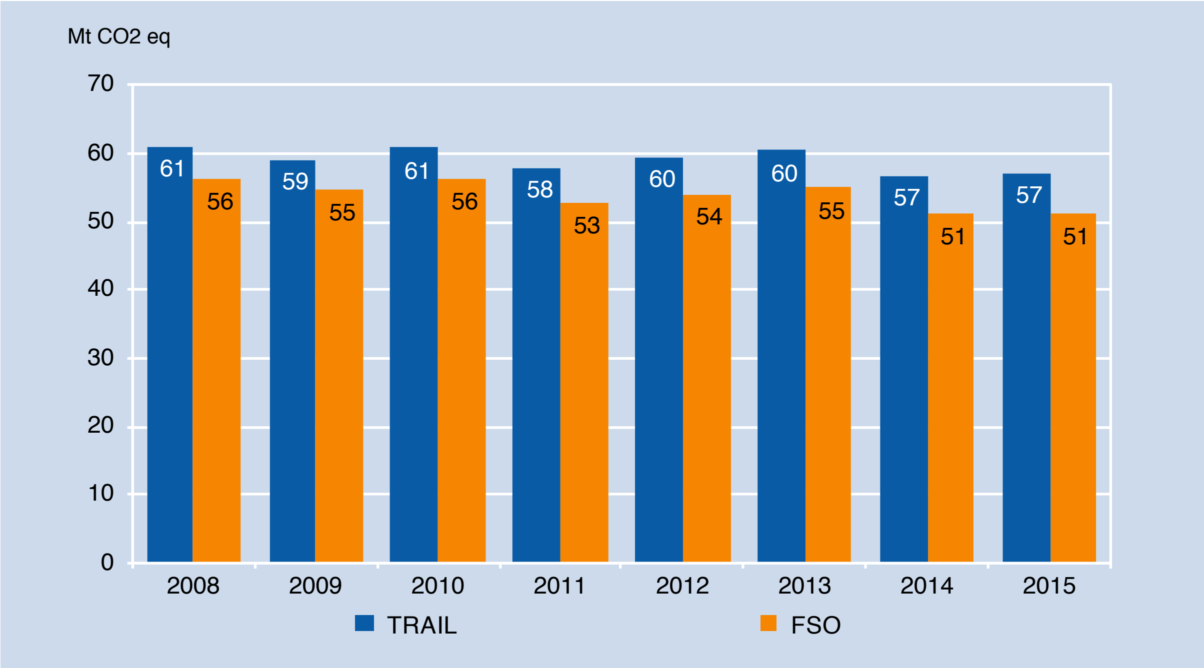
[11] In the meantime, the FSO has updated their results and now also include the other greenhouse gases.

[12] It also includes non-monetary silver and certain gold and silver-based coins.

[13] This is due to the fact that non-monetary gold was included in the Swiss foreign trade statistics in 2012, which is later than the reference year of the Swiss EE-IOT, 2008.

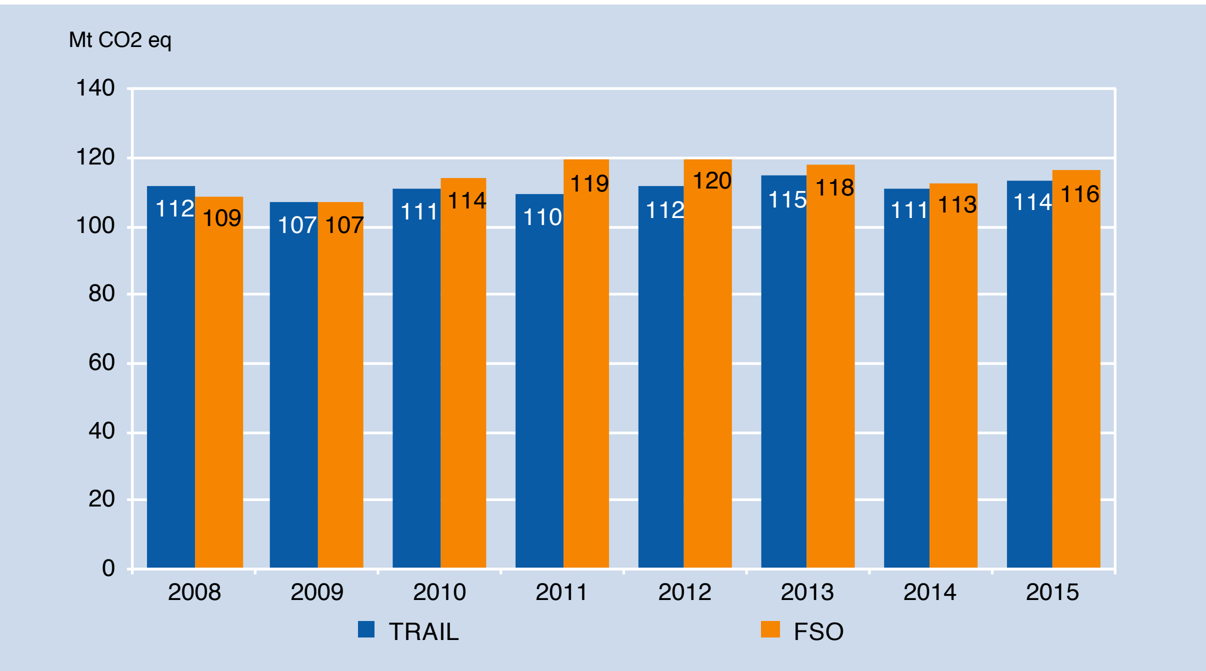
Figure 4: Development of the Swiss domestic greenhouse gas emissions between 2008 and 2015



Quelle: Treeze, BFS, Darstellung Rütter-Soceco

Figure 5 shows the results for the development of the greenhouse gas footprint of Swiss consumption between 2008 and 2015. According to the TRAIL approach, the greenhouse gas footprint remained largely stable with some variation between the years. The FSO approach reports a slight increase from 109 Mt in 2008 to 116 Mt CO_2 eq in 2015. The results show similar values for the first and the last years of the time period, but somewhat larger deviations in 2011 and 2012. Overall the differences are surprisingly small as they lie in a range of between 0% and 8%.

Figure 5: Development of the greenhouse gas footprint of Swiss consumption between 2008 and 2015



Quelle: Treeze, BFS, Darstellung Rütter-Soceco

4.3.2 Comparison of Swiss greenhouse gas emissions in 2008

To study the reasons for these differences in more detail and to include all calculation methods, we analyse the greenhouse gas emissions and the greenhouse gas footprint of Switzerland in the year 2008.

Figure 6 displays the greenhouse gas footprint of Swiss consumption according to the four approaches as the balance of three components:

- domestic emissions plus
- emissions induced by imports minus
- emissions induced by exports.

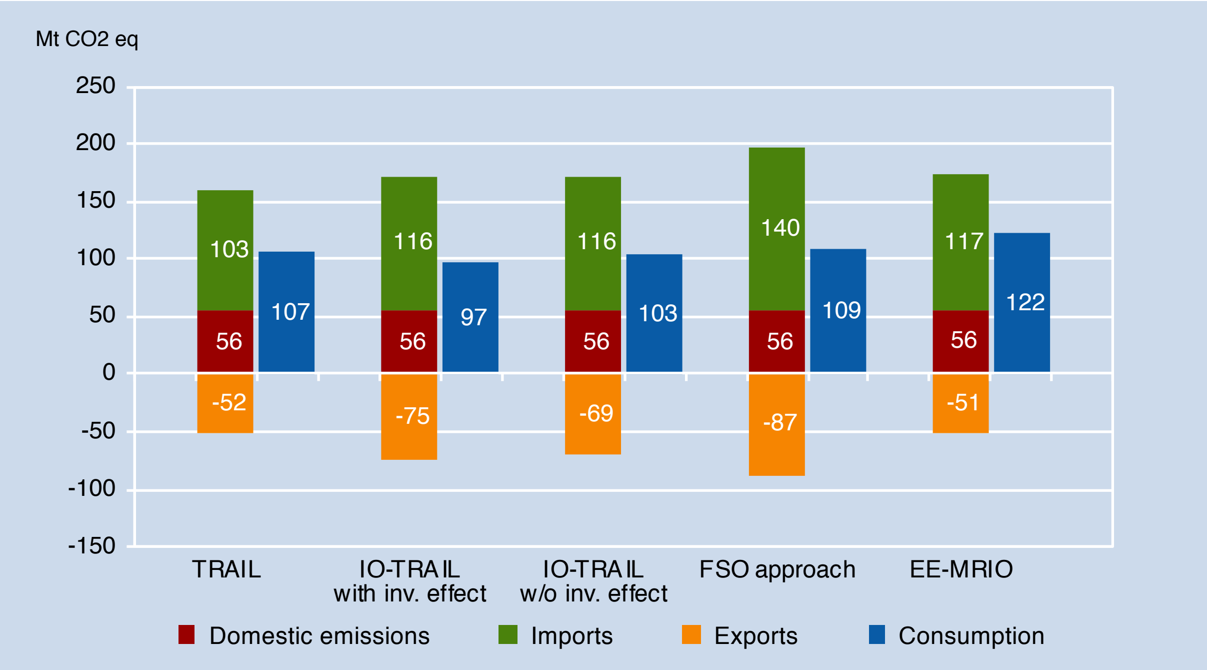
The IO-TRAIL approach is shown in two variants, one with and one without including the investment effect in the industries' production functions. The results for the consumption-based greenhouse gas footprint are in a range between 97 Mt CO_2 eq for the IO-TRAIL approach with the investment effect and 122 Mt CO_2 eq for the EE-MRIO approach. All approaches show similar results for domestic emissions. Differences are mainly due to import- and export-related emissions.

We first compare the results of the TRAIL approach with those of the IO-TRAIL approach with the investment effect. The IO-TRAIL approach leads to higher import- and export-related emissions. Regarding the import-related emissions, the differences are mainly due to different data used. Mainly the import volumes differ, while the emission intensities are similar between the two approaches. Due to the revision of trade in the national accounts, the imports of goods are lower and the service imports are higher in the TRAIL approach, thus leading to lower imported emissions. Furthermore, with its net concept of electricity imports the TRAIL approach only considers electricity imports used for domestic consumption (thus considering only exports of domestically produced electricity, see below), whereas the IO-TRAIL approach considers all electricity imports (and all electricity exports, see below) according to the national electricity statistics. The environmental impacts of electricity consumption are lower in the TRAIL approach.

Regarding the export-related emissions, the differences are caused by differences in data and in methodology. The methodological difference refers to the fact that in the TRAIL method the export-based emissions are calculated by directly linking exports of goods in physical units and exports of services in monetary units with LCA data. By contrast, in the IO-TRAIL approach the information from the Swiss EE-IOT is used to calculate firstly domestic output and domestic emissions induced by exports and secondly imports induced by exports. The emissions induced abroad by imports are then calculated by linking these imports with LCA data.

The data-related differences are similar to the import side. Due to the SNA revision the exports of goods and services are higher in the TRAIL approach than in the IO-TRAIL approach, leading to higher emissions. This effect is overcompensated by a larger emission intensity of exports in the IO-TRAIL approach. This larger emission intensity is largely due to the modelling of electricity exports. The TRAIL approach considers exports from domestic production only, while the IO-TRAIL approach considers all exports according to the national electricity statistics. Furthermore, while the IO-TRAIL approach considers the same average technology mix for domestic electricity consumption and for electricity exports, the TRAIL approach applies a specific technology mix of electricity exports, that contains a higher share of hydroelectric power plants and thus results in a lower GHG emission intensity than in the IO-TRAIL approach.

Figure 6: Comparison of the greenhouse gas footprint of Swiss consumption 2008



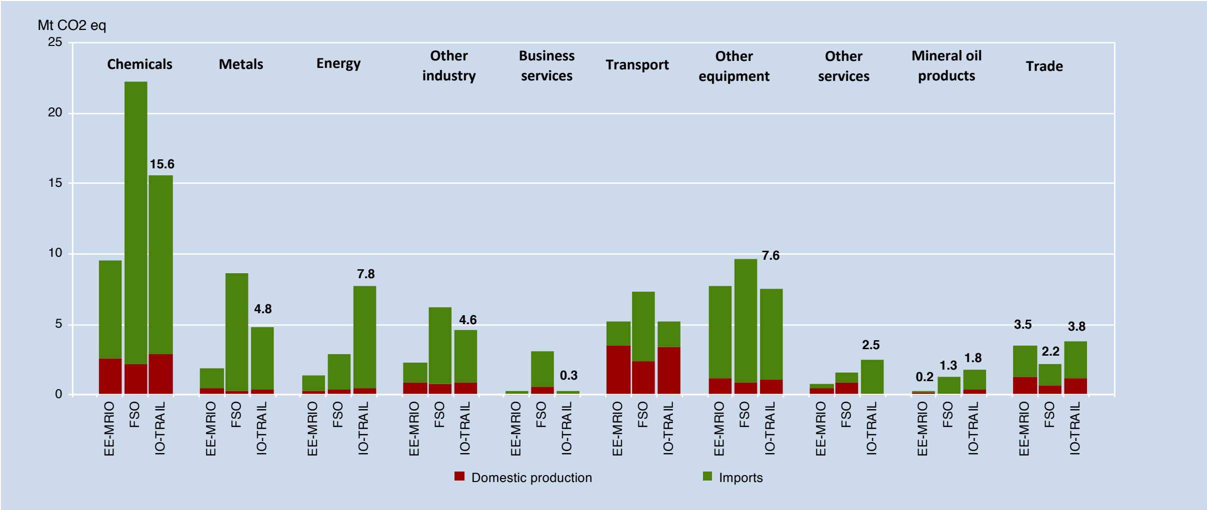
Quelle: Treeze, BFS, Rütter-Soceco, OECD, WIOD, Darstellung Rütter-Soceco

The comparison of the other approaches leads to the following insights:

- Including the investment effect in the IO-TRAIL approach reduces the greenhouse gas footprint of consumption by 6 MT CO_2 eq or 6%.
- In the FSO approach the greenhouse gas footprint is similar to the result of the TRAIL approach, but the import- and export-related emissions are significantly higher than in the TRAIL and also the other approaches.
- The greenhouse gas footprint from the EE-MRIO approach is the highest among the compared approaches with 122 Mt CO_2 eq. Compared to the TRAIL approach the export-related emissions are similar, while the import-related emissions are significantly higher.

Figure 7 compares the export-related emissions by industry for the IO-based approaches. To enhance comparability with the other approaches, the IO-TRAIL approach without the investment effect is shown. The figure shows the ten product groups with the largest average deviations among the approaches. For several product groups, i.e. chemicals, metals and other industry, but also for business services, transport and other equipment, the FSO approach shows the highest and the EE-MRIO approach the lowest emissions. The IO-TRAIL approach shows the highest emissions for exported energy, other services and mineral oil products. It would be necessary to analyse the results of the various approaches in even more detail to explain the reasons for these differences. This was not possible in the context of this paper.

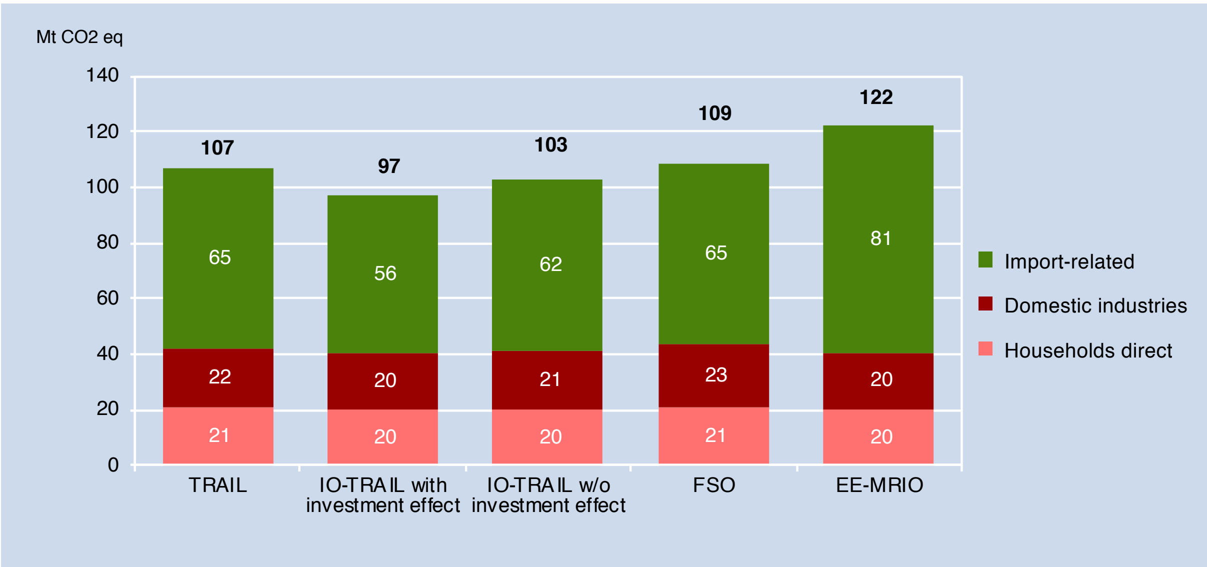
Figure 7: Comparison of export-related GHG emissions by exported product group, 2008



Quelle: Treeze, BFS, Rütter-Soceco, OECD, WIOD, Darstellung Rütter-Soceco

In the following Figure 8 the greenhouse gas footprint of consumption is allocated to domestic and import-related emissions. While the domestic emissions of households and industries are largely similar, the differences between the approaches are mainly caused by differences in import-related emissions. The underlying data do not allow to analyse the import-based emissions by imported product group for every approach.

Figure 8: Breakdown of greenhouse gas footprint to domestic and import-related emissions

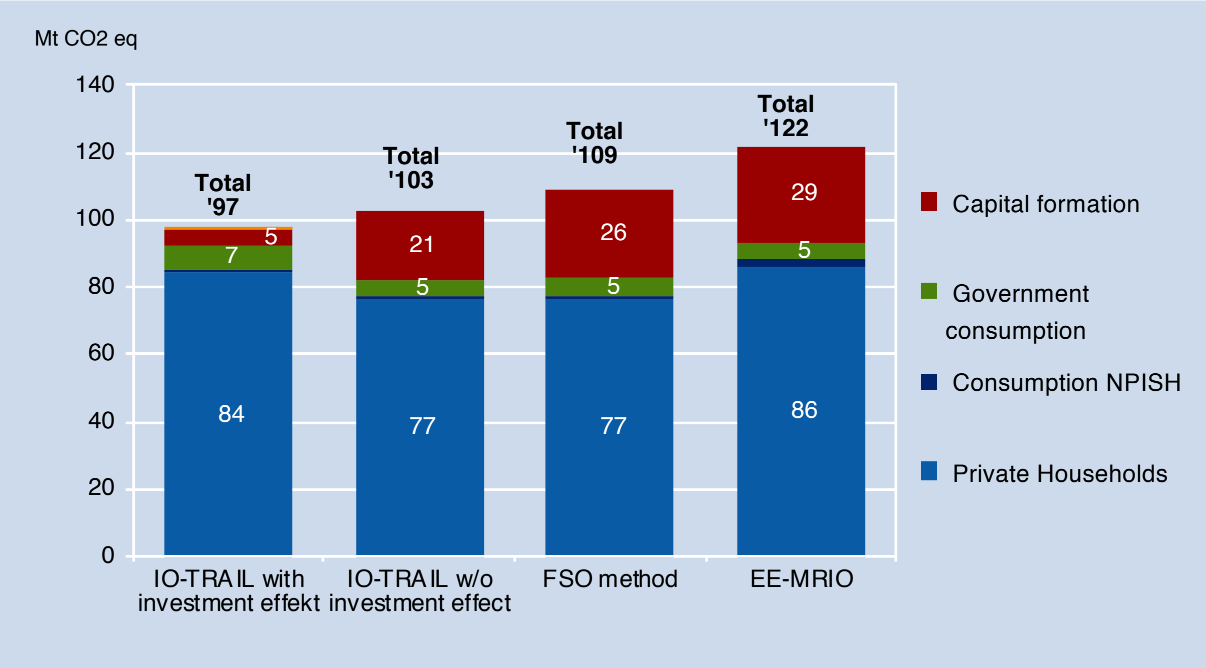


Source: Treeze, FSO, Rütter Soceco, OECD, WIOD, Depiction Rütter Soceco

In a different perspective the greenhouse gas footprint is shown by final demand sector. Only the TRAIL method does not support this perspective. The comparison of the IO-TRAIL approach with and without the investment effect shows its relevance. In the approach with the investment effect the relevance of capital formation as a driver is reduced to the impact of net capital formation. As explained above, depreciation of investment goods is part of the supply chains induced by the other final demand sectors (consumption of private households, non-profit organisations and government). In the approach without the investment effect the final demand sector "capital formation" includes capital depreciation. Correspondingly, the emission effect of the other final demand sectors excludes the supply chain effects of capital depreciation, which is why they are lower. The other two approaches, the FSO approach and the EE-MRIO approach, exclude the investment effect. Comparing their results with the results of the IO-

TRAIL approach without the investment effect reveals that the FSO approach delivers higher results for capital formation than the IO-TRAIL approach. The EE-MRIO approach yields higher results for all final demand sectors apart from government consumption, that is characterised by low-emission-intensive services.

Figure 9: Comparison of the Swiss greenhouse gas footprint by final demand sector

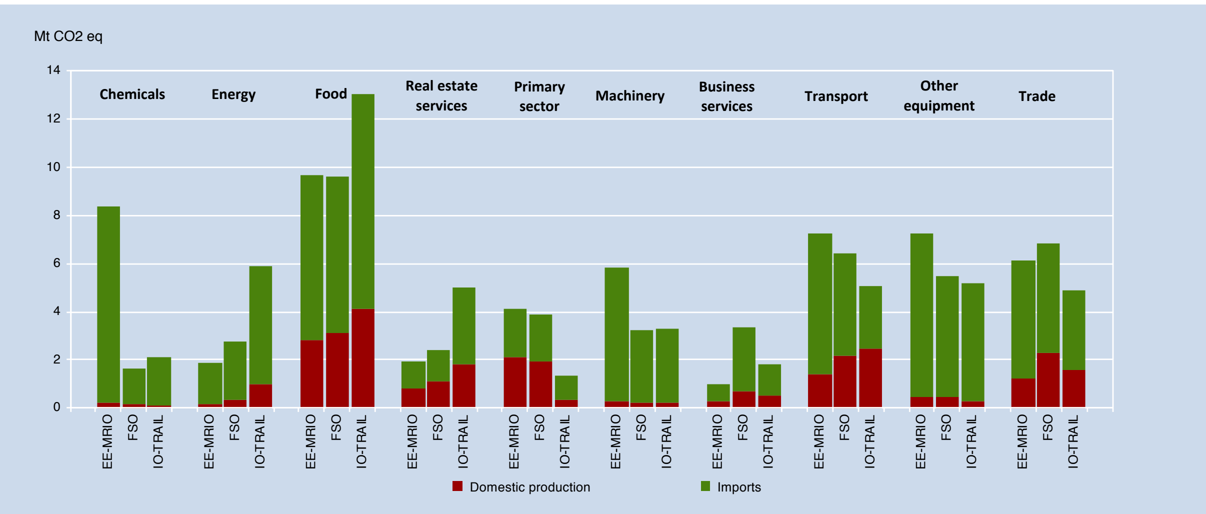


Quelle: Treeze, BFS, Rütter-Soceco, OECD, WIOD, Darstellung Rütter-Soceco

Remark: NPISH: Non-profit-organisations serving households

Figure 10 allows to track the differences in greenhouse gas emissions of the product groups related to final demand. It displays the ten product groups with the largest average deviations in greenhouse gas emissions among the approaches. There is no clear picture. Different approaches reveal higher and lower greenhouse gas emissions for the different product groups.

Figure 10: Comparison of the greenhouse gas footprint by product group consumed in Switzerland in 2008



Quelle: Treeze, BFS, Rütter-Soceco, OECD, WIOD, Darstellung Rütter-Soceco

The EE-MRIO method leads to much higher emissions for chemicals, machinery and other equipment than the other approaches. The IO-TRAIL method delivers higher emissions for energy and real estate services. The higher emissions for food seem to be compensated by lower emissions for products from the primary sector (agricultural products), which could be influenced by different allocations of food to private consumption in the different IO tables. The FSO approach yields high emissions for business services and to a lesser extent for trade. Thus, the differences between the approaches do not show systematic biases.

5. Conclusions and recommendations

The methodological comparison of the different calculation approaches has revealed their specific strengths and limitations. The empirical comparison of the Swiss greenhouse gas footprint has shown that the compared approaches arrive at almost identical domestic greenhouse gas emissions, since they use the same data sources. They yield significantly different import- and export-based greenhouse gas emissions. The resulting greenhouse gas footprint of Swiss consumption is fairly similar. Some of the reasons for the differences were identified, e.g. the different modelling of electricity imports and exports. Other differences are more difficult to explain without analysing the data in even more detail. The analyses show that a few consumed, imported and exported product groups are responsible for the major share of differences.

Each of the compared approaches can be further developed and strengths of the different approaches can additionally be combined to improve results.

Improvement of the existing approaches

- The *TRAIL approach* can be improved by increasing the disaggregation level of product groups linked to LCA data, to reduce errors of aggregation or mislinkage. Imports and exports of transport services could be recalculated in physical units and their environmental impacts could be calculated with LCA data. The development in time of the environmental impacts of imports is more challenging. Systematic time series of life cycle inventories of industrial processes other than electricity mixes and (to a lesser extent) power plants are hardly available. In the next possible update, the CPA[14] classification instead of the current SITC classification should be used for representing imports and exports, since it is better compatible with the NOGA classification used in Swiss national accounting and IO tables. This would improve alignment with the IO-TRAIL approach (see below).
- The *IO-TRAIL approach* could be improved by working with an IOT in hybrid units, where the use of homogeneous goods like mineral oil products, electricity or natural gas in industries and households is recorded in physical units, thus introducing the physical allocation principle for selected environmentally relevant goods. In the next possible update, the CPA classification instead of the current SITC classification should be used for representing imports and exports, since it is better compatible with the NOGA classification used in Swiss national accounting and IO tables.
- The *FSO approach* could be improved by comparing the greenhouse gas footprint results of imports with results from an MRIO approach to test the assumptions that the greenhouse gas footprint of Swiss imports from EU countries mirrors the greenhouse gas footprint of EU-average exports and that the greenhouse gas footprint of Swiss imports from non-EU countries can be estimated with GDP-based multipliers. The results of these comparisons could be used to include correction factors into the FSO approach correcting for a potential systematic bias. Other improvements could include
  - distinguishing between different importing countries within the EU,

[14] CPA: Classification of Products by Activity; SITC: Standard International Trade Classification; NOGA: Nomenclature générale des activités économiques (Allgemeine Systematik der Wirtschaftszweige)

  - increasing the number of non-EU countries to better account for differences in emission intensities,
  - improving the GDP-based emission multipliers by including other greenhouse gases other than CO2 and by using exports to Switzerland instead of GDP as a denominator,
  - basing the calculations on the Swiss energy IOT 2014 (Nathani et al. 2019) to improve the calculation of energy and transport based emissions.
- The homogeneity assumption is important in the *MRIO approach,* stipulating that the greenhouse gas footprint of Swiss imports can be calculated with industry-average data from the Swiss trading partner countries. This assumption could be tested by comparing the product-mix of Swiss imports with the average product-mix of industries in the Swiss trading partner countries.

Combination of approaches

Regarding possible combinations of existing approaches, we focus on a combination of the IO-TRAIL approach with the MRIO approach. A major strength of the IO-TRAIL approach is that it combines a wide scope of analytical options with modelling specificity and flexibility. Especially the supply chains of imported homogeneous bulk products can be modelled with available and up to date LCA data. The method has limitations regarding LCA data availability for complex and heterogeneous product groups such as specific machinery and for services. These imported products could be modelled using an EE-MRIO. A combination of these approaches would entail linking certain imported product groups with LCA data and the remaining product groups with an EE-MRIO. As a first step the results of the two approaches should be analysed in detail to identify the reasons for differences in results. Additionally, adequate criteria should be developed for the decision, which of the imported products should be analysed with LCA data and which products with the EE-MRIO approach. To facilitate this comparison, the IO-TRAIL method should first switch to the CPA classification (see above).

Harmonisation of approaches

We recommend harmonising some of the key assumptions and system boundary choices of the TRAIL, IO-TRAIL and FSO approaches, in particular:

- treatment of non-monetary gold and platinum group metals: should these precious metals be excluded from consumption based analyses and reported separately? If included should imports and exports of platinum group metals be quantified using a gliding average?
- electricity trade: should this be modelled based on available physical data published by Pronovo or on the electricity statistics from the Swiss Federal Office for Energy?
- investment effects: Should investment effects be transferred into the interindustry matrix or kept as part of final consumption?
- indirect effects of airplanes on climate: should indirect effects of air transportation be included in the global warming potential of kerosene burned by airplanes? If so, which factor should be applied?

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7. Abbreviations

AEA:	Air emission accounts
EE-IOT:	Environmentally extended input-output table
EE-MRIOT:	Environmentally extended multiregional input-output table
ESA:	European System of National Accounts
GHG:	Greenhouse gases
IOT:	Input output table
LCA:	Life cycle assessment
MRIOT:	Multiregional input output table
NA:	National accounts
NMG:	Non-monetary gold
SEEA:	System of Environmental Economic Accounting
SNA:	System of national accounts

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