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New methods and environmental indicators supporting policies for sustainable consumption in Sweden

Final report – PRINCE phase 2

Nils Brown, Simon Croft, Elena Dawkins, Göran Finnveden, Jonathan Green, Martin Persson, Susanna Roth, Chris West, Richard Wood

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Preface

The first PRINCE programme (Policy Relevant Indicators for Consumption and Environment) ran between 2014 and 2018 with the goal of exploring ways to improve and expand the set of consumption-based indicators to estimate the environmental pressures linked to Swedish consumption, both within Sweden and abroad. The PRINCE programme was finalised 2018 with a report: https://www.naturvardsverket.se/globalassets/media/publikationer-pdf/6800/978-91-620-6842-4.pdf

More information is available at the web site: https://www.prince-project.se/

This current one-year project, known as PRINCE 2, is a so-called add-on to the PRINCE programme, to communicate the results further, especially the scientific articles produced, and reflect on how to further improve the measurement of impacts from consumption. The goals of PRINCE 2 have been to communicate the results and the PRINCE programme to the Swedish Environmental Protection Agency and other key stakeholders, to summarize the use of PRINCE results in policy and other areas, to further develop data and indicators in the areas of fisheries, tropical deforestation, biodiversity and chemicals with a view to establishing new indicators for measuring environmental pressures from Swedish consumption.

The project was financed by the Swedish Environmental Protection Agency's (Naturvårdsverket) environmental fund (miljöforskningsanslaget) where the main aim is to finance research and produce knowledge for the benefit of the Swedish Environmental Protection Agency and the Swedish Agency for Marine and Water Management.

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The Swedish Environmental Protection Agency, March 2022

Maria Ohlman
Head of Sustainable Development Department

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Executive summary

KEY FINDINGS

- The first PRINCE project has had significant influence on policy processes:
  - motivating the investigation of a goal for Sweden's consumption-based greenhouse gas emissions
  - supporting the development of data for monitoring the UK's new 25 Year Environment Plan
  - supporting the development of deforestation strategy for the European Union
- Experimental time series for consumption-based indicators for deforestation-related greenhouse gas emissions, veterinary antibiotics and pesticides produced in PRINCE 2 meet quality requirements to be considered for official statistics.
- Experimental time series for consumption-based indicators produced in PRINCE 2 for hazardous chemical product use, biodiversity and fisheries require further evaluation and methodological development before they can be considered for official statistics.
- Human and financial resources are necessary to be able to produce and maintain official statistics in the areas noted above
- The potential for other indicators from PRINCE 1 (land, material flow and water) to be produced as official statistics requires further investigation
- There is still large potential for increased policy uptake for consumption-based approaches

Introduction

Developments in the policy landscape and data capabilities in the last 10 years or so have greatly increased the significance of consumption-based indicators. In Sweden, the PRINCE (Policy Relevant Indicators for National Consumption and Environment) projects are at the forefront of these developments. The first PRINCE project ran between 2015 and 2018 with the goal of exploring ways to improve and expand the set of indicators used to estimate the environmental pressures linked to Swedish consumption, both within Sweden and abroad. This report has been produced in the second PRINCE project (PRINCE 2). The goals of PRINCE 2 are as follows:

- communicating the results of PRINCE 1 to the Swedish Environmental Protection Agency (SEPA) and other key stakeholders
- summarizing the use of PRINCE 1 results in policy and other areas
- further developing data and indicators in the following areas, with a view to establishing new indicators and official statistics for measuring environmental pressures from Swedish consumption:
  - fisheries
  - tropical deforestation
  - biodiversity
  - chemicals.

PRINCE 1: Research outcomes

A key outcome of the first PRINCE project was the environmentally extended input-output model to calculate consumption-based indicators for Sweden (the Prince model). It is a so-called coupled model. The model has two key strengths. Firstly, it uses Sweden's official economic and environmental statistics to calculate the environmental pressures arising from production in Sweden, in combination with real data from the EXIOBASE dataset on economic production and related environmental pressures in the global economy to calculate environmental pressures arising from Sweden's imports. Simpler models would use only Swedish data and apply modelling assumptions to assess pressures from imported production. Secondly, the model combines the two data sources noted without requiring complex and burdensome rebalancing procedures for the large amounts of data required.

PRINCE 1 produced environmental indicators for Swedish consumption in the following areas:

- material use (including: bio-based materials, fossil fuels, metals and non-metallic minerals)
- water use (blue water consumption)
- land use and land-use change (tropical deforestation)
- greenhouse gas emissions (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O))
- other air emissions (particulate matter (PM10, PM2.5), nitrogen oxides (NO_x), sulfur dioxide(SO_2))
- energy use (separately for fossil fuels and biofuels)
- use of hazardous chemical products (HCPs)
- use of veterinary antibiotics in food production
- use of pesticides in food production
- emissions of hazardous chemicals
- potential impacts of hazardous chemicals.

In most but not all of these areas, time series were produced for the years 2008 to 2014. A final report from the first PRINCE project and the data produced are freely available on the PRINCE website (www.prince-project.se). These provide the most complete picture of Sweden's global consumption-based environmental pressures yet available.

Results show that Sweden's consumption-based greenhouse gas emissions per capita declined between 2008 and 2014 (Palm et al., 2019; Steinbach et al., 2018) by almost 20%. Statistics Sweden has since then extended the time series to 2019 as part of its official statistics production, with latter years showing a similar rate of decline as earlier. While an encouraging direction of travel, further and more rapid declines will be necessary to achieve the Paris climate goals of 1.5°C warming and avoid the worst impacts of climate change. The results also show that the emissions occurring abroad are larger than those occurring domestically. Similar trends are also seen for other air pollutants: nitrogen oxides, sulphur oxides and particulate matter.

Indicators for the use of HCPs, veterinary antibiotics and pesticides, as well as emissions and potential human and ecotoxicological impacts of some hazardous substances, were evaluated in PRINCE 1 for one year (2014). For all indicators, most of the use, emissions and impacts from Swedish consumption occurred abroad. The different chemicals indicators pinpointed different product groups and countries as the most important ones, suggesting that they complement each other (Persson et al., 2019). PRINCE 2 builds on this work, and developed experimental time series for selected chemicals indicators (see Chapter 5 below).

Results were also calculated for use of land, materials and water. For natural resources the trends were slightly different. Land use related to Swedish consumption did not change significantly during the studied time period. It was also noted that Swedish consumption requires more land use in Sweden than abroad. The total material consumption was similarly fairly constant during the time period. Most materials that are used for Swedish consumption come from abroad (Palm et al., 2019; Steinbach et al., 2018). The total material use can be further divided into bio-based materials (28% of total for the year 2014), fossil-based materials (22%), metallic materials (17%) and non-metallic minerals (33%) (Fauré et al., 2019). For water use, there was a slight decrease between 2008 and 2014 (Palm et al., 2019; Steinbach et al., 2018). The water required for Swedish consumption was largely used abroad.

PRINCE 1 also included several sectoral and methodological studies. For example, Cederberg et al. (2019) studied Sweden's food consumption and showed a significant proportion of environmental pressures arising in the EU and Latin America. A special study connected to this showed that tropical deforestation arising due to Swedish consumption gave rise to significant greenhouse gas emissions that are not otherwise included in Sweden's consumption-based totals (Pendrill, Persson, Godar & Kastner, 2019). The work on tropical deforestation has been followed up in PRINCE 2 and reported in Chapter 4 below. The special study on fisheries from PRINCE 1 (West et al., 2019) has also been followed up in Chapter 6 below. A sectoral study on the consumption of information and communication technology products in Sweden has shown that rebound effects can be reversed by directing consumption towards products with lower emissions intensities (Joyce et al., 2019). Other studies in PRINCE 1 covered maritime emissions (Schim van der Loeff, 2018) and water scarcity (West, 2018) as well as several methodological studies (e.g. Dawkins et al., 2019; Moran et al., 2017).

PRINCE 1 in policy and statistics

The calculation improvements achieved by the PRINCE model were a major factor in the Swedish EPA's recommendation at the end of 2018 that consumption-based greenhouse gas emissions for Sweden be published as official statistics. The official statistic on greenhouse gas emissions is used as an indicator tracking progress towards the generational goal and the environmental quality objective for reduced climate impact. It is also used in Sweden's national follow-up of Agenda 2030 for sustainable development.

The advances in the PRINCE project were also noted in the Swedish Government's decision to launch an inquiry into establishing national consumption-based goals for greenhouse gas emissions. The Swedish Parliamentary Committee on the Environmental Goals will present the outcome of the inquiry in early 2022 and has made use of the official statistics throughout its work.

The PRINCE model has also been applied by Statistics Sweden to calculate environmental indicators for the Swedish National Board of Housing Building and Planning. These indicators are used to track progress towards the environmental quality objective "good built environment". These data cover not only greenhouse gas emissions but also sulphur oxides (SOx), nitrogen oxides (NOx) and particles.

Statistics Sweden plays an active role in the development of consumption-based environmental statistics worldwide, communicating about the PRINCE model and developing processes to improve the timeliness of data production. Statistics Sweden has also applied detailed data output from the PRINCE model in the Mistra Sustainable Consumption research programme to evaluate the potential for consumption practices currently performed by a small number of consumers to contribute to reduced consumption-based environmental pressures through mainstreaming the practices to the whole population.

Work from PRINCE 1 on deforestation risk has seen policy uptake in the European Parliament and Commission and is being considered for use in indicators on consumption-based greenhouse gas emissions for Denmark. PRINCE 1 results in many areas including deforestation and water scarcity have been further developed to provide monitoring indicators for the UK's 25 Year Environment Plan.

Gap analysis: Deforestation

The deforestation gap analysis in PRINCE 2 has focused on the greenhouse gas emissions arising from land-use change. In PRINCE 2, the deforestation model has been improved in a number of ways including modelling for individual crops, filtering out forest loss in managed plantations, estimates of pasture extent in Brazil, and attribution of forest loss to beef versus leather. The resulting time series shows that the consumption-based greenhouse gas emissions due to deforestation are 2.8 million tonnes (Mt) carbon dioxide equivalents in 2018. This is a decrease of 34% compared to 2005. Results show divergent trends for different food groups. Although deforestation greenhouse gas emissions due to Sweden's consumption of Brazilian beef are much lower than in 2005, they have been steadily increasing again since 2011. Increases have also been seen due to consumption of Indonesian palm oil. Deforestation-related greenhouse gas emissions arising from other food products have decreased between 2012 and 2018 from 2.3 to 0.9 Mt carbon dioxide equivalents. The greenhouse gas emissions due to non-food consumption have remained relatively constant, fluctuating around 1 Mt carbon dioxide equivalents over the whole time period.

The potential to use the methods and data developed to assess deforestation-related greenhouse gas emissions to produce official statistics is presented in Chapter 4 below.

Gap analysis: Biodiversity

In PRINCE 2 scoping work was carried out considering potential biodiversity metrics for consumption-based accounting. An overriding consideration in the scoping is that biodiversity is highly complex in comparison to, say, measuring greenhouse gas emissions. This is due to the complicated relationships between different organisms and biophysical flows making up ecosystems that support biodiversity. One implication of this complexity is that metrics in use are always a simplified representation of the biodiversity that is being measured. The scoping delineates a number of different types of metrics in relation to this: footprint metrics covering simply the land use of economic activities and sectors; metrics directly estimating biodiversity impacts; and those assessing ecosystem services (i.e. the services provided by the ecosystem that are directly exploited by humans). A number of different types of metric within those assessing biodiversity impacts were also identified: approaches *assessing threats* to species arising from specific industrial sectors; approaches assessing changes in biodiversity based on modelled relationships to landcover changes; and approaches connecting production systems to spatially defined species ranges. The scoping identified recent research work using these three types of metric.

A further feature of the measurement complexity noted is that it can be useful to apply multiple separate metrics that provide a richer understanding of biodiversity impacts that are measured. It is possible to produce time series for many biodiversity metrics for Swedish consumption from a dataset produced for an experimental statistic with similar metrics for the UK. Swedish consumption can be assessed in the dataset according to harvested area, tropical deforestation, predicted species loss and species richness. Updates to the dataset as a whole including more recent reference years are currently being discussed. Further evaluation of these data is required before these biodiversity indicators can be considered for official statistics.

In light of the increasing availability of relevant metrics, it is recommended that simple metrics be adopted almost immediately in order to assess Sweden's consumption-based biodiversity impacts. At the same time, the field is developing rapidly. It is therefore important to review regularly the metrics used in light of changing data availability, modelling capabilities and consumption practices.

Gap analysis: Marine capture fisheries and aquaculture

The FAO data sources that were used in PRINCE 1 to calculate the consumption-based indicators for fisheries were supplemented by data from the Sea Around Us database from the University of British Columbia. This extra data source made it possible to include region- and species-specific estimates of catch methods and discards. Sweden's marine capture fish consumption has decreased by over two thirds between 1998 and 2018. According to the PRINCE 2 calculations, across the major gear types considered, pelagic trawl has decreased the most, with decreases of about 90% between 1998 and 2018. Though bottom trawling has decreased in absolute terms between 1998 and 2018, it has increased in *relative significance* for Sweden's fish consumption. Further validation work is required in relation to the time series developed in PRINCE 2 for capture fisheries before indicators can be considered for official statistics.

PRINCE 2 built further on PRINCE 1 by addressing Swedish consumption of products of aquaculture, also using Food and Agriculture Organization (FAO) data as input. The results show that in the past two decades almost 50% of Swedish consumption of aquaculture products is from Norwegian production. They also show that almost 50% of Swedish consumption is of salmon (*Salmo salar*). It is further observed that salmon farming has relatively high phosphate emissions per ton of live fish weight compared to other species-systems. Further work is needed to produce more consumption-based aquaculture indicators for Sweden, including, for example, eutrophication impacts arising from aquaculture.

Gap analysis: Chemicals

The gap analysis in PRINCE 2 in the chemicals area produced time series of Sweden's consumption-based use of HCPs, veterinary antibiotics and pesticides.

Input data for veterinary antibiotic use was based on the time series available from the European Surveillance of Veterinary Antimicrobial Consumption (ESVAC). Veterinary antibiotic use in other countries was extrapolated from the European data using economic data from EXIOBASE. The results show that Sweden's consumption-based use of veterinary antibiotics has decreased by almost 50% between 2008 and 2019. Throughout the time series, the proportion of Sweden's consumption-based veterinary antibiotic use coming from Swedish production amounted to only 10% or less of Sweden's total consumption-based use. This is in spite of a majority of animal products in Sweden (meat, eggs and dairy products) being produced domestically. The necessary extrapolation of input data to non-reporting countries (i.e. outside Europe) may lead to an underestimate for products from these countries; however, they do count for only a small proportion of Sweden's consumption-based veterinary antibiotic use.

Sweden's consumption-based use of pesticides remained relatively unchanged between 2008 and 2019, with small fluctuations in the total over the time series. The proportion of the consumption-based pesticide use arising from Sweden's domestic production decreased however between 2008 and 2019 by nearly 40%. In 2019, Sweden's domestic production was responsible for less than 20% of Sweden's total consumption-based pesticide use, with over 50% coming from products imported from the rest of Europe. Input data on pesticide use comes from the FAO's global dataset and is therefore assumed to be of high quality.

Input data for Sweden's consumption-based use of HCPs was geographically extrapolated from the Swedish Chemicals Inspectorate's time series for HCP use in Sweden classified by producing industries to the rest of the world. The results show that Sweden's consumption-based use of HCPs has increased by over 50% from 8.0 million tons in 2013 to 12.5 million tons in 2019. HCP use by producing industries in Sweden constitutes at least 35% of Sweden's consumption-based use. Products imported from other parts of Europe constitute almost 50% of Sweden's consumption-based use of HCPs, with the remainder mainly from China and the United States. It was found that the geographical extrapolation used for HCPs produced data that differed significantly from Eurostat data with an equivalent scope. The work also found minor discrepancies in the input data from the Swedish Chemicals Inspectorate, though it was judged that these did not lead to any significant changes in the results for the time series presented.

The chemicals work in PRINCE 2 demonstrated the viability of using the methods and input data for pesticides and veterinary antibiotics to produce official statistics for Sweden. For HCPs further investigation of data sources and methodological improvement are necessary.

Official statistics

The indicators developed in PRINCE 2 (or, in the case of biodiversity, that are possible to develop) were assessed according to the code of practice for the production of official statistics. A particular focus has been on three of the five legally-mandated criteria for statistical quality – relevance, accuracy, and coherence and comparability.

Indicators in all the areas for the gap analyses can satisfy the relevance quality criterion in light of the high degree of policy interest in each of the areas. For deforestation land-use change, pesticides and veterinary antibiotic use, the gap analyses also demonstrated the possibility of producing informative and coherent time series according to well-established and communicated methodologies, and therefore fulfil criteria for "coherence and comparability". Source data for these indicators are also either based in well-established peer-reviewed research or produced as official statistics according to institutional mandates. In these ways it is judged that the indicators can fulfil the "accuracy" criteria for official statistics. The rigour applied in the gap analyses did reveal the limitations for the indicators. A well-developed understanding of such limitations is important in statistics production. From the perspective of the production of official statistics it is necessary that these limitations, such as differences in data collection procedures between reference years in the time series or the level of aggregation that is best suited for using the indicators, are recorded and communicated as part of publication procedures.

Further analysis and possible methodological development are also required for indicators for HCP use, capture fisheries, aquaculture and biodiversity to be considered for official statistics.

The other two legally mandated criteria for statistical quality "timeliness and punctuality" and "accessibility and clarity" were not prioritized in the analysis of the indicators produced in the gap analyses. This is because the processes and procedures in place at Statistics Sweden will be the foundation for achieving these criteria in any future time series production for official statistics. Finally, it is noted that to take the step from the experimental time series presented in PRINCE 2 to the production and maintaining of official statistics for the indicators, the necessary human and financial resources need to be in place.

Future outlook

Both PRINCE projects have offered the valuable opportunity for collaboration between policy-making, statistics production and research. The foundation of the first PRINCE project has been built upon for statistics production and research in recent years in Sweden and beyond. One very significant development here is the investigation of an official target for Sweden's consumption-based greenhouse gas emissions.

The PRINCE 2 project has demonstrated the further potential of the PRINCE work to answer new policy needs. Having said that, the central policy relevance of the PRINCE model is that it connects macroscopic environmental data with economic data that are relevant for decision-making at many levels of government and in the private sector. Therefore, the policy applications recorded so far should be considered a beginning for the application of consumption-based and related indicators.

1. Introduction

Sweden has made a commitment "to hand over to the next generation a society in which the major environmental problems in Sweden have been solved, without increasing environmental and health problems outside Sweden's borders". This is Sweden's generational goal[1] – the foundation of Sweden's environmental objectives. But how do we know if Sweden is on track? How do we investigate whether Sweden is making improvements domestically at the expense of environmental and health problems abroad? The environmental impacts within Sweden's borders may be steadily reduced as Sweden decarbonizes and holds itself to strict environmental standards, yet much of what Sweden consumes is manufactured abroad and delivered to Sweden via complex global supply chains. Many of these global supply chains go through countries without similar environmental and social regulations to those in Sweden.

Sweden keeps good data on the environmental performance of its farms, factories and transportation and energy systems. Having said that, Sweden's imports amount to over 40% of domestic production in the economy. Sweden's environmental commitment means that we need to keep track of the environmental pressures linked to imported goods and services, too.

This is the background of the first PRINCE (Policy-Relevant Indicators for National Consumption and Environment) project, which ran from 2015 to 2018. It was funded by the Swedish Environmental Protection Agency (SEPA) and the Swedish Agency for Marine and Water Management. The goal of the first PRINCE project was to explore ways to improve and expand the set of indicators used to estimate the environmental pressures linked to Swedish consumption, both within Sweden and abroad. This report has been produced in the second PRINCE project (PRINCE 2). The goals of PRINCE 2 are as follows:

- Communicate the results of PRINCE 1 to the Swedish (EPA) and other key stakeholders
- Summarize the use of PRINCE 1 results in policy and other areas
- Further develop data and indicators in the following areas, with a view to establishing new official statistics for measuring environmental pressures from Swedish consumption:
  - fisheries
  - deforestation
  - biodiversity
  - chemicals.

[1] https://www.sverigesmiljomal.se/miljomalen/generationsmalet/

Subsequent sections in this report follow the goals of the PRINCE 2 project outlined above. Chapter 2 presents the results of the PRINCE 1 project, its uptake in policy in Sweden and beyond and discusses the further potential for the uptake of results in policy. Subsequent chapters present each of the gap analyses performed in PRINCE 2 in turn. In Chapter 7, the potential for indicators in the areas for gap analyses and beyond to be produced as official statistics for Sweden are discussed. Finally, in Chapter 8 the future outlook for the ongoing policy relevance of PRINCE is discussed.

Each of the gap analyses has taken as a starting point the final outcomes of the first PRINCE project (except for biodiversity, which was not considered in PRINCE 1) in the relevant area and aimed to build further on them in light of the goals of PRINCE 2 noted above. Practically this means that the actual scope and procedure for each gap analysis varies. This is especially so for biodiversity, which was not considered in the first PRINCE project.

The term "consumption" is used to mean different things in different scientific traditions and contexts. In the PRINCE projects generally and in this report it is used to refer to consumption in the sense of domestic final demand in the economy. Further discussion about the different uses of the word "consumption" is presented in the "Definitions and terminology" box in Appendix 1.

2. PRINCE in research and policy

Key messages

- In the first PRINCE project, the PRINCE model was developed, a hybrid environmentally extended input-output model greatly improving the calculation procedure for Sweden's consumption-based environmental pressures.
- The PRINCE model has been used to calculate Sweden's consumption-based environmental pressures for at least 19 different indicators.
- There is a growing demand for consumption-based indicators at supranational, national and local policy levels.
- Major policy uptake of PRINCE results include:
  - Swedish inquiry into national targets for consumption-based greenhouse gas emissions
  - monitoring for multiple Swedish environmental quality objectives – generational goal, good built environment, limited climate impact
  - monitoring for UK 25 Year Plan for the Environment.
- PRINCE indicators and methods have untapped extra policy potential in relation to Swedish environmental and economic policies and targets.

Developments in the policy landscape and data capabilities in the last 10 years or so have greatly increased the potential for consumption-based indicators to influence decision making. The PRINCE project has played a significant role in these developments in Sweden and beyond.

This chapter firstly summarizes the research outcomes of the first PRINCE project and related research since. Then it presents the policy landscape for consumption-based indicators, the role of PRINCE work in policy development so far and the potential future role for PRINCE and consumption-based approaches more generally. Appendix 7 provides a list of all the peer-reviewed scientific articles produced from the first PRINCE project.

2.1 The PRINCE model

A key output of the first PRINCE project is the PRINCE model itself. The model uses the general methodology of environmentally-extended input-output (EEIO) analysis. It is a so-called coupled-model that uses two major sources for input data:

- Sweden's official economic statistics and official statistics on environmental pressures from a production perspective
- economic data and data on environmental pressures from a production perspective for the world economy from the global multiregional input-output database EXIOBASE.

The model combines these data without the need for complicated calculations rebalancing detailed economic data on product supply and demand. By using EXIOBASE the model also calculates the environmental pressures that Swedish consumption gives rise to abroad using real data for the global economy which previous more simple approaches do not manage. The model is presented in more detail in Appendix 1 and in Wood and Palm, (2016), Steinbach et al. (2018) and Palm et al. (2019). Interestingly this modelling approach has also been adopted in Denmark for the first reporting of consumption-based greenhouse gas emissions to the Danish Council on Climate Change.

2.2 Research findings of PRINCE 1 and beyond

2.2.1 Consumption-based indicators for Sweden

This PRINCE model was used to calculate a broad set of indicators, in most cases for a time series from 2008 to 2014:

- greenhouse gas emissions
- other air emissions (particulate matter (PM10, PM2.5), nitrogen oxides (NO_x), sulphur dioxide)
- energy use (separately for fossil-fuels and biofuels)
- use of hazardous chemical products (HCPs) (only one year)
- use of veterinary antibiotics in food production (only one year)
- use of pesticides in food production (only one year)
- emissions of HCPs (only one year)
- potential impacts of hazardous chemicals (only one year).

In addition, EXIOBASE alone was used to calculate indicators from 2008 to 2014 for:

- material use (including bio-based materials, fossil fuels, metals and non-metallic minerals)
- water use (blue water consumption)
- land use.

Results show that Sweden's consumption-based greenhouse gas emissions generally declined between 2008 and 2014 (the final year of the PRINCE 1 analysis; Palm et al., 2019; Steinbach et al., 2018) by about 15%. The results also show that the emissions occurring abroad (about 60% of the total) are larger than those domestically (about 40% of the total). Similar trends are also seen for other-air pollutants: nitrogen oxides, sulfur oxides and particulate matter.

Consumption-based indicators for the use of HCPs, use of veterinary antibiotics, use of pesticides, emissions of some hazardous substances and potential human and ecotoxicological impacts from emissions of some hazardous substances were evaluated for a single reference year, 2014. For all indicators, most of the use, emissions and impacts from Swedish consumption occurred abroad. The different chemicals indicators pinpointed different product groups and countries as the most important ones, suggesting that they complement each other (Persson et al., 2019). PRINCE 2 builds on this work, and developed an experimental time series, as described in Chapter 5.

For indicators for use of land, materials and water, the EXIOBASE model was used directly and not the PRINCE model. For these natural resources the trends were slightly different. Sweden's consumption-based land use was about 225 000 km^2 and did not change significantly between 2008 and 2014. About 65% of the total land use arose in Sweden itself, with the remainder abroad. This balance is in contrast to the balance for many other indicators calculated. The total material consumption was similarly fairly constant during the same time period at about 230 000 kilotonnes. About 65% of the materials that are used for Swedish consumption come from abroad (Palm et al., 2019; Steinbach et al., 2018). The total material use can be further divided into bio-based materials (28% of the total for the year 2014), fossil-based materials (22%), metallic materials (17%) and non-metallic minerals (33%) (Fauré et al., 2019). For water use, there was a slight decrease between 2008 and 2014 (Palm et al., 2019; Steinbach et al., 2018). The water required for Swedish consumption was largely used abroad.

Besides environmental impacts, the PRINCE model can also be used for calculating different socio-economic impacts. The value added increased between 2008 and 2014 in line with consumption growth (Palm et al., 2019). However, the relationship between impacts from domestic and foreign sources was largely reversed compared to most environmental impacts, as about 75% of the added value from Swedish consumption largely came in Sweden, whereas most of the environmental impacts occurred abroad (Persson et al., 2019). For all indicators, results are also presented for the product groups and the most important countries contributing to overall totals (Fauré et al., 2019; Steinbach et al., 2018).

2.2.2 Sectoral and methodological studies in PRINCE 1 and beyond

The PRINCE 1 project also included several sectoral and methodological studies. One sectoral study focused on environmental impacts related to Swedish consumption of food products (Cederberg et al., 2019). It shows that Sweden exerts a significant environmental footprint in other countries, mainly in the EU and Latin America. Linked to that was a special study on how emissions of greenhouse gases related to deforestation can be linked to trade (Pendrill, Persson, Godar & Kastner, 2019). PRINCE 1 also included a special study on fish consumption (West et al., 2019) which is followed up in a gap analysis in PRINCE 2, see Chapter 6 below. A sectoral study on the consumption of information and communication technology products in Sweden also showed how second-order rebound effects assuming constant household consumption expenditures can be calculated using the PRINCE model (Joyce et al., 2019). It showed how rebound effects can be reversed, leading to decreased environmental impacts, if consumption is directed towards products with lower emission intensities. More special studies are presented in Steinbach et al. (2018). Finally, a study demonstrated how subnational supply chain data might be integrated into consumption-based accounting to improve the spatial specificity of production-to-consumption linkages (Croft et al., 2018).

The main water indicator calculated in PRINCE 1 considered water use only. The impact of water use, however, depends significantly on the scarcity of water in different regions. In light of this, approaches for including water scarcity were tested (West, 2018) in PRINCE 1. Since then, a report from a consensus building process by the "Water Use in Life Cycle Assessment (WULCA) working group" of the

UNEP[2]-SETAC[3] Life Cycle Initiative has been published (Boulay et al., 2018). They suggest the use of the AWARE factors which represent the relative Available WAter REmaining per area in a watershed after the demands of humans and aquatic ecosystems have been met.

Data from the PRINCE project have been extensively used in a study for the research project Mistra Sustainable Consumption. This work used PRINCE data to evaluate changes in environmental pressures from household consumption in Sweden due to the scaling-up of consumption practices currently performed in small proportions of the Swedish population. The study also developed scenarios for rebound effects that might arise in conjunction with the noted up-scaling. The assessment was done for greenhouse gas emissions, land use, use of HCPs, blue water consumption, consumption-based value added and employment.

Three different perspectives for environmental indicators

Consumption-based environmental indicators provide a complement to a territorial perspective (as used comprehensively in United Nations Framework Convention on Climate Change-related reporting and target setting) and the production perspective (a starting point for the System of Economic and Environmental Accounts).

The territorial perspective includes all environmental pressures arising on Swedish territory. The production perspective starts from the perspective of economic production and includes the direct environmental pressures from all Swedish economic actors, irrespective of where on the globe these take place.

Calculating production-based environmental pressures from territorial measures requires the following steps:

- Subtraction of environmental pressures from foreign companies within Swedish territory. This includes, for example, foreign transport companies operating in Sweden.
- Addition of environmental pressures from Swedish companies outside of Swedish territory. This includes mainly international transport carried out by Swedish companies.

The consumption perspective aims to evaluate the environmental pressures arising from consumption by Swedish economic actors. Consumption-based environmental pressures can be calculated from production-based environmental pressures by:

- Adding environmental pressures arising due to products imported by Sweden
- Subtracting environmental pressures arising due to products exported by Sweden.

[2] United Nations Environment Programme

[3] Society of Environmental Toxicology and Chemistry

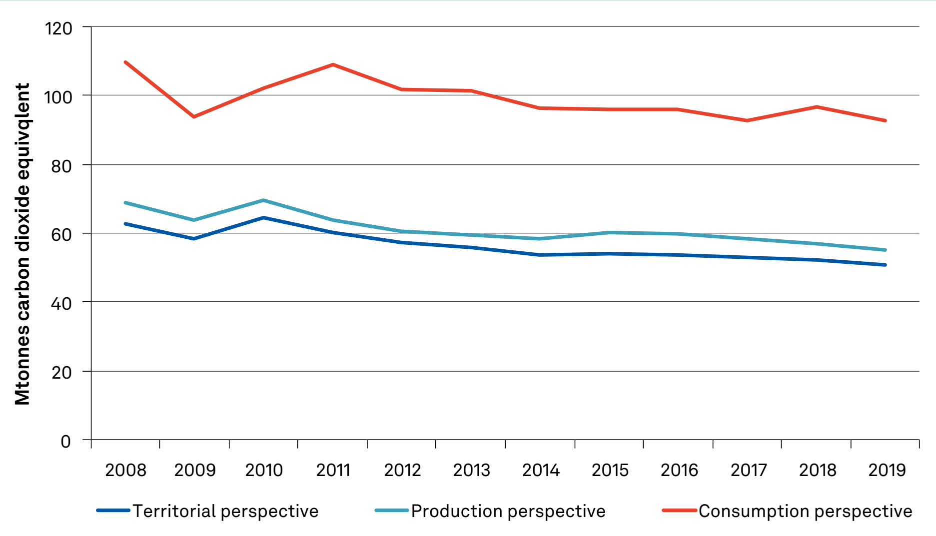

Figure: Sweden's greenhouse gas emissions with territorial, production and consumption perspective.

Source: Swedish Environmental Protection Agency, (2021a); Statistics Sweden, (2021a).

Sweden's greenhouse gas emissions with a territorial perspective are lower than those with a production perspective because emissions due to international transport are included in the latter. Consumption-based greenhouse gas emissions are higher than production emissions because of the emissions arising from products imported to satisfy Sweden's domestic consumption.

2.3 Why are consumption-based indicators so important for policy?

Consumption-based environmental indicators provide a unique perspective in support of policies for sustainability. The central policy relevance of consumption-based indicators and the methods used to produce them is that they connect environmental pressures to the economic production activities, exchanges and demands that give rise to them. Among other things, consumption-based indicators therefore challenge environmental policymakers to look beyond the boundaries of domestic economic production and national territories. This is because the consumption perspective considers environmental pressures arising from both domestically produced and imported goods and services. This a significant motivation for using consumption-based greenhouse gas emissions as an indicator tracking progress toward the generational goal (see above and Swedish Environmental Protection Agency, 2021b).

2.4 Policy needs for consumption-based indicators

Consumption-based indicators are in demand in the wider policy landscape. Goal 12 (responsible production and consumption; United Nations, 2020a) and Goal 8 (decent work and economic growth; United Nations, 2020b) of the global community's Agenda 2030 system of Sustainable Development Goals both include a consumption-based indicator (material footprint) to monitor progress. The UN's 10 Year Framework Programmme on sustainable consumption and production patterns (included in goal 12 above) encompasses areas such as public procurement, education about sustainable lifestyles, food, and building and construction. In all of these areas the further development of consumption-based indicators can provide valuable policy support. Domestically, Sweden has adopted a strategy for sustainable consumption (Swedish Government, 2016) largely reflecting priorities outlined in the 10 Year Framework Programme and Goal 12 above. In early 2022 the Cross-Party Committee on the Environmental Objectives (Miljömålsberedningen) will present findings from an inquiry into national goals for consumption-based greenhouse gas emissions (described in more detail in Section 2.6.2 below).

Policy needs for consumption-based approaches for environmental indicators are also growing. For example, carbon border adjustments – fees for product import based on the greenhouse gas emissions arising from their production – have been proposed as part of the European Green Deal (European Commission, 2021a). Consumption-based environmental indicators offer a starting point for evaluating specific policy designs and for following up on policy outcomes. One outcome of the United Nations Framework Convention on Climate Change Conference of the Parties (COP26) was a multilateral declaration on deforestation and land-use change (United Nations, 2021a) echoing incoming due diligence regulations being introduced for the EU (European Commission, 2021b).

2.5 How do policy-makers use consumption-based indicators?

A recent research study (Dawkins et al., 2021) closely connected to the PRINCE project asked local and national policymakers directly how they used consumption-based indicators. The findings show that the quantitative information in the indicators supports policymakers' prioritization of measures aiming at sustainable consumption, for example by identifying hotspot products with the highest embodied emissions. Even if the data do not provide absolute certainty as to the exact levels of environmental pressures, policymakers contend they are nonetheless important in this overall guiding function.

The findings of the study also point to a broader significance. Consumption-based indicators can counteract the tendency to initiate policy from the narrow perspective of single industries in isolation, for example transport or electricity production, to considering whole supply chains for produced products. Policy-makers also noted that consumption-based indicators offer the possibility to highlight the role of behavioural change for mitigation of environmental pressures and support a deeper transformative change in environmental policy-making. At the local level, policy-makers observed that consumption-based indicators highlight the significance of procurement as a driver of environmental pressures. Some even observed that shifting from a production to a consumption perspective may support a deeper transformative change in environmental policy-making.

2.6 Uptake of PRINCE 1 results in policy and statistics

2.6.1 Sweden's official statistics on consumption-based greenhouse gas emissions

The methodological developments in the calculation procedure for Sweden's consumption-based environmental pressures that were achieved in the PRINCE project (see Palm et al., 2019 and earlier in this chapter) were a pivotal factor in the SEPA's recommendation at the end of 2018 that consumption-based greenhouse gas emissions be published as official statistics. Time series for Sweden's consumption-based greenhouse gas emissions had been published previously. The significance of publication as official statistics is that they are produced and regularly updated according to quality criteria established in the Swedish statistics law. According to the law, the data are published with a comprehensive documentation of statistical quality, supporting transparency of the methods and data used. Practically, the official statistics are also published with a higher level of detail with more variables than consumption-based data have been previously.

Sweden's official statistics for consumption-based greenhouse gas emissions were published for the first time in 2019, and have been updated yearly since then. The published time series starts in 2008 and ends with the year T–2 where T is the year of publication. The time series published in 2021 ran therefore from 2008 to 2019. The time series covers Sweden's greenhouse gas emissions for the following variables:

- emissions source (domestic or imported production)
- emissions for each component of final demand (household consumption, government consumption, investments and exports)
- emissions for 50 product groups according to the Standard for Swedish product classification by industrial sector, SPIN (Standard för svensk produktindelning efter näringsgren)[4]
- emissions for private consumption: the statistics are also presented for 107 product groups according to the international Classification of Individual Consumption According to Purpose.

Largely on the basis of advances made in the first PRINCE project, Statistics Sweden has a leading role among national statistical offices in the field of consumption-based statistics. In 2020 Statistics Sweden headed up a group of statistical offices and researchers from around the world surveying and presenting methods currently used to produce statistics in consumption-based environmental pressures. The resulting Eurostat statistical working paper covers methods used to produce statistics on consumption-based greenhouse gas emissions, material flow accounts in raw

[4] Calculations are performed for 91 product groups which are further aggregated to 50 product groups for confidentiality reasons.

material equivalents, and experimental methods for calculating consumption-based waste statistics (Brown et al., 2021).

In an ongoing project financed by Eurostat, Statistics Sweden is exploring the possibility of improving the timeliness of statistics on consumption-based greenhouse gas emissions. Currently, the official statistics are produced with a time lag of approximately two years. The project is investigating the possibility of producing a time series with a time lag of six months instead. According to the initial scoping exercise performed, the following domestic data are available sufficiently quickly to be used for producing data with improved timeliness:

- economic production with a high level of detail
- greenhouse gas emissions with a production perspective
- foreign trade data
- final demand in the economy.

However, detailed data on intermediate demand in the economy (i.e. industries' own product demand) are not available. Implementation of the desired timeliness improvement therefore requires the input of data on intermediate demand from the last available year and rebalancing tables for the relevant levels of final demand and industrial production. EXIOBASE already includes now-casted data based on the International Monetary Fund and can therefore be used in the implementation of the desired timeliness improvement. With a successful result, it would therefore be possible to produce an experimental time series for consumption-based greenhouse gas emissions up to reference year 2021 as early as the middle of 2022 using this method.

2.6.2 Applications in policy and decision-making in Sweden

INQUIRY INTO A STRATEGY FOR CONSUMPTION-BASED GREENHOUSE GAS EMISSIONS FOR SWEDEN

In 2020, the Swedish government instructed the Cross-Party Committee on the Environmental Objectives (Miljömålsberedningen) to carry out an inquiry into the development of a strategy for consumption-based greenhouse gas emissions, including the possibility of establishing a national target. The inquiry is also investigating how to assess and compare the greenhouse gas emissions arising from Sweden's exports and the role of public procurement in driving greenhouse gas emissions. The government directive authorizing the inquiry cited the methodological advances in the first PRINCE project in its justification. Experts at Statistics Sweden's group for environmental accounts have contributed in many ways in the course of the inquiry. Firstly, the official statistics have been presented and discussed with the cross-parliamentary members of the committee. Secondly, Statistics Sweden was consulted in relation to the part of the inquiry assessing the greenhouse gas emissions for Sweden's exports. Finally detailed data output from the original PRINCE results were delivered together with detailed economic data to support the scenario analysis carried out in conjunction with the inquiry.

The inquiry is focused on greenhouse gas emissions, but at the same time, notes that attention should be paid to potential synergy effects and conflicts with other environmental quality objectives. Therefore, the broad indicator set developed in the PRINCE projects are highly relevant even for this inquiry.

MONITORING INDICATORS FOR SWEDEN'S ENVIRONMENTAL QUALITY OBJECTIVES AND AGENDA 2030

The methodological development resulting from the first PRINCE project has also been applied to calculate indicators produced by Statistics Sweden's environmental accounts group for monitoring progress towards the environmental quality objective "good built environment". These data cover not only greenhouse gas emissions but also sulphur oxides (SOx), nitrogen oxides (NOx) and particles. Indicator production here includes modelling the environmental pressures from all economic output from the building and real estate sectors together. This requires a slightly different modelling approach from that used to look at consumption-based environmental pressures specifically and has potential applications for other economic sectors.

The official statistics on consumption-based greenhouse gas emissions are further used for monitoring progress in relation to Sweden's generational goal and the goal for limited climate impact as well as Agenda 2030 goals.

APPLICATIONS FOR OTHER DECISION-MAKERS

Data on emissions of greenhouse gases are also important when private organizations or individuals want to reduce their carbon footprint. In order to calculate a benchmark, for testing impacts of different choices and to monitor the development, climate calculators can be useful. They need to have data for the emissions associated with different products and product groups. Data from the PRINCE projects can be used in that context, both by consultants making calculations for companies, organizations and public agencies, and by online calculators that can be used by individuals as well organizations. An example of the latter is Svalna which is using PRINCE data.[5]

2.6.3 Policy applications beyond Sweden

The method developed in PRINCE 1 to estimate deforestation and associated greenhouse gas emissions embodied in the production, trade and consumption of agricultural and forestry commodities has been used to inform several policy processes, primarily in a European context. In particular, key documents underlying legislative proposals on imported deforestation from the EU Parliament (Heflich, 2020) and the European Commission (2021b) have drawn upon the data provided by Pendrill et al. (2020) on deforestation risk embodied in EU imports, both broadly to motivate EU action and specifically to design the proposed policies.

Individual European countries are also staring to make use of the data: the United Kingdom is using the data for indicators related to climate and biodiversity impact of agricultural imports (Croft et al., 2021) and the Danish Energy Agency is using the data in developing indicators on consumption-based carbon emissions for Denmark (Energistyrelsen 2021). In addition, the data are used by numerous environmental organizations monitoring developments and providing policy advice related to deforestation (e.g. Ceres, 2020; Wedeux & Schulmeister-Oldenhove, 2021).

PRINCE 1 methodologies are also instrumental in developing UK monitoring and policy. In early 2018, the UK Government published a new "25 year plan to

[5] Svalna: https://svalna.se/web/en/products/calculator

improve the environment"[6] which contained commitments to leave a lighter footprint on the global environment, and particularly to support zero-deforestation supply chains. An objective of work associated with the 25 Year Environment Plan is to provide a consumption-based indicator which also allows linkages to subnational supply chains, with work pioneering this approach originally published based on the outcome of PRINCE project activities (Croft et al., 2018).

Development of the indicator framework for the UK Government is described in Croft et al. (2021) and currently includes:

- Integration of EXIOBASE to improve time-series coverage (previously GTAP – global trade analysis project – data were used, which can still be used as an alternative to EXIOBASE when required).
- Integration of wood and beef production and trade information to complement the existing coverage of Food and Agriculture Organization (FAO) agricultural commodities.
- Integration of deforestation characterization factors drawn from Pendrill et al. (2020) which are in turn based on another output from the PRINCE project (Pendrill, Persson, Godar, & Kastner, 2019).
- Integration of other indicators covering water consumption and scarcity (based on annualized water footprint and WULCA AWARE factors), plus two simple biodiversity-linked metrics.
- Development of an interactive dashboard making this information available[7].

We understand that the results from interim data releases have been used to support the implementation of upcoming UK supply chain due diligence regulation (UK Government, 2020), a new industry-led UK Soy Manifesto[8] and the framework has been recommended by the UK Government within a recent submission to the Convention on Biological Diversity.[9]

A period of further development of this experimental consumption-based indicator is envisaged over the next 2–3 years, with improvements likely to focus on:

- Further development of environmental indicators, particularly biodiversity.
- Expansion to other commodities (e.g. mineral products).
- Integration of alternative datasets/assumptions to allow sensitivity analysis across different methods (e.g. GTAP vs EXIOBASE, alternative physical trade-data etc.).
- Further development of features within the online dashboard.

[6] https://www.gov.uk/government/publications/25-year-environment-plan
[7] www.commodityfootprints.earth
[8] https://www.uksoymanifesto.uk/
[9] https://s3.amazonaws.com/cbddocumentspublic-imagebucket-15w2zyxk3prl8/1e588e51b3c0baee3fa04d65cd2f588e

2.7 Potential future policy applications for PRINCE indicators and methods

Beyond the specific instances of policy uptake noted above, there exists a currently untapped monitoring potential for indicators developed in the PRINCE project. Figure 1 demonstrates the potential connections between indicators included in the PRINCE projects (including the gap analyses presented here) and Sweden's environmental quality objectives. Also relevant here is that in addition to the overarching formulation of the generational goal, it includes seven bullet points covering recovery of ecosystems; conserving biodiversity and the natural and cultural environment; good human health; efficient materials cycles free from dangerous substances; sustainable use of natural resources; efficient energy use; and patterns of consumption which should cause as little environmental impact as possible. The final point suggests that environmental indicators related to consumption should cover many aspects and therefore that several of the PRINCE indicators are of relevance assessing progress towards the generational goal.

The parts of the generational goal emphasizing that resource use should be sustainable and efficient suggest that indicators related to land, materials and water could be of interest and possibly further developed. Currently the terrestrial material use is monitored in relation to both the Swedish Environmental Quality Objectives and Agenda 2030. It could be interesting to follow up from a consumption perspective as well. National and international policies on circular economy further point to the importance of monitoring material use in this way. In order to use the PRINCE model, Statistics Sweden needs to develop its material accounting. It can, however, be noted that there are currently no Swedish policy targets related to material use specifically.

The PRINCE indicator on water use is clearly linked to the Sustainable Development Goal 6 on clean water. This could benefit from the further development of metrics for water scarcity that were considered in a methodological study in PRINCE 1 (see Section 2.2.2 above).

For PRINCE indicators in the chemicals area there is a clear connection to the generational goal including the bullet point on minimizing impacts on human health as well as the bullet point that resources should be used efficiently and with minimum amounts of hazardous chemicals circulated. There are also connections to the Sustainable Development Goals as well as national and European policies on circular economy and hazardous chemicals.

As noted previously in this chapter, the essential significance of consumption-based indicators and the methods used to produce them is that they provide a macroscopically detailed connection between environmental pressures and metrics used by policy-makers to monitor the national economy. The potential to use the methods from the PRINCE model and other consumption-based models to inform economic policy from an environmental perspective beyond consumption has arisen in Section 2.6.2 in this report. The main examples here include assessing the environmental pressures connected to national imports and exports and in guiding public procurement. At the same time, there exists untapped potential to use methods from PRINCE to assess and track for example government stimulus policy, interest rate setting and the operations of the financial sector.

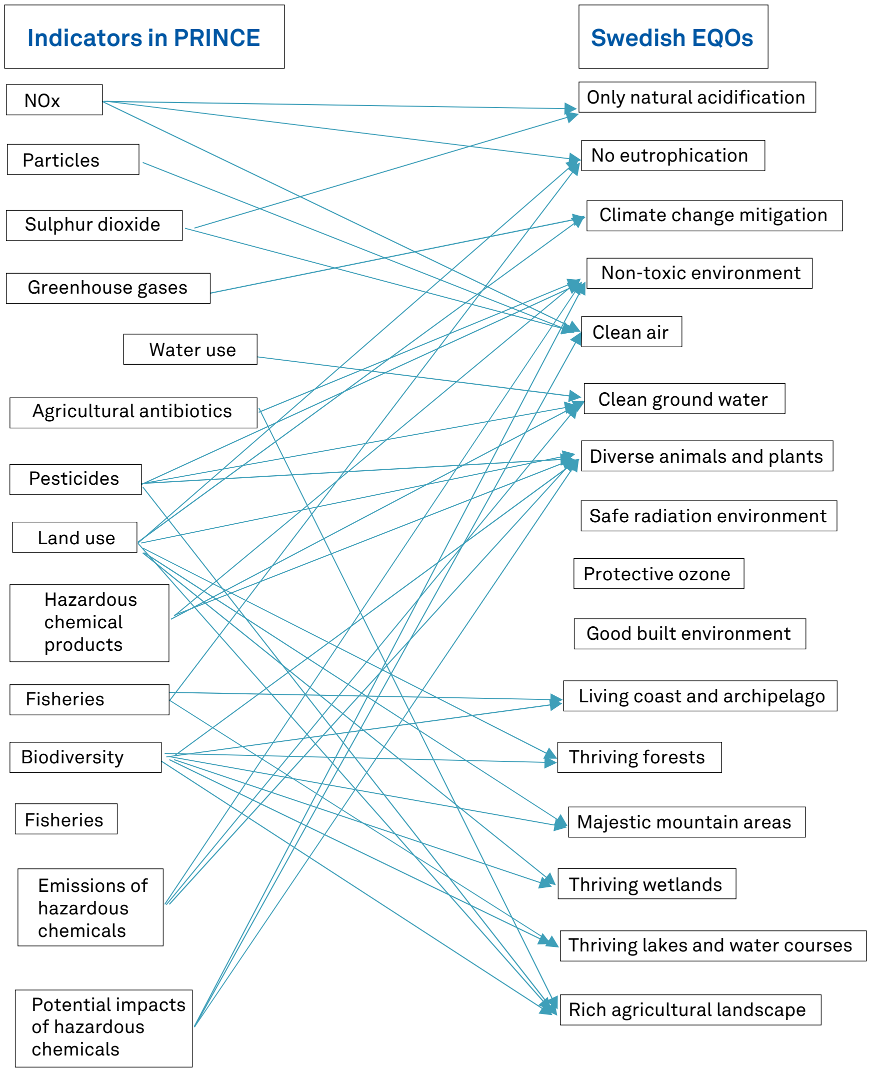

Figure 1: Schematic showing connections between areas for PRINCE indicators (left) and Swedish environmental quality objectives (EQOs) (right).

3. Gap analysis: Biodiversity

Key messages

- Sweden should move ahead in the immediate term with incorporating simple, yet “fit for purpose”, metrics of biodiversity impacts into their consumption-based accounts to allow biodiversity to enter into policy processes around trade and sustainability.
- Metrics and tools should be kept under review to consider whether to incorporate new and potentially more complex measure(s).
- In particular, assessment should also be made of the potential to improve upon areas of biodiversity impact which are less well researched and/or where data are less readily available – for example, links between pollution and species loss, and impacts in non-terrestrial environments linked to consumption.
- Support should be provided particularly to the maintenance of datasets and tools to keep them current and responsive.

3.1 Introduction

In the first PRINCE project, biodiversity was not explicitly included, although it has strong associations with land use and tropical deforestation[10], which were. In the following sections, we describe some of the existing approaches and options available for applying biodiversity metrics in the context of an environmentally extended multiregional input-output model (MRIO). Our focus on biodiversity losses telecoupled to Swedish consumption motivates the use of commodity-specific MRIOs and steers us towards metrics that consider the biodiversity impacts of land conversion, which is the major driver of terrestrial biodiversity loss today.

3.1.1 International policy imperatives

We must deal with biodiversity losses and the global demand that drives them. The global Sustainable Development Goals provide an overarching framing – notably in Goals 14 and 15 (United Nations, 2015) – that commit international governments to biodiversity protection and restoration. It is clear, too, that loss and degradation of biodiversity and ecosystem services is associated with clear and present risks to delivery of the Sustainable Development Goals across the spectrum and it will be hard or impossible to deliver them without first addressing the impacts of our unsustainable consumption behaviours on our natural environment.

[10] We refer to “tropical” forests for convenience, but note that throughout this appendix, we intend the term to include both tropical and sub-tropical forests, as used in the analyses by Pendrill et al. (2019a).

The "super year" for biodiversity of 2020 was delayed but eventually arrived with a series of international meetings and commitments. Biodiversity was spotlighted in the UN Framework Convention on Climate Change COP26 – and particularly the role of international markets in driving deforestation and biodiversity loss through the Forest, Agriculture and Commodity Trade (FACT) dialogue (Tropical Forest Alliance, 2021). Biodiversity was also featured in the recent compact of the G7: "*As advanced economies and major consumers within global supply chains and markets, we recognise our unique role and acknowledge the negative and unsustainable impact our economic activity can have on nature and wildlife, abroad as well as at home*" (G7, 2021). 2021 also marked an important milestone when the UN Statistics Commission adopted a new statistical standard for Ecosystem Accounts (SEEA EA). While it does not provide a single biodiversity account, there are overlaps; for example, the presence of ecosystem types and condition accounts regarding the biotic ecosystem characteristics (United Nations, 2021b). Yet the issue of developing mechanisms and measures to monitor and report overseas biodiversity loss is still not adequately addressed. Against the backdrop of the first global biodiversity assessment since 2005, which highlighted the significant and ongoing declines in biodiversity and its services (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019), and the fact that most of the Aichi Targets for Biodiversity are unmet, the Convention on Biological Diversity COP15 is vital for setting action for the post-2020 framework agenda and tools to monitor progress will be critical.

In recent years there has been significant interest in identifying and eliminating deforestation from global supply chains. This includes proposed due diligence legislation on illegal deforestation from the UK Government, (2020) and proposed regulation from the European Commission "to minimise the EU's contribution to deforestation and forest degradation worldwide and promote the consumption of products from deforestation-free supply chains in the EU" (European Commission, 2020a). At the same time, our ability to map and measure the deforestation risk of commodity production and trade has gained pace (see Chapter 4 for detailed description of this work) with advances and increased accessibility of remotely sensed landcover imagery and large-scale, but high resolution, data on commodity production and trade (e.g. Croft et al., 2018, 2021; Godar et al., 2015; Pendrill, Persson, Godar, & Kastner, 2019; Pendrill, Persson, Godar, Kastner, et al., 2019). Such studies highlight the importance of understanding transboundary impacts of our consumption habits to ensure that unsustainable demand is not simply being out-sourced, thereby continuing to contribute to global forest losses (Hoang & Kanemoto, 2021).

3.1.2 Why biodiversity matters in consumption-based accounting

While such methods have greatly improved our understanding of international drivers of environmental impacts, questions remain as to the efficacy of understanding and mitigating our biodiversity impacts, using proxies such as harvested area or, even, tropical forest loss (Pendrill, Persson, Godar, & Kastner, 2019; Pendrill, Persson, Godar, Kastner, et al., 2019). While tropical forests are undoubtedly a haven for global biodiversity, if we do not consider variation of biodiversity within forests, then our methods are unable to differentiate between forests of lower or higher biodiversity and, more critically, we cannot consider issues of rarity, complementarity and irreplaceability that are associated with the uniqueness of species, communities and ecosystems. Moreover, a focus on tropical forest misses the potentially high and/or unique biodiversity found in non-forest ecosystems, and it entirely precludes consideration of temperate biodiversity (Green et al., 2020; West et al., 2020).

The *Dasgupta Review* highlighted that humans, our society and our well-being exist as a part of nature, and biodiversity underpins all Earth's life support systems (Dasgupta, 2021). However, our current use of natural resources is unsustainable (Dasgupta, 2021, p. 101) and the rates of species loss suggest that the world's sixth mass extinction is under way (Ceballos et al., 2015). One of the major drivers of this is land-use change (Souza et al., 2015) and the appropriation of natural habitat for agriculture (Donald, 2004). The Dasgupta Review also highlights the role that international trade (and its liberalization) has had in maintaining and increasing our global ecological footprint (Dasgupta, 2021, p. 379). Against a background of increasing recognition of the critical role that biodiversity and ecosystems play in our well-being, and the threats that they face, governments are looking to understand their global impacts on the environment through a consumption-based lens. A recent Chatham House report highlights that the primary driver of biodiversity loss is from agriculture – driven by our global food system (Benton et al., 2021). Trade in agricultural commodities has the potential to both increase impacts on biodiversity – for example through increasing the market and consumption of cash commodity crops in biodiverse tropical countries – or decrease impacts – through a net sparing of land, induced by greater yields and efficiencies (Kastner et al., 2021). It is important to take a consumption-based approach to consider Sweden's role in the global food system from multiple perspectives and, with substantial consumption of tropical deforestation-risk commodities (see also Chapter 4), it is vital that biodiversity impacts are given explicit consideration.

3.1.3 The issue of complexity

The concept "biodiversity" refers simply to all the variety of life. However, it is a multifaceted concept, underpinned by the genetic diversity among all life, and culminating in complex and interdependent ecosystems that are maintained by a multitude of ecological processes arising both from the interdependencies between species and individual organisms, and from their abiotic environment.

This complexity, however, means that any "biodiversity footprint" can only ever be a proxy for the true value of biodiversity. It is not possible to reduce it to a simple or single metric (Vanham et al., 2019). Instead, attempts to use a consumption-based accounting framework to measure our impacts on biodiversity must use credible proxies to understand the trends of biodiversity impacts associated with consumption. In doing so, there is a potential trade-off between the availability and simplicity of a biodiversity metric and its ability to reflect shifts in environmental "qualities" in landscapes linked to production systems.

To help simplify some of this complexity, Pereira et al. (2013) suggested the use of Essential Biodiversity Variables to report and manage biodiversity change. They describe how observations (both measured *in situ* and remotely sensed) must feed into six essential biodiversity variables that underpin our ability to understand and report on the state of biodiversity: genetic composition; species populations; species traits; community composition; ecosystem functioning; and ecosystem structure (GEO BON, n.d.; Pereira et al., 2013). Marques et al. (2021) further highlight that multiple metrics are likely needed, but impacts should, at the very least, represent two aspects of biodiversity: firstly extinction risk of species and secondly ecosystem function.

Biodiversity is in addition highly heterogeneous across space. The recent advances in spatialized and detailed production datasets and trade models have greatly improved our ability to model biodiversity impacts of consumption (see Appendix 3 on this topic).

3.2 What is state of the art for incorporating biodiversity into consumption-based accounts?

The Institute for European Environmental Policy (IEEP) (2021) categorizes biodiversity footprints in terms of (a) ecological footprints, such as land or forest area; (b) biodiversity footprints for those metrics which more directly estimate losses of biodiversity; and (c) ecosystem service footprints, which pertain to the impacts on the benefits that arise from nature. In this chapter, we consider (b) – those that specifically address biodiversity (rather than a more utilitarian measurement of benefits that it provides) and allow assessment of heterogeneous biodiversity value even *within* a single landcover class.

A number of studies have provided consumption-based accounts of biodiversity impacts at national level. These can be broadly summarized as those based on the known threats to species, those based on species-habitat relationships, and those that use mapped species ranges (Table 1; see further detail in Appendix 2, Table 5).

Table 1: Broad categories of approaches to using multiregional input-output models to quantify the role of agricultural commodity trade in driving biodiversity loss.

Approach	Brief description	Example
Assessing threats	The International Union for Conservation of Nature (IUCN) and BirdLife International provide global information on threats for thousands of species. These threats can be associated with particular sectors of an MRIO to understand the economic drivers of species threats and associate them with particular consuming regions and sectors.	Lenzen et al., 2012; Moran & Kanemoto, 2017
Species–habitat relationships	Using modelled relationships between biodiversity and landcover, we can attribute species impacts to landcover changes. This includes characterizing biodiversity changes at broad scales such as within an ecoregion (e.g. applications of the countryside species-area relationship) or at fine scales, such as specific landcover classes (e.g. in applications of mean species abundance or biodiversity intactness index).	Alkemade et al., 2009; Chaudhary et al., 2015; Chaudhary & Kastner, 2016; Newbold et al., 2016
Species ranges	IUCN and BirdLife International provide spatial information on the ranges of thousands of species. These can be used to identify the most biodiverse areas and to associate particular production systems with risks to biodiversity. This can be conducted at fine scales using detailed crop production information, or aggregated (e.g. to jurisdictional boundaries).	de Baan et al., 2015; Durán et al., 2020; Kitzes et al., 2017; Mair et al., 2021

3.3 What are the short- and longer-term options and opportunities for integration of biodiversity into Swedish accounts?

The majority of studies linking national level footprints to global biodiversity impacts have done so using metrics derived from the countryside species-area relationship (cSAR; Marques et al., 2021; Table 5 in Appendix 2). However, other tools are increasingly available, as is the recognition that multiple perspectives on the status of, and impacts upon, biodiversity are useful.

In the development and application of biodiversity footprinting metrics, it is important to consider carefully the following set of questions:

- **What is being measured?** We cannot measure biodiversity itself, so our metrics are based on subsets and proxies. These may link primarily to the potential pressure placed on existing biodiversity (e.g. by overlaying production and species richness), or may attempt to quantify impacts more accurately (e.g. by linking land use change directly to species loss). However, we need to carefully consider what our metric is measuring and whether that is something that we want to know about and/or whether it can serve as useful input to our decision-making processes.
- **What is driving biodiversity impact in the metric?** Most biodiversity metrics are linked to land use change, but others are used too. Linked to the previous point, therefore, it is important to know what is, and is not, considered within the metric.
- **How easy is it to apply?** How are the data accessed and is there enough documentation of the methods to understand and apply in a new context? Are the data globally available, free to use, and sufficiently up to date to inform current policy to mitigate biodiversity losses?
- **How easy is it to communicate?** Biodiversity is an intuitively simple concept, but its measurement can quickly become highly technical. How easy is it for a lay person to understand the implications of the metric?
- **How responsive is the metric to real-world changes?** An emergent property of some of the previous considerations – around what drives the metric and how up to date the input data are – relates to the responsiveness of the metric. As biodiversity changes, is this reflected in footprinting metrics, or are changes driven only by changes in the trade model itself (i.e. by volumes and sourcing locations)? And what about the spatial resolution of the data: does this allow for biodiversity trends to be picked up?

3.4 Biodiversity-extended consumption-based accounting tools available now

A handful of tools, built on the approaches and methods described in Table 1 (and Table 5 in Appendix 2), are already developed for application to consumption-based biodiversity footprinting. This includes LC-Impact, which provides several ecosystem quality measures (Verones et al., 2020) – including on water stress, ecotoxicity, eutrophication, acidification and climate change – alongside their land-use change based biodiversity impact assessment, based on Chaudhary et al. (2015). Bjelle et al. (2021) combine these life cycle impact assessment methods for biodiversity with EXIOBASE 3rx, a version of the MRIO that disaggregates “Rest of World” regions to countries, thereby expanding country coverage from 49 to 214 (Bjelle et al., 2019).

Building on the work conducted in PRINCE 1 (Croft et al., 2018), the Sustainable Consumption and Production group in SEI-York, in collaboration with the Joint Nature Conservation Committee, an advisor to the UK Government, have undertaken to apply the input-output trade analysis (IOTA) framework by hybridizing EXIOBASE (EXIOBASE 3; Stadler et al., 2021) with physical production and trade data from the FAO. Outputs from this work are provided within a public and freely available indicator dashboard (www.commodityfootprints.earth; Croft et al., 2021). This allows us to consider Sweden’s consumption and production of agricultural commodities within the global context (Table 2; Croft et al., 2021). It shows that in 2017 around half of the agricultural commodity production driven by Swedish consumption was produced outside Sweden.

Within this dashboard, Sweden’s biodiversity impacts can be considered in terms of a commodity’s harvested area, its tropical deforestation risk (Pendrill, Persson, Godar, Kastner, et al., 2019), its regional species loss impact (according to the methods of Chaudhary & Kastner, 2016, a cSAR-based metric), or its overlap with species ranges (species-hectares-based risk metric). The latter two metrics are relatively crude representations of biodiversity value and importance, but offer a standardized and relatively intuitive and simple method for incorporating biodiversity considerations into Sweden’s accounts. Together, these four metrics provide different perspectives on Sweden’s consumption based biodiversity impacts, but show in common that biodiversity impacts arise disproportionately outside its borders (Table 2 and Figure 2).

Table 2: Swedish consumption and production of agricultural commodities in 2017 (Croft et al., 2021).

	Sweden’s consumption-based environmental pressure		
	Domestic	**Foreign**	**Total**
Mass (tonnes)	20.9 mn (52%)	19.5 mn (48%)	40.4 mn
Harvested area (ha)	0.6 mn (21%)	2.3 mn (79%)	2.9 mn
Tropical deforestation (ha)	-	5 400 (100%)	5 400
Predicted species loss (species)	0.4 (4%)	9.7 (96%)	10.1
Species richness weighted area (species ha)	161 mn (17%)	800 mn (83%)	961 mn

Note that the dashboard also provides metrics on the CO_2 emissions associated with tropical and sub-tropical deforestation and on various water and water scarcity metrics. Both could have indirect impacts on biodiversity, but that is not quantified so they are excluded from this table.

3.4.1 Model choice, complexity and trade-offs

In choosing a consumption-based biodiversity footprint, it is important to consider the potential trade-offs of metric complexity against accessibility, tangibility, cost and replicability. The most complex models may well be difficult to communicate, thereby losing their political relevance, and prove to be too abstract for their audience. Moreover, they will likely be costlier to develop and maintain and may require more specialist skills to use than simpler methods. Comprehensiveness of an indicator – for example in covering wider geographies, more species, or better incorporating ecological processes – may come at the expense of responsiveness. Timely action is vital and the key question, therefore, is whether more complex models provide different – and more accurate – assessments of biodiversity impacts compared to their simpler counterparts.

The biodiversity foot-printing literature is awash with different metrics and is an increasingly confusing space for private and public sector decision-makers to operate within. Several efforts are under way to help alleviate this confusion and provide much-needed guidance – particularly focused on the biodiversity metrics (rather than the production to consumption models). These include the Align project[11] “Aligning accounting approaches for nature”, which builds directly on two previous projects: Aligning Biodiversity Measures for Business[12] and Transparent[13]. The Align project aims to assist the European Commission’s efforts to support businesses and other stakeholders in developing standardized natural capital accounting practices, including for biodiversity measurement. The project is led by the World Conservation Monitoring Centre Europe and intends to engage a broad range of stakeholders to develop generally accepted accounting procedures for biodiversity and natural capital. Also of note, is the Science Based Targets Network,[14] which aims to provide targets for biodiversity to business and cities. The focus of this network is on developing measurable and actionable targets, meaning that it is in close step with biodiversity metric developments.

3.5 Next steps and future developments

Biodiversity data and metrics are always improving and evolving. For example, the Species Threat Abatement and Restoration metric, which combines information on species ranges and on threats, has been developed to support the development of science-based species targets for the Science Based Targets Network, but also shows promise for application in national footprints (IEEP, 2021; Mair et al., 2021). It is based on species data (BirdLife International, 2021; International Union for Conservation of Nature (IUCN) Red List of Threatened Species[15]) and is conceptually similar to a combination of the species threat and species range metrics described above. We are also aware of ongoing research efforts within the Trade Hub project[16] – including those to further develop the Biodiversity Intactness Index (a population

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[11] https://ec.europa.eu/environment/biodiversity/business/align/index_en.htm
[12] https://www.unep-wcmc.org/featured-projects/aligning-biodiversity-measures-for-business
[13] Transparent: https://capitalscoalition.org/project/transparent/
[14] https://sciencebasedtargetsnetwork.org/earth-systems/biodiversity/
[15] Version 2021-2: https://www.iucnredlist.org/
[16] https://tradehub.earth/

abundance-based measure) to incorporate aspects of land management and mitigation measures beyond simple classifications of low/medium/high intensity (e.g. Chaudhary & Brooks, 2018; Kastner et al., 2021) and in understanding the relative role that climate impacts have on biodiversity versus direct land footprints, from a consumption-based perspective.

As previously highlighted, any biodiversity footprint will only ever be a proxy for the true value, and will always face some lag between real-world impacts and the acquisition and processing of data to produce outputs for policy. Approaches that use multiple metrics have the best chance of representing the reality, and of picking up trends in biodiversity in a timely manner. Recent papers have demonstrated the importance of including a range of biodiversity indicators for a more comprehensive picture (Marquardt et al., 2019; Verones et al., 2020).

As documentation shows (Croft et al., 2021), much of the input data used to produce the indicator dashboard for Sweden's consumption-based biodiversity impacts presented in Figure 2 and Table 2 are institutionally produced and maintained or from peer-reviewed research publications. Most of the input data are updated regularly, though not always annually. This brief analysis suggests that the indicators produced for Sweden may satisfy quality requirements for official statistics in the dimensions of accuracy, comparability and timeliness. Going forward, a more detailed analysis compared to the quality requirements for official statistics should therefore be carried out for the method and data sources described in Croft et al. (2021) in particular considering each indicator separately.

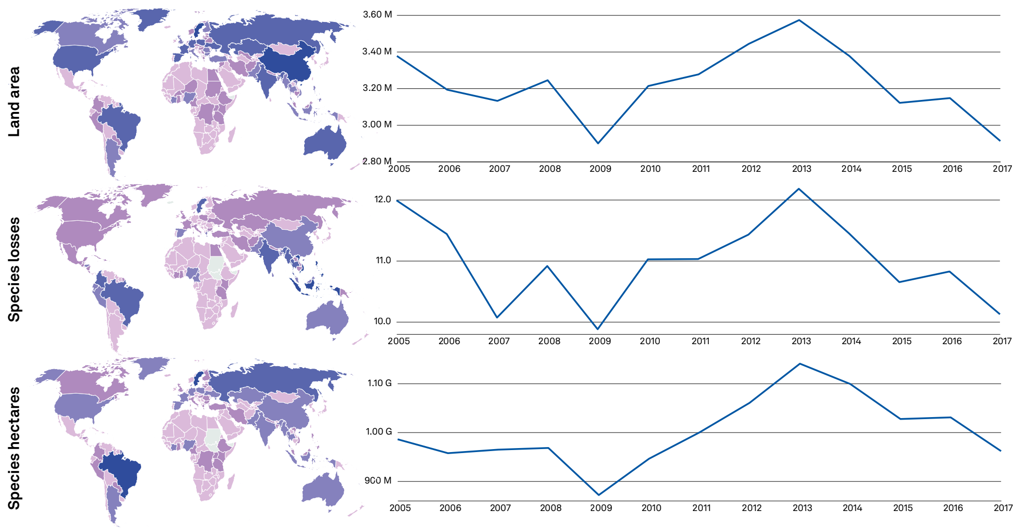


Figure 2: An example comparison of Sweden's consumption footprint, measured as land area, species losses and species hectares. In the maps, different colours reflect the severity of potential risk from low to high. (Croft et al., 2021).

3.5.1 Biodiversity dialogue discussions

As part of the PRINCE 2 project, a focused dialogue on the results of the biodiversity gap analysis was conducted with members of Swedish policy organizations (SEPA and the Swedish Food Agency). Discussions centred on the following topics of interest linked to the relevance of biodiversity in consumption-based accounting to Swedish policy considerations, and requirements for future development in this area:

- **Alignment with policy and other use-cases:** General interest was expressed in the potential to integrate specific biodiversity information into consumption-based approaches. It was emphazised that we need to be able to identify the impacts of consumption on biodiversity loss in a similar way to threats posed by greenhouse gas emissions, in order that the two can be considered alongside one another. Biodiversity data were seen as relevant in active discussions linked to dietary transition and product-choice, and it was noted also that policy was moving towards the consideration of ecosystem service implications of economic activities, for which biodiversity has a key underpinning role. Here, it was noted that to ensure relevance to decision-making, data linked to biodiversity must include sectoral and regional breakdowns of results to allow assessment of which industries are important, how "direct" Swedish exposure to risk is, and how biodiversity impacts vary across sourcing locations. Additionally, it was felt important that biodiversity metrics deployed in future should be tailored towards conservation priorities (i.e. weighted towards species that are threatened).
- **Methodological comprehension:** The biodiversity metric landscape is complex and – in comparison with other measures such as those linked to climate change – embryonic in terms of uptake for example, national accounting frameworks. While some metrics (e.g. those based on species-area relationships) are more commonly used, a variety of metrics exists, many of which share similar methodological underpinnings or input datasets. With this in mind, it is important that decision makers understand what is being measured and how results are influenced either by the underpinning biodiversity dynamics, or conversely via the trade/consumption relationships captured by the MRIO models to which they are attached. Additional work would be useful to understand complementarity in methods and approaches. Explanation of how biodiversity-linked conclusions are "driven" by these dynamics is necessary to ensure that decision-makers can interpret the data effectively and without the risk of dismissing information due to its complexity or limitations.
- **Development of simple approaches:** Bearing in mind the two points above, it was felt that it would be beneficial to continue investigation of the development of several simple metrics for biodiversity linked to Swedish consumption, complemented by additional dialogue to help decision makers understand the technical options and the costs and opportunities associated with each. Further investigation with a set of simple metrics would facilitate continued exploration of the utility and viability of metric development, for example for national statistics. Metrics could then be developed over time to become more complex in response to user requirements, although it was noted that it was important that they remain relatively simple to ensure ongoing tractability and accessibility to as wide a range of potential users as possible. It is recommended that dialogue between Swedish policymakers and the research community involved in developing biodiversity indicators continues to understand the short- and longer-term potential for their uptake.

3.6 Conclusions

While the interest in consumption-based accounting for biodiversity impacts rises, trends in biodiversity continue to decline. Therefore, specific and explicit inclusion of biodiversity in consumption-based accounting – beyond area-based assessment of other environmental impacts – is crucial. Existing studies show that Sweden's international trade has significant biodiversity-related impacts. In relation to this, this study has shown several data sources that can be used to measure these impacts.

Models and tools to measure impacts on biodiversity and incorporate them into footprints continue apace, and more sophisticated tools may better capture biodiversity's complexity, and distil key information on impacts, allowing it to be woven into decision-making processes. Crucially, though, we already have enough information to begin taking important steps. Moreover, it remains unclear as to whether and when additional complexity in modelling biodiversity impacts will lead to different and better decisions. Countries must, therefore, begin incorporating biodiversity considerations into their accounting principles in order to establish the processes and procedures for measuring and mitigating biodiversity within the context of concurrent environmental, social and economic concerns. We cannot wait for perfect data. That moment will not come.

4. Gap analysis: Deforestation land-use change

Key messages

- We estimate that the carbon emissions from tropical deforestation due to Swedish consumption amounted to 2.8 Mt carbon dioxide equivalents in 2018, two-thirds of which was due to food consumption.
- While total food-related deforestation carbon emissions have decreased by 1 Mt carbon dioxide equivalents from 2012 to 2018, emissions due to the two most important commodities – Brazilian beef and Indonesian palm oil – are increasing.
- Due to the lack of spatially explicit production and trade data, the indicator should be interpreted as a measure of deforestation risk, but as such it fulfils the accuracy criteria for official statistics.
- The relevance criteria for official statistics are clearly fulfilled, with the indicator already being used by other European countries and EU institutions, and could complement existing estimates of consumption-based greenhouse gas emissions for Sweden.

4.1 Introduction

As highlighted in the previous chapter, the main driver of terrestrial biodiversity loss is land-use change, in particular the expansion of agricultural land uses at the expense of tropical forests and other natural habitats. Moreover, tropical deforestation is a major contributor to climate change – accounting for about a tenth of global greenhouse gas emissions (Intergovernmental Panel on Climate Change, 2019) – and impoverishes hundreds of millions of people who are dependent on forests for their livelihoods (Shackleton et al., 2011; Wunder et al., 2014).

The drivers of this environmental change are increasingly found at far distances from the tropical forests being lost, in the markets (domestic and international) for agricultural and forestry commodities produced on the cleared land. This increased commercialization and globalization of the drivers of deforestation has long been recognized (Rudel et al., 2009). However, until recently there were no comprehensive data linking consumption of agricultural commodities to deforestation and associated environmental impacts.

4.2 Filling a data gap on deforestation and trade

In PRINCE 1, we set out to fill this data gap by constructing a model that quantified the extent to which consumption in Sweden and elsewhere is contributing to tropical deforestation. What we found was that every year over 5 million hectares of forest loss across the tropics can be attributed to the expansion of cropland, pastures and forest plantations, and associated commodity production (Pendrill, Persson, Godar & Kastner, 2019; Pendrill, Persson, Godar, Kastner, et al., 2019).

While the bulk (around two-thirds) of demand for these commodities is still domestic, carbon emissions from deforestation embodied in international trade are still substantial, amounting to 1 billion tons of carbon dioxide equivalents per year (1 Gt CO_2 equivalents/yr) in the period 2010–14. As a result, we estimated that about a tenth of the carbon footprint of a Swedish diet is due to the consumption of imported commodities that contribute to deforestation in the tropics, primarily beef and soybeans (for animal feed) from Latin America and palm oil products originating in Southeast Asia. In total, it was estimated that Swedish consumption was associated with emissions of 4 Mt CO_2 equivalents from deforestation in 2011, half of which was due to food consumption. To put these numbers in perspective, they are in the same order of magnitude as Sweden's territorial emissions of methane and nitrous oxide from agriculture (each amounting to about 3 Mt CO_2 equivalents/yr).

4.3 An updated deforestation emissions footprint for Sweden

For this report, we have updated the deforestation attribution model, making several improvements: First, we now attribute deforestation to commodities based on the expansion in the harvested area for each individual crop in the FAOSTAT database. This improves the attribution over the approach taken in the first PRINCE project, where attribution was based on changes in area for broader crop groups (conforming to the EXIOBASE agricultural sectors), as that approach might mask trends in harvested area for crops within a group (e.g. concurrent expansion and contraction for different crops within an aggregated crop group). Further, the spatial mask used to filter out forest loss in managed plantations has been extended to more countries; we now use better (remote sensing-based) estimates of pasture extent in Brazil (the biggest driver of deforestation); and we divide the deforestation attributed to expanding pastures between beef and leather (see Pendrill et al., 2021a for details). Finally, the time series is extended to 2018. The results for this updated model (Pendrill et al., 2022), in terms of deforestation emissions embodied in Swedish final consumption in the period 2005–2018, are shown in Figure 3.

The updated results indicate that the share of deforestation emissions that is due to final food consumption (versus non-food sectors) is higher than previously estimated, between 65 and 80%. The deforestation emissions due to non-food final consumption has remained rather constant, fluctuating around 1 Mt CO_2 equivalents/yr throughout the time period, while the food-related consumption emissions show diverging trends. On the one hand, deforestation emissions due to consumption of Indonesian palm oil and Brazilian beef have increased steadily since 2011 (following a sharp decline early in the period due to the dramatic reduction in deforestation for expanding pastures in the Brazilian Amazon), reaching 0.9 Mt CO_2 equivalents in 2018. On the other hand, deforestation emissions due to the rest of food consumption have decreased significantly between 2012 and 2018, from 2.3 to 0.9 Mt CO_2 equivalents/yr. In particular, there have been dramatic reductions in the deforestation carbon emissions associated with consumption of beef from other Latin American countries, as well as vegetables, fruits and nuts from Africa. The reduction for these commodities in particular, and other food commodities in general, can only be partly explained by reduced deforestation for the commodities consumed (mainly the case for vegetables, fruits and nuts in Africa), but also reflect consumption changes (e.g. reduced consumption of Latin American beef and Asian oil seeds). Still, despite these reductions, total deforestation due to Swedish food consumption remains at just under 2 Mt CO_2 equivalents in 2018.

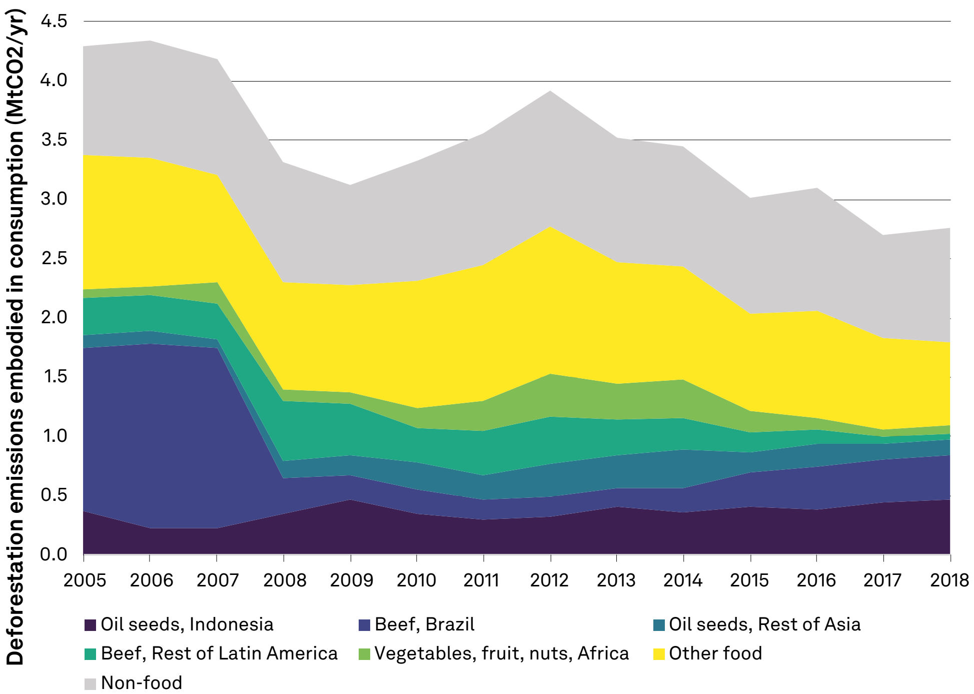


Figure 3: Greenhouse gas emissions from deforestation embodied in Swedish final consumption, in the period 2005–2018, as estimated by the deforestation attribution (Pendrill et al., 2021a) and EXIOBASE models. Emissions are divided between final consumption in food sectors and non-food sectors, following Cederberg et al. (2019).

4.4 Official statistics and limitations

In interpreting these results, it is important to understand a few key limitations of the deforestation attribution model – stemming both from underlying data uncertainties and model structure. Starting with the former, a recent review of the extent to which expanding agricultural land is causing forest loss (Pendrill et al., 2021b) gives cause for caution: there are large uncertainties in both the amount of deforestation across the tropics and the statistics on agricultural land expansion (especially for pastures), implying that we still have an incomplete understanding of the role of agriculture in driving deforestation across the tropics.

On model structure, because the attribution of deforestation is made using land-use statistics at (primarily) national level, it cannot distinguish between cases when a commodity is driving deforestation directly or indirectly; that is, where the commodity production in question is expanding on just cleared forest land, or when it is expanding on other land uses, pushing these into forests. Though for major forest risk commodities like palm oil and soybeans, in major deforestation frontiers, there is more ample evidence against which the model results have been validated and shown to give reasonable results (Pendrill, Persson, Godar, Kastner et al., 2019; Pendrill et al., 2021b).

Still, these model limitations imply that the results should be interpreted as a degree of deforestation risk associated with production, trade and environment. Another reason for this is the fact that the input-output model is also aggregated at national level, implying that we cannot distinguish trade in products sourced from agricultural frontier areas where deforestation is occurring, from those coming from established agricultural production areas. Though, it should be noted that this limitation holds for all estimates of consumption-based greenhouse gas emissions (or other environmental impacts), as the PRINCE model (and other MRIOs) are based on average emission intensities, and do not reflect within-country or within-industry variability in production practices.

Despite the data and model limitations, we argue that the estimates of deforestation emissions as estimated by the model presented here fulfil the criteria for official statistics, as outlined in Table 4. The relevance of this indicator is clearly evident from the ways in which the data have already been used by different actors for developing consumption-based accounting indicators informing key policy processes, primarily in the EU (see also Chapter 2), and the overall importance of deforestation in driving climate change and biodiversity loss. Accuracy is also judged be sufficient (it can be argued that this is a clear instance of where "it is better to be vaguely right than exactly wrong"; Read, 1898), as long as the limitations of the methodology and implications for interpretation of results are clearly communicated. There is also a commitment to periodically update the model, extending the time series, as new data on deforestation and agricultural statistics become available (annually for the former, typically with a lag of a few years for the latter), fulfilling the timeliness criteria.

There are also plans to develop the deforestation attribution model to reduce some of these limitations and improve accuracy, primarily by incorporating more detailed data on deforestation for different commodities where available (e.g. soy in Latin America; Song et al., 2021) and improving the spatial resolution by drawing upon subnational agricultural statistics for more countries than Brazil and Indonesia. This would have the additional benefit of facilitating the extension of the model to also assess the biodiversity impacts of deforestation (not only, as now, climate impacts). As noted previously, the spatial resolution of driver data is crucial for accurately assessing biodiversity impacts. As the forest-loss data underlying the deforestation attribution model already have high spatial resolution (roughly 30 metres, with global extent), the limitation is currently in the agricultural statistics (in particular for individual crops or commodities).

4.5 Policy implications

Estimates of the extent to which Swedish (and EU) consumption is driving deforestation and associated impacts on carbon storage and biodiversity in tropical forest landscapes are key for informing ongoing policy processes on how to reduce these impacts. As noted above, key actors are already using the data from PRINCE 1 in this way. For Sweden, the deforestation emissions data could be incorporated in the official statistics for consumption-based greenhouse gas emissions. This could help inform policy to reduce these emissions, especially if Sweden adopts a target for consumption-based greenhouse gas emissions, as is currently discussed.

5. Gap analysis: Chemicals – use of hazardous chemical products, pesticides and veterinary antibiotics

KEY MESSAGES

- Sweden's consumption-based use of veterinary antibiotics decreased by almost 50% between 2008 and 2019.
- Sweden's consumption-based use of pesticides stayed relatively unchanged between 2008 and 2019.
- Imported products are responsible for a large majority of Sweden's consumption-based use of pesticides and veterinary antibiotics.
- Experimental time series developed for veterinary antibiotics and pesticides support the publication of official statistics.
- Further methodological developments are required before an indicator on Sweden's consumption-based use of hazardous chemical products can be made into official statistics.

5.1 Introduction

It is estimated that contemporary societies make use of over 350 000 different chemicals (Wang et al., 2020). Pollution and exposure arising from poor management for these chemicals can lead to negative impacts on human health, ecosystems and economies (Diamond et al., 2015; Persson et al., 2022; Pruss-Ustun et al., 2011, 2016; Walker et al., 2012). Targets and policies exist at a number of levels aiming to address these issues. At a global level, the United Nations Environment Programme initiated the Strategic Approach to International Chemicals Management in 2006 and are currently developing a post-2020 agenda. Chemicals are addressed in many separate goals related to Agenda 2030 (see United Nations, 2015), in particular Goal 12 on Sustainable Consumption and Production, Goal 3 on Good Health and Well-being, Goal 6 on Clean Water and Sanitation, Goal 11 on Sustainable Cities and Communities and Goal 14 on Life Below Water.

In 2020 the European Commission (2020b) launched the chemicals strategy for sustainability, which includes, among its broad aims, to "better protect citizens and the environment and boost innovation for safe and sustainable chemicals". Among specific actions it also aims to establish key performance indicators to measure the effectiveness of policies in the area. On a national level, “a non-toxic environment” is one of Sweden’s 16 environmental quality objectives and aims for an environment where traces of artificial chemicals are close to zero, with a negligible effect on humans and ecosystems. The generational goal also states that “human health is exposed to minimal environmental impacts” and that “resource cycles are efficient and as far as possible free from hazardous substances”.

In agriculture, the European Directive on the sustainable use of pesticides has been in place since 2009 (European Commission, 2009), and aims broadly to reduce the risk of pesticides use and their impacts on human health and the environment. The European Commission has also developed a harmonized approach to report the use of antimicrobial medicines in agricultural animals (European Medicines Agency, 2018).

5.2 Method

In light of the policy initiatives mentioned above, the first PRINCE project developed a method to produce data on use of hazardous chemical products (HCPs), use of pesticides (including breakdowns for pesticide groups – herbicides, insecticides and fungicides), use of veterinary antibiotics arising due to Swedish consumption, emissions of some hazardous substances and potential impacts of these emissions. Steinbach et al. (2018), Persson et al. (2019) and Cederberg et al. (2019) report results for these data for a single reference year. The purpose of the chemicals work in PRINCE 2 is to produce time series for some of these indicators.

Compared to PRINCE 1, one methodological change has been made which has an influence on the country the use of the chemical is allocated to, but not the total amount. In PRINCE 1, the chemical use was allocated to the country where the chemical product was used, whereas in PRINCE 2 the chemical use is allocated to the country which Sweden is importing from.

The procedure used to produce time series for each indicator *from a production perspective* is outlined below. From these input data, the PRINCE model is applied to produce data for each indicator from a consumption perspective.

5.2.1 Veterinary antibiotics

The European Medicines Agency (EMA) has been collecting and publishing data on sales of veterinary antibiotics in European countries for a time series running from 2010 through 2018 at the time of writing (European Medicines Agency, 2018). Data availability has steadily grown throughout the time series, with data for 20 countries in 2010 and for 30 countries in 2018. These data are the starting point for calculating global veterinary antibiotic use as a new input to the PRINCE model along with EXIOBASE economic data as described below. Firstly, complete time series for veterinary antibiotic usage for countries reporting to the EMA as above were calculated. For countries with incomplete time series in the original EMA data, extrapolations backwards and forwards in time are used. Since it was noted that veterinary antibiotic use is decreasing markedly for most countries reporting data, extrapolations were made using data on monetary production for relevant animal product groups in EXIOBASE and the change in veterinary antibiotic use per unit monetary production between the closest two years for which data were available.

The average intensity of veterinary antibiotic usage in reporting countries for a given year is used as a proxy to calculate veterinary antibiotic usage in non-reporting countries in conjunction with monetary data for production of animal products in EXIOBASE for non-reporting countries. Veterinary antibiotic use for each EXIOBASE country/region was then assigned to six animal products in EXIOBASE in proportion with the monetary production for each product.

5.2.2 Pesticides

The original input data for calculating global pesticide use as input to the PRINCE model are taken from the FAO.[17] The data have a global coverage with over 160 countries. There are also separate data sources for total pesticide use and for subcategories within this – insecticides, herbicides and fungicides. These were used to establish separate time series in PRINCE 2 for total pesticide use and each of the subcategories mentioned.

EXIOBASE requires data input for five rest of world regions (rest of world Africa, rest of world Asia and Pacific, rest of world America, rest of world Middle East and rest of world Europe) which are not exactly aligned with the geographical classifications in the FAO source data. To produce data on pesticide use aligned with these EXIOBASE regions, firstly, the average intensity of pesticide use per unit productive land area for representative countries in each EXIOBASE region was calculated from FAO data. These intensities were then multiplied with data on productive land area in EXIOBASE to derive pesticide use for each region.

As noted in the first PRINCE project, FAO pesticide use data for China have been over-reported. As in the single year calculations in PRINCE 1 this was resolved by making the assumption that Chinese FAOSTAT data are reported as *total use* rather than total use of *active substance* and an appropriate correction factor applied. In the case of data on Germany's use of insecticides, a time series break in FAO data was noted. In light of this, data used for Germany's use of insecticides were taken from Eurostat's data instead. Pesticide use for each EXIOBASE country/region was then assigned to the eight crop-producing sectors in EXIOBASE in proportion with the monetary production for each product.

5.2.3 Use of hazardous chemical products

In PRINCE 2, this work has focused on the use of HCPs *excluding petroleum-based fuels*. Statistics Sweden's environmental accounts group produces statistics about HCP use by industrial sector (with a production perspective) based on the registry maintained by the Swedish Chemicals Inspectorate (Statistics Sweden, 2021a).

The unit cost of HCPs purchased (in SEK/ton) for Swedish producing industries was calculated from these data in combination with monetary data on purchases of HCPs by producing industries from Statistics Sweden's input-output tables. Assuming that the intensity of HCP use in other countries and regions is the same as in Sweden, the HCP use in producing industries in countries and regions outside Sweden can be calculated from Swedish unit costs and data on HCP purchases globally from the EXIOBASE global input-output tables.

[17] FAOSTAT: https://www.fao.org/faostat/en/#data/RP

In the course of producing the time series for HCP, reporting errors were noted in the source data for HCP use by industrial sector for Sweden in C19 – refined petroleum products. Corrected data were not made available in a timeframe to be included in the calculations for this report. It was judged that this error did not significantly affect the overall magnitude and trend for the years 2008 and 2013 to 2019. However, it was also noted that for the years 2010–2012 this error did in particular affect the development of the time series. In light of these considerations, we present results only for the continuous time series from 2013 through 2019.

5.3 Results

5.3.1 Veterinary antibiotics

As shown in Figure 4 in 2008, Sweden's consumption-based veterinary antibiotic use was 120 tonnes. By 2019, this had decreased by 47% to 63 tons. Of the total calculated, the veterinary antibiotic use in Swedish production amounts to between 7 and 10% of the total consumption-based veterinary antibiotic use. This is due to very low veterinary antibiotic use in Swedish agriculture compared to all other nations and in spite of the fact that meat and dairy products produced in Sweden account for a majority of those consumed in Sweden (Jirskog, 2021; Jordbruksverket, 2021). Other countries in the EU27+[18] group account for almost 70% of Sweden's total consumption-based veterinary antibiotic use, due to meat and dairy imports from these countries (Jordbruksverket, 2020). This is a methodologically interesting observation, since the time series has been produced using data sources based on reporting by European countries.

The decrease in Sweden's consumption-based veterinary antibiotic use is largely due to decreases in veterinary antibiotic use in all countries reporting to the EMA. Other contributing factors may be that meat consumption in physical terms in Sweden has decreased by over 10% since 2016 (Jordbruksverket, 2021) and that the proportion of Swedish products supplying Swedish demand has been increasing over the past few years (Jordbruksverket, 2021).

Figure 4 shows that Spain is the largest single exporting country responsible for Sweden's consumption-based veterinary antibiotic use for many years in the time series. It is also noted that the increase in veterinary antibiotics from Spain between 2013 and 2017 arises at the same time as the EMA notes a change in Spain's reporting methods.

[18] EU27+ comprises the EU27 plus Switzerland, Norway, Iceland and the United Kingdom of Great Britain and Northern Ireland.

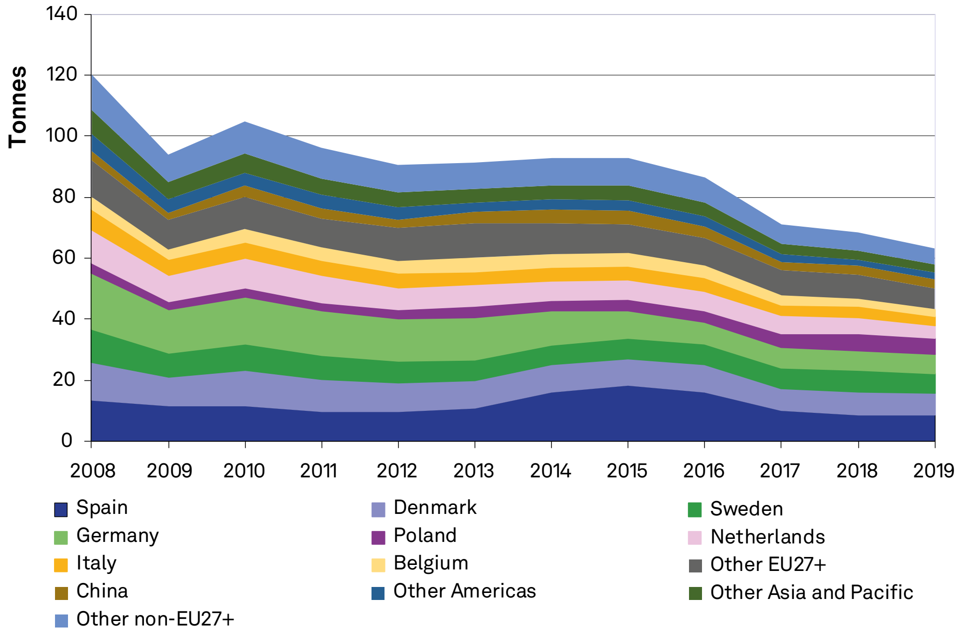


Figure 4: Consumption-based veterinary antibiotic use for Sweden in tonnes of active substance.

Results in Figure 5 show that Sweden's consumption of food products (CPA [Classification of Products by Activity] C10–12) and agricultural products (CPA A01) together account for between 55 and 65% of the total veterinary antibiotic use arising due to Swedish final demand. Major contributors in the category "other products" include food and beverage serving services (CPA I56, i.e. restaurants and cafés) with between 6 and 10% of the total; public services (such as health, education and social work) with between 8 and 10% of the total, and textiles, apparel and leather products (CPA 13–15) with up to 5% of the total.

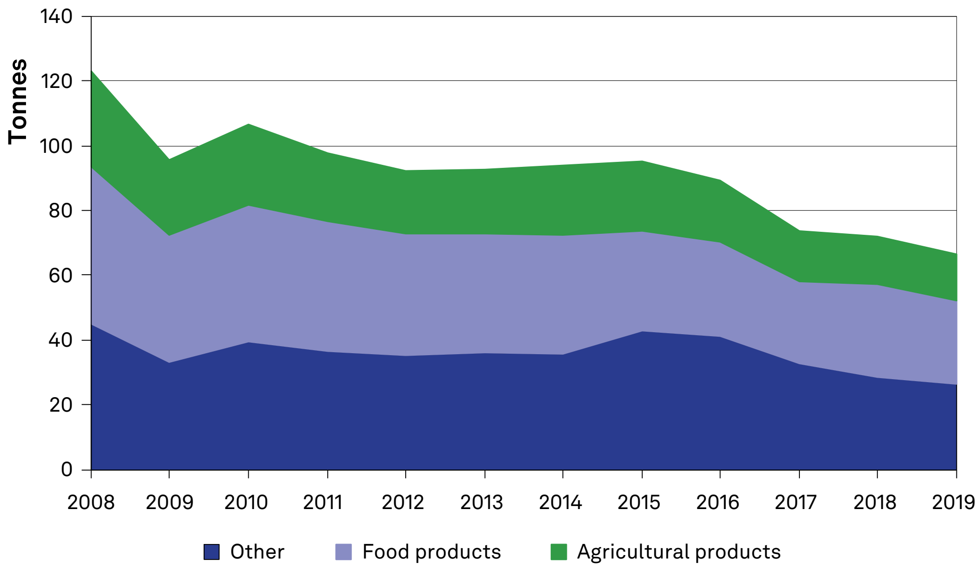


Figure 5: Veterinary antibiotic use in tonnes of active substance due to Swedish consumption by type of product.

5.3.2 Pesticides

Figure 6 shows that Sweden's consumption-based total pesticide use has decreased slightly from over 6000 tonnes of active ingredient in 2008 to about 5400 tonnes in 2019. Pesticide use in Sweden is consistently the largest single contributor in the time series shown, though it only contributes 28% of the total at most (in 2008). By 2019, pesticide use in Sweden contributes only 19% to the total. In 2008, countries in the rest of the EU27+ group contribute 43% of the total pesticide use. It is noted that the decrease in pesticide use arising in Swedish production shown in Figure 6 of 38% mirrors the overall decrease in pesticide use in Swedish production in the input data used suggesting that this has arisen as a result of measures in production rather than changes in consumption. By 2019, the EU27+ group contributed over 50% to the total shown i Figure 6. Considering pesticide use from the perspective of producing countries shown in Figure 6, a small absolute increase arises in the EU27+ group between the start and the end of the time series. Considering member states more specifically, the figure shows that for Swedish consumption-based pesticide use in products exported from Denmark decreases by about 50% between 2008 and 2019. This decrease also mirrors decreases in pesticide use in overall Danish production as given in the input data for this work, also noting that the absolute quantity of Swedish imports of agricultural and food products from Denmark over the time period of the study reduces only modestly. On the other hand, pesticide use in products from Spain increases by 88% between 2008 and 2019. These large increases arise at the same time as increases in Sweden's import of agricultural and food products from Spain and increases in pesticide use in Spanish production. Pesticide use for products from the Netherlands increases from 2008 to reach a maximum of 662 tons of active ingredients by 2016, only to decrease again to slightly above the 2008 level by 2019.

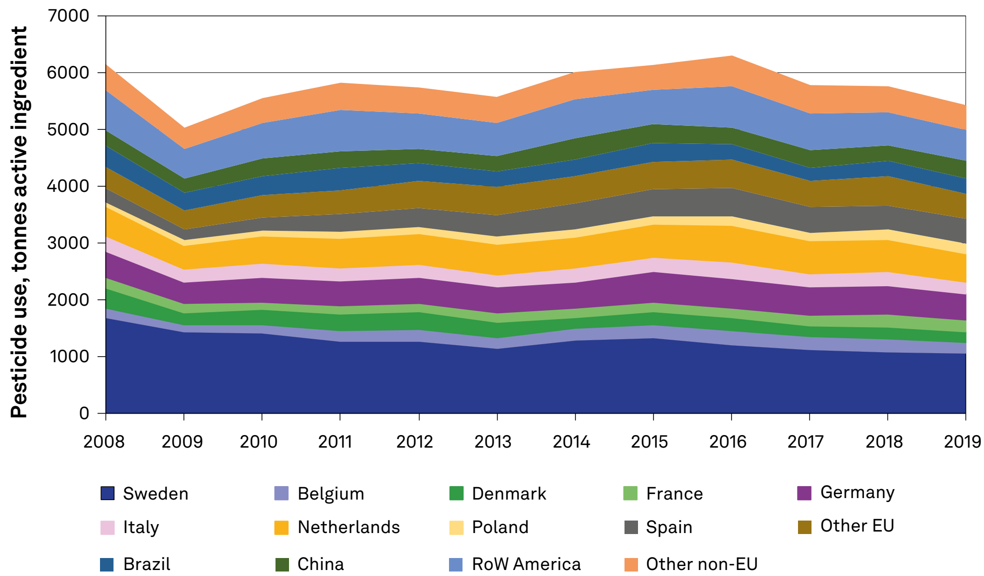


Figure 6: Sweden's consumption-based pesticide use, tonnes of active substance.

Products exported from regions outside the EU27+ group contribute around 30% of Sweden's total consumption-based use consistently throughout the time series. Sweden's consumption-based pesticide use that occurs in producing countries outside the EU decreased by 13% between 2008 and 2019. As shown in the figure this decrease mainly occurs in Brazil and the Rest of World America region.

Figure 7 shows Sweden's consumption-based total pesticide use by country of use and different product groupings. Noting that Figure 8(c) shows that the pesticide use from other products covers 47 product groups, it is clear that the consumption of food products and agricultural products together dominate consumption that is connected to pesticide use. Among the 47 product groups in the other products category, the largest single product group category is accommodation and food services (I55–56), contributing between 5 and 8% of the total pesticide use. The public sector products public administration (O84), education (P85), and health care and social services (Q86–88) together contribute between 6 and 9% of the total pesticide use arising.

Figure 7 also shows notable changes in Sweden's total consumption-based pesticide use for "other products" and "agricultural products" between 2014 and 2015. These differences arise at the same point in the time series where changes in the methods to produce Sweden's input-output tables arise and are therefore treated with caution. Either side of this time series break in economic input data, Figure 7(a) shows a decreasing trend for pesticide use from agricultural products and a relatively constant trend for food products (Figure 7(b)). Ignoring the large increase in pesticide use due to other products between 2014 and 2015 (Figure 7(c)), pesticide use is relatively changeable but about 10% lower in 2019 than in 2008.

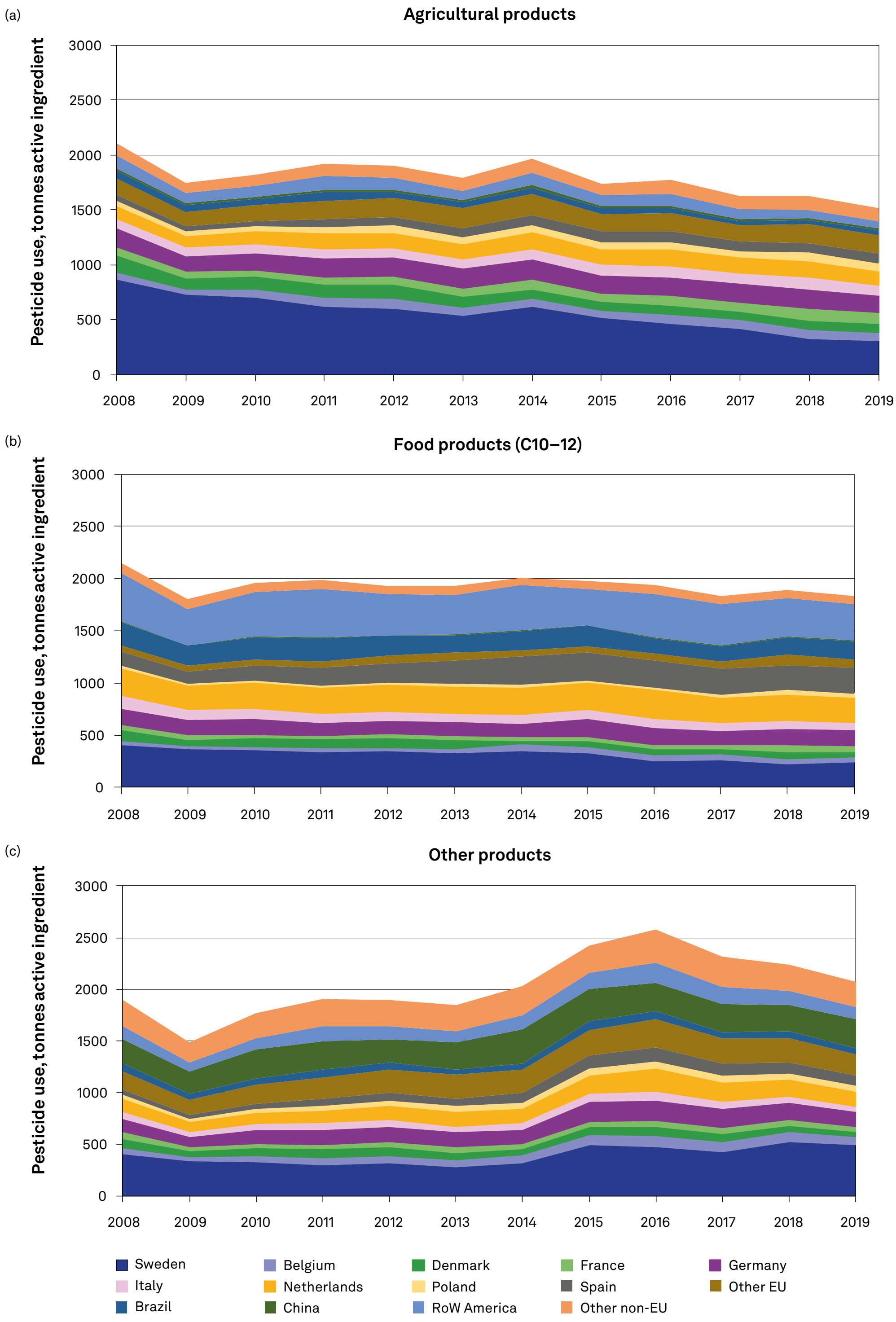


Figure 7: Sweden's consumption-based pesticide use in (a) agricultural products (A01), (b) food products (C10–12) and (c) all other products (47 product groups in total).[19]

[19] In comparing the time series it should be noted that the official Swedish input output tables from Statistics Sweden's national accounts group have been revised according to a general review for the years 2015 and onward. The tables for 2014 and earlier years have not been reviewed. This has been reported in Statistics Sweden's official statistics on environmental pressures with a consumption perspective. The large increase shown for pesticide use arising from other products (Figure 7(c)) between 2014 and 2015 should therefore be judged with caution.

Figure 8 shows Sweden's consumption-based herbicide, fungicide and insecticide use by producing country. The figure shows the variation in the trends between the different pesticide types and also the variation in countries. Sweden is the largest single producer country for consumption-based use of herbicides, and the decrease in herbicide use due to Swedish consumption between 2008 and 2019 is largely due to reductions of use in Swedish production. A large proportion of the total increase in Sweden's consumption-based fungicide use between 2008 and 2019 is due to the increase coming from Spanish production. Germany is the largest single producer country for Sweden's consumption-based insecticide use, and insecticide use attributed to Germany has increased between 2008 and 2019.

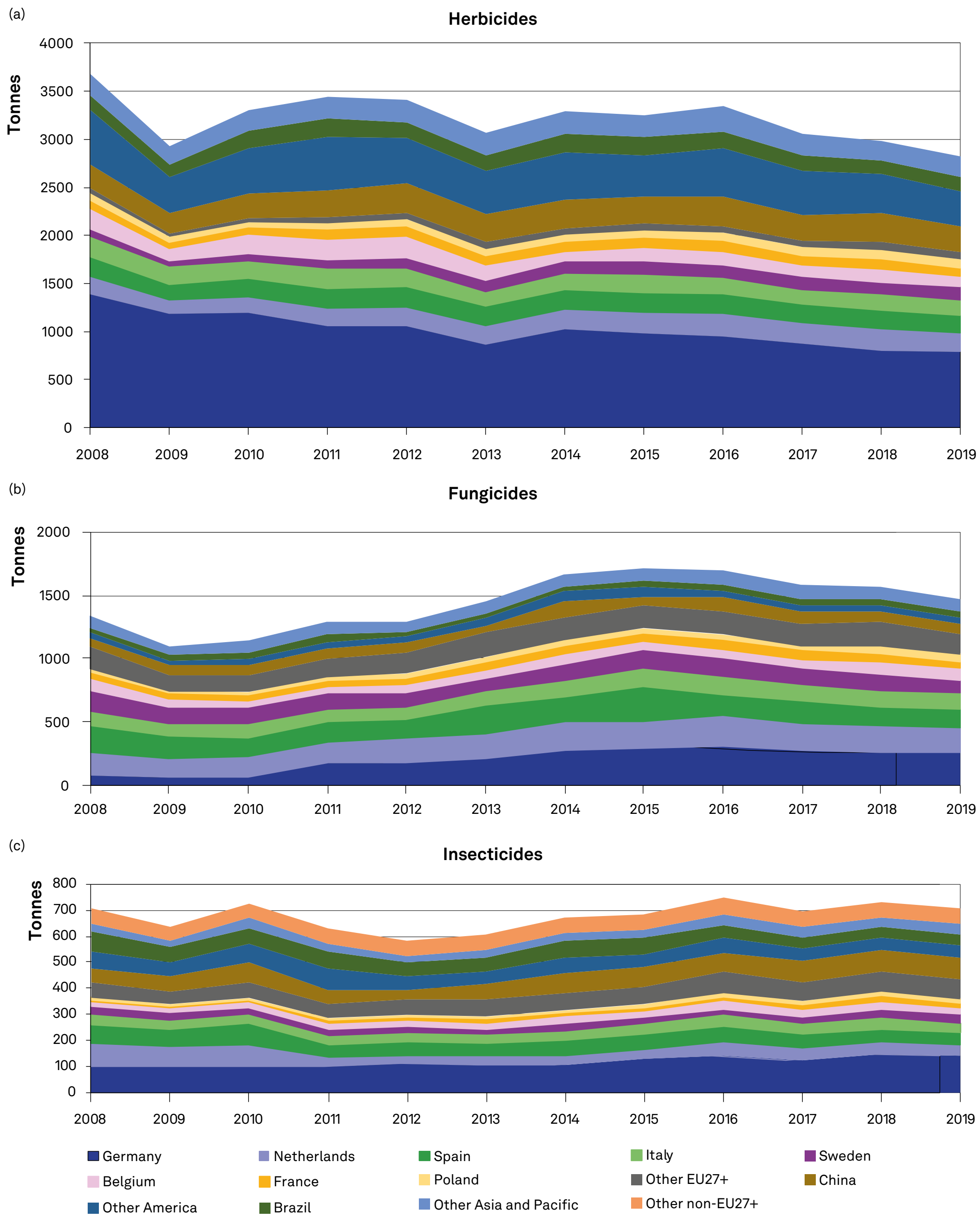


Figure 8: Time series for Sweden's consumption-based use of (a) herbicide, (b) fungicide and (c) insecticide.

5.3.3 Use of hazardous chemical products

Figure 9 shows that Sweden's consumption-based use of HCPs has increased by over 50% from 8.0 million tons in 2013 to 12.5 million tons in 2019. The large increase shown between 2014 and 2015 coincides with a large increase in use of HCPs in production in C23 non-metallic minerals (including cement). The period 2014–2015 also coincides with the time series break in the official Swedish input-output tables arising from the general review of the national accounts. This increase should therefore be considered with caution.

The figure also shows that Sweden is the largest single producing country for its own consumption-based use of HCPs, contributing 35% or more of the total use depending on the year. Other producing countries in the EU27+ group contribute consistently 44% or more of Sweden's consumption-based use of HCPs over the time series. Among producing countries outside the EU27+ group, China contributes the most with almost 10%.

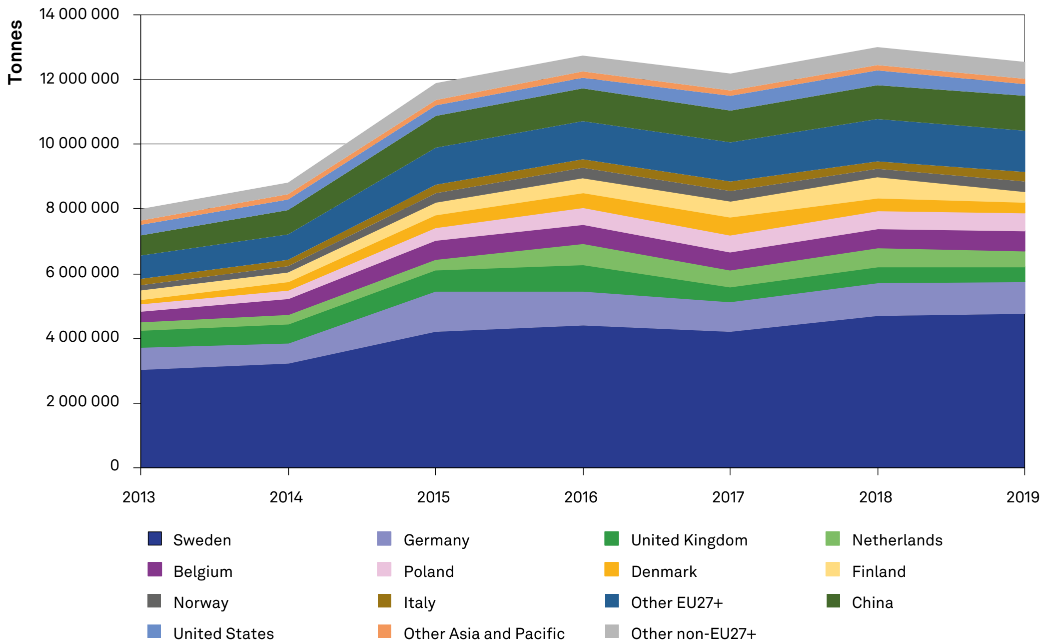


Figure 9: Time series for Sweden's consumption-based use of hazardous chemical products.

Figure 10 shows that construction products (that is buildings and infrastructure) are the single largest consumed product group for use of HCPs, followed by retail, real estate and chemicals and pharmaceuticals. All have increased their chemical use between 2013 and 2019.

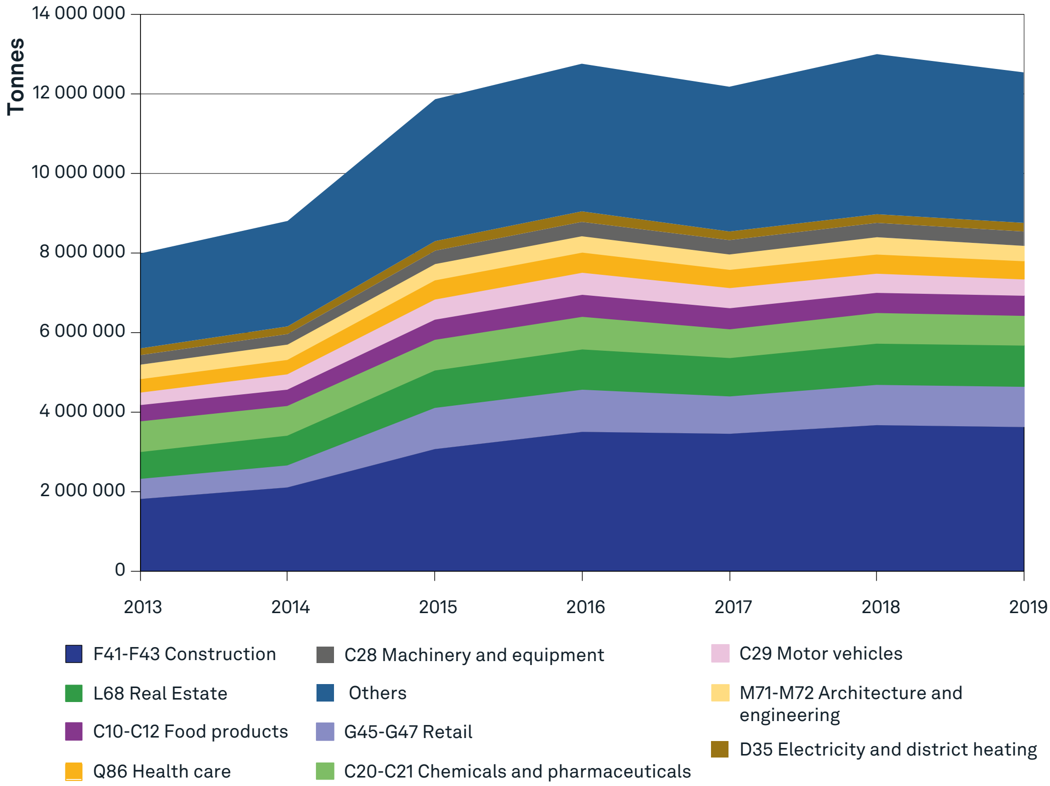


Figure 10: Sweden's consumption-based use of hazardous chemical products by consumed product.

5.4 Discussion

5.4.1 Limitations

The experimental time series production performed in PRINCE 2 has provided a further understanding of the possibilities and potential limitations of producing consumption-based statistics for Sweden in these areas.

For example, a time series break arose between 2014 and 2015 because the general review of Statistics Sweden's National Accounts was applied to all reference years for 2015 and after but not before. Another time series break can be noted in ESVAC documentation for reporting of veterinary antibiotics from certain countries (European Medicines Agency, 2018).

Also, geographical extrapolations have been necessary. For HCP, extrapolation to global HCP use has been made from physical HCP use data for Sweden, which is a small sample population. This was done in light of the lack of sufficiently detailed input data for countries and regions outside Sweden. Eurostat publishes a time series for production-based HCP use in the EU27 (not for separate countries).[20] These data were not used as source data in this work due to a lack of sufficient geographical and sector-wise detail. Since these data are production-based, they are not directly comparable to the final consumption-based results for this work. However, these data can be interesting to validate the extrapolation applied here from the Swedish data to the rest of the EU27. A comparison between Eurostat's production-based HCP use in the EU27 and the equivalent data extrapolated in this work shows that this work overestimates production-based HCP use in the EU27 by up to a factor of two. Trend-wise, the extrapolation for production-based HCP use in the EU27 in this work shows an increase of over 70% between 2013 and 2018 compared to a near-negligible increase of 3% over the same time period according to Eurostat's data. The result of this comparison limits the scope of the conclusions that can be drawn from the results as shown in Figure 9 and Figure 10. Methodological improvements may be applied to improve the accuracy of the extrapolation that incorporate the Eurostat data. The scope of the conclusions for Sweden's consumption-based HCP use are also limited by the previously noted discrepancies in the input data for C19 – refined petroleum products.

For veterinary antibiotic use, it was necessary to extrapolate from the available input data from ESVAC to countries and regions for which data were not available to provide input to the PRINCE model for consumption-based veterinary antibiotic use. Comparison with single-year, production-based estimates of veterinary antibiotic use in Tiseo et al. (2020) suggests that the work here underestimates the use of antibiotics in China and Brazil. The effect of this potential underestimation on the results in Figure 4 and Figure 5 is that they show a slightly lower total consumption-based use than would have been the case if production-based values for China and Brazil had been closer to values reported in Tiseo et al. (2020). However, the order of magnitude, overall trend and breakdown between import and domestic production is not significantly changed. Going forward, there is good potential to improve the methodology here to produce input data for the model, for example

[20] Eurostat – Data Explorer (europa.eu): https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_chmhaz&lang=en

by including the results from Tiseo et al. (2020) in the extrapolation procedures. A further improvement possibility is to consider physical data such as live weight of production animals and the intensity of production when making allocations and extrapolations for veterinary antibiotic use.

The FAO datasets used for pesticides provide global coverage in input data and a geographical extrapolation procedure was not necessary. A reclassification of sorts was required to adjust the geographical coverage of the FAO input data to the five EXIOBASE “rest of world” regions, and methodological improvement could be applied here by considering more countries from the FAO input data when making this adjustment. A further potential methodological improvement could be to consider physical source data for making product-level classification from the single-value per country input data rather than economic. The method used here does not consider the relative risk arising from the pesticides used (only the quantity of active ingredient), which is a feature of the harmonized risk indicators used in the European Commission’s Directive on the sustainable use of pesticides. This offers further potential for methodological development to answer policy needs.

5.4.2 Official statistics

For veterinary antibiotic use and pesticides, this gap analysis has shown that the methods used to assess consumption-based environmental indicators in PRINCE 1 can be applied to produce time series with highly relevant information for policy-makers. For consumption-based HCP use the gap analysis has shown that it is possible to produce a coherent time series. However, the analysis also showed uncertainties in the input data and the geographical extrapolation that need to be better understood to improve the potential for policy support.

It is clear from ongoing policy processes, for example related to follow up of Agenda 2030 targets and Sweden’s environmental quality objectives, that there is a user need for the kinds of macroscopic indicators monitoring chemicals generally. Thus, all of the indicators considered in this gap analysis satisfy the relevance dimension of statistical quality.

One key outcome of the first PRINCE project with respect to the indicators covered here is that the source data used should meet the following criteria:

- be produced and regularly updated institutionally
- be freely available online
- have the potential to be classified by producing industry.

These requirements are met for the time series for all of the indicators considered in this gap analysis. In light of this, the resulting time series shown in the previous sections, and the scientific and statistical foundations of the PRINCE model, the indicators for veterinary antibiotics and pesticides broadly satisfy the quality dimensions for official statistics accuracy, comparability and timeliness. However, for consumption-based HCP use the uncertainties noted in input data and the extrapolation procedure require further investigation in order to satisfy in particular the accuracy requirement for official statistics.

5.4.3 Next steps

A key next step for the production of official statistics in the areas of pesticides and veterinary antibiotics based on the experimental series developed here is to provide sufficient financial resources to Statistics Sweden's environmental accounts to ensure the production and maintenance of the time series according to the necessary quality requirements.

In these areas a dialogue with policy-makers and other stakeholders should be initiated with a view to methodological developments to further increase policy relevance for these indicators. For veterinary antibiotics this could include time series for different animal species and different types of antibiotic. For pesticides this includes developing indicators for relative risk relating to the harmonized risk indicators reported in conjunction with the EU Directive on the sustainable use of pesticides.[21]

For the consumption-based use of HCPs the first step is to investigate and mitigate the noted uncertainties in input data and the extrapolation procedure applied. This can be achieved with a detailed analysis of the method Eurostat uses to produce time series for production-based HCP use compared with Statistics Sweden's data on HCP use from a production perspective. A focus here is on methodological improvement to include the Eurostat in an improved extrapolation procedure.

In PRINCE 2, the focus has been on the *use* of chemicals, and the drivers of environmental problems (see also Persson et al., 2019). In the previous PRINCE project indicators for emissions and potential impacts of emissions of hazardous chemicals were proposed. It was also suggested that the different types of indicators would complement each other since they provided different results. These indicators should also be further developed: however, this requires work on developing the necessary data which are not readily available.

[21] Harmonized risk indicators: https://ec.europa.eu/food/plants/pesticides/sustainable-use-pesticides/harmonised-risk-indicators_sv

6. Gap analysis: Fisheries extensions

Key messages

- Fisheries are under-represented in studies which consider consumption-based impacts, yet they are an essential nutritional and economic resource, and important to the delivery of the Sustainable Development Goals.
- Opportunities exist to explore the contribution to consumption of production from both capture and aquaculture sources, and their associated impacts.
- For marine capture fisheries, highly resolved data on capture methods and discards (both of which are important components of sustainability) can be linked to international landings records to provide a powerful environmental extension.
- The potential exists for similar extensions linked to aquaculture, particularly for impacts associated with eutrophication, though more work is needed to compile suitable global data for this purpose.
- To provide an extension suitable for national statistics, additional work is required to further harmonize and validate data inputs and model results. Exploration of additional sustainability-linked concerns – such as fisheries stock status and more detailed greenhouse gas accounts for fisheries – would also be beneficial.

6.1 Importance and wider policy context

According to the FAO's *The State of World Fisheries and Aquaculture 2020* report (FAO, 2020a), between 1990 and 2018, there was a 14% increase in global capture fisheries production (from 84 to 96 million tons), and a 527% increase in global aquaculture production (from 13 to 82 million tons). While in 1990, 90% of fish stocks were estimated to be within biologically sustainable levels, by 2017 this had dropped to 66%. The Sustainable Development Goal 14, "Life Below Water" focuses on the conservation and sustainable use of the oceans, seas and marine resources, with the Convention on Biological Diversity (2016) also highlighting their important role in food security and livelihoods. WWF's *Living Planet Report 2020* (Almond et al., 2020) highlights the importance of capture fisheries and aquaculture in driving biodiversity loss. Yet fisheries have received limited attention in consumption-based accounting studies in comparison with terrestrial impacts.

Even with the rise of aquaculture, capture fisheries remain an important global industry and it is therefore important to improve consumption-based accounting to help analyse their impacts. These impacts depend on specific variables such as the life history characteristics of the species caught (e.g. its reproductive or growth rates), the region in which it is caught and method of catch. Catch methods are particularly important given their potential role in habitat destruction, and their relationship to the wasted portion of capture fisheries production: discards. Highly aggregated analyses (such as material footprint accounts, which collate fisheries products with other material dependencies) overlook these aspects and their potential impacts. Within the first PRINCE project an initial analysis was undertaken, expanding the understanding of capture fisheries dependencies in Swedish consumption (see summary below).

Swedish capture fishery policy and management is positioned under the Common Fisheries Policy of the EU, which has a primary aim of ensuring exploitation of living aquatic resources that provides sustainable economic, environmental and social conditions. For domestic policy in Sweden, this will of course relate primarily to the sustainability of its own fishery fleet. But capture fisheries linked to Swedish consumption may be international in nature: fleets may operate in distant waters, fisheries products are commonly imported, and production may be embedded in wider systems (e.g. used as inputs for aquaculture or animal feed).

In this new gap analysis, we build upon PRINCE's earlier work by (a) for marine capture fisheries, implementing more robust and detailed information on catch methods (fishing gear type) and associated discard rates to improve our understanding of the potential impacts of production linked to consumption; and (b) expanding coverage of aquaculture production linked to consumption, along with the scoping of opportunities for further expansion to cover aquaculture's potential environmental impacts. We finish by discussing opportunities for further work and the suitability of this type of information for national statistics.

In PRINCE 1, we prepared a dedicated consumption-based time series for capture fisheries. This entailed the use of publicly accessible datasets which were compiled to form a number of extensions to the EXIOBASE model. FAO FishStat (FAO, 2020b) was used to provide species-specific annual catch quantities and data on the location of catch (by FAO fishing area). FishBase (Froese & Pauly, 2021), a repository of species-level information, was used to link additional catch data; specifically, the main global catching method used and a "vulnerability score" associated with species life-history characteristics. In addition, an estimate of the discards (unused material extraction) associated with fishing activity was included to account for the high mortality rate of fish which are caught but returned to the sea. Global discard rates, based on data compiled by FAO, were used for the taxonomic orders linked to shrimp and tuna, and a separate rate was used for all other fish species. A case study was published with Swedish-specific results, with an academic paper available describing the methods and containing global analyses (West et al., 2019).

6.2 Marine capture fisheries improvements in PRINCE 2

6.2.1 Objectives of investigation in PRINCE 2

In this gap analysis, we explore opportunities for strengthening our prior fisheries extensions via the incorporation of additional information linked to capture production and its sustainability. In PRINCE 1, our analysis of two important components of this sustainability was lacking: for catch methods, we simply adopted a globally generic estimate of the main catch method from FishBase, which does not reflect the diversity in methods used for each species internationally; for discards, we also utilized coarse (global-level) estimates of discards to understand the potential for consumption to be linked to this unexploited and materially wasteful portion of capture.

6.2.2 Methods

The starting point for the development of fisheries extensions in PRINCE 2 remains FAO FishStatJ (FSJ) production data. These provide the mass of capture (and aquaculture production; see Section 6.3) that can be linked to the EXIOBASE3 MRIO. Importantly, the integration of fisheries production information into an MRIO structure thus includes fisheries products for human consumption, for use in feed materials (including fish products used in turn for aquaculture) and in any other non-food uses. "Consumption" as expressed in indicative results from the gap analysis presented below does not attempt to break down these uses (but see Section 6.4.2). Our work in PRINCE 2 has sought to extend this mass information, provided at species or species-group classification, to ascertain the catch methods utilized and associated discards with more specificity than achieved in PRINCE 1. Specifically, we provide species- and regionally refined estimates of catch methods and associated discards. This provides a significant improvement in the robustness of the link between captured mass estimates and these important components of fisheries sustainability.

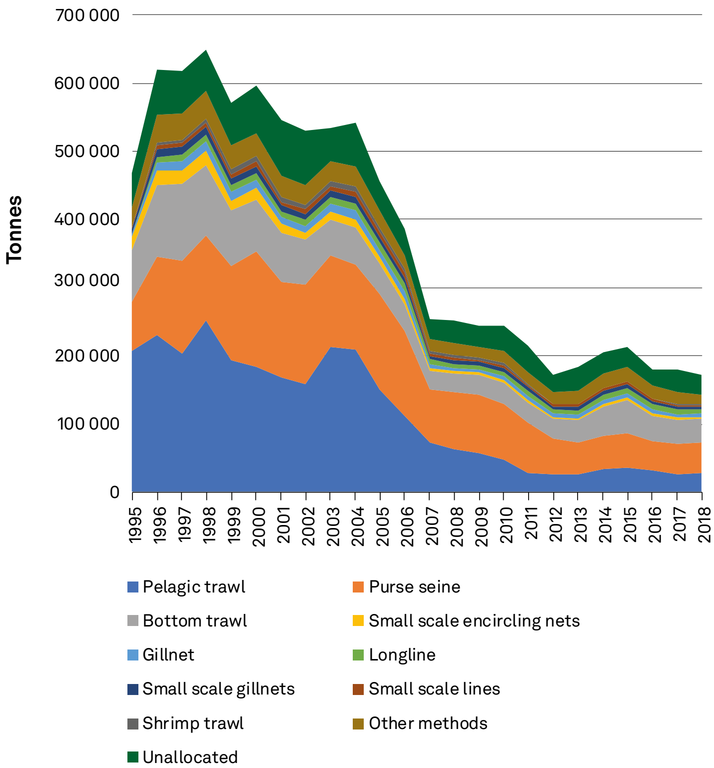
To achieve this, we utilize the database provided by Sea Around Us (SAU; Pauly et al., 2020; Pauly & Zeller, 2015), a research initiative at The University of British Columbia, that assesses the impact of fisheries on the marine ecosystems of the world. Specifically, the Sea Around Us catch reconstruction database comprises national (for all maritime countries and territories of the world) capture fisheries catch by year (1950–2018), including fishing country, taxon name, fishing sector (industrial, artisanal, subsistence and recreational), catch type (landed vs. discarded), reporting status (officially reported vs. unreported), input data source and spatial location of catch such as Exclusive Economic Zone and FAO fishing area. This information is matched to the fisheries statistics from FSJ to compile the environmental extensions which are then linked to the EXIOBASE3 model (production records are assigned to the appropriate country or region within the "Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)" sector). Extension sheets were prepared for each year between 1995 and 2018 to provide consumption-based results.

Additional description of the methods adopted to integrate the statistics is provided in Appendix 4.

6.2.3 Illustrative results

Figure 11 shows the Swedish consumption footprint (landings) of marine fish between 1995 and 2018 for those captures which have been successfully matched to the Sea Around Us fishing gear types, plus the unallocated portion of the catch. This indicates the importance of three primary fishing methods to the captures linked to Sweden: pelagic trawl, purse seine and bottom trawl. The relative role of pelagic trawl appears to have declined over the period, purse seines have become relatively more important, with bottom trawling declining in relative terms and then rebounding.

(a)



(b)

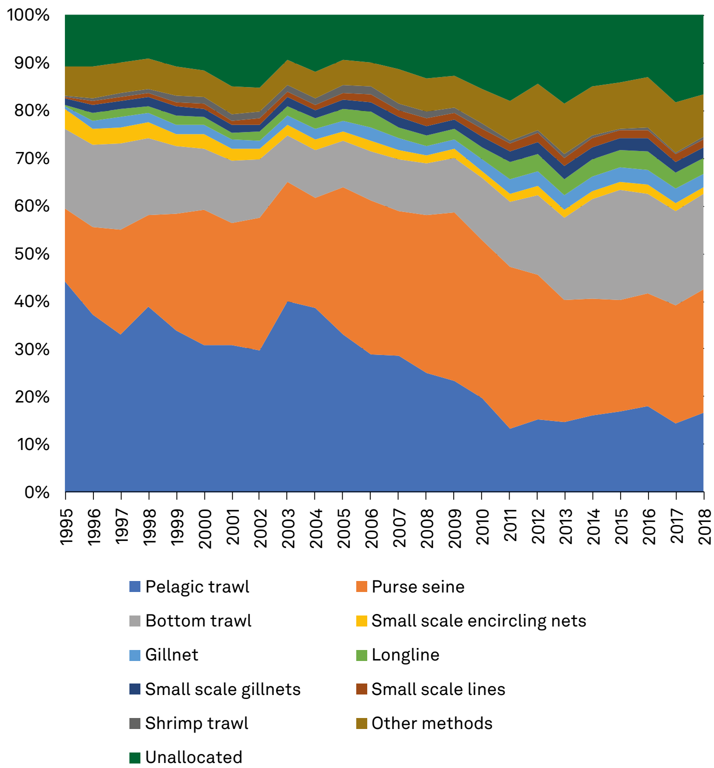


Figure 11: Gear type associated with marine fisheries capture embedded in Swedish consumption. Hatched area represented catch unallocated to gear type. (a) absolute values; (b) relative values.

Figure 12 shows the species comprising captures. The relative importance of European sprat to the consumption footprint has clearly decreased.

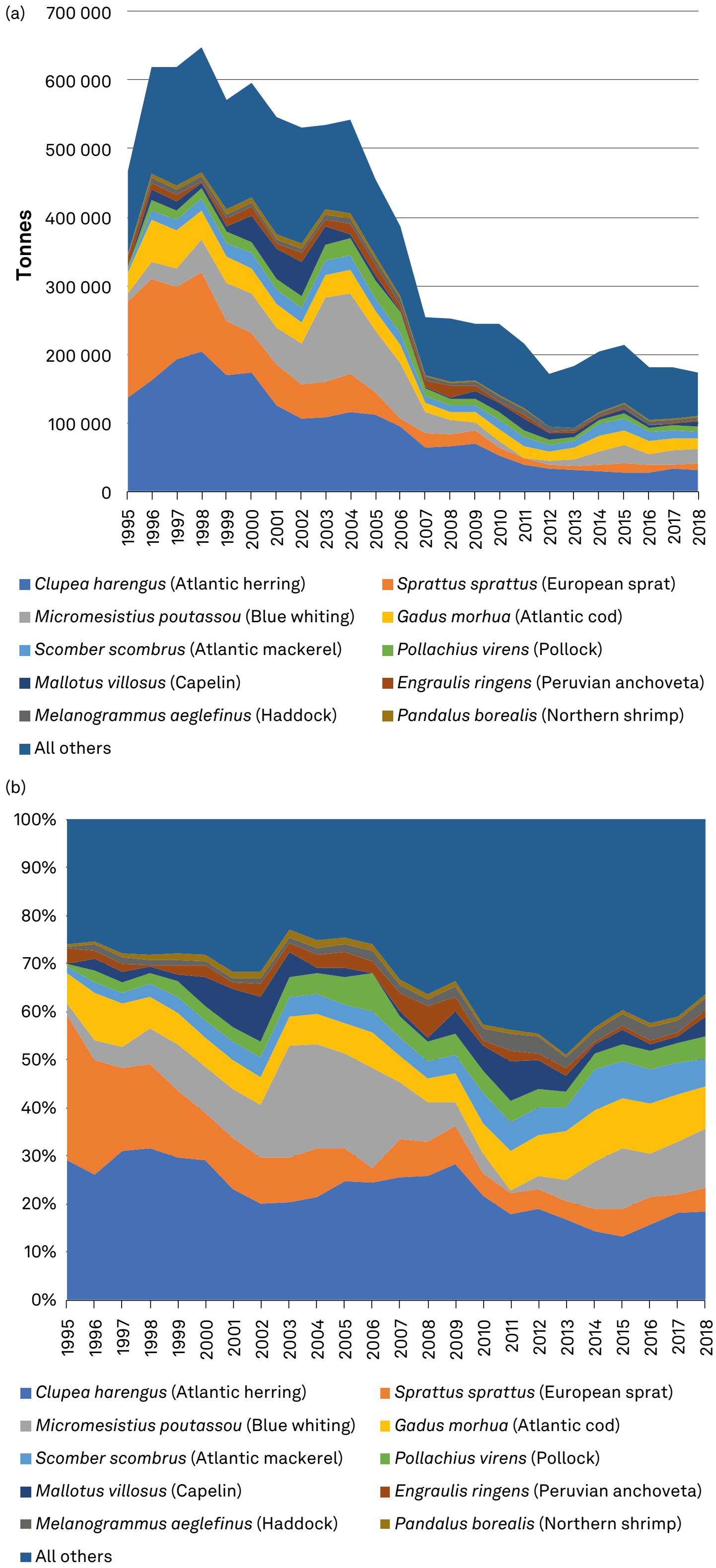


Figure 12: Species involved in marine capture fisheries embedded in Swedish consumption. (a) absolute values; (b) relative values.

Figure 13 illustrates the gear type profile of an important species to the Swedish consumption profile, Atlantic cod (*Gadus morhua*). Total capture that can be allocated to a gear type is 15,032 tonnes tonnes (a further 59 tonnes of capture was not associated with a gear type) for 2018, and estimated discards are 225 tonnes, providing an overall discard rate of 1.5% (which is low in relative terms). In 1995, total captures were 29,468 tonnes, and discards were 1802 tonnes, a discard rate of 6.1%. This change can be explained by the decreased use of ‘other nets’ which were associated with a discard rate of 10% in 2005. One can also observe a decrease in the relative utilization of bottom trawling but its share in the discards has increased, which is associated with its increasingly high discard rate (3.7% in 2018).

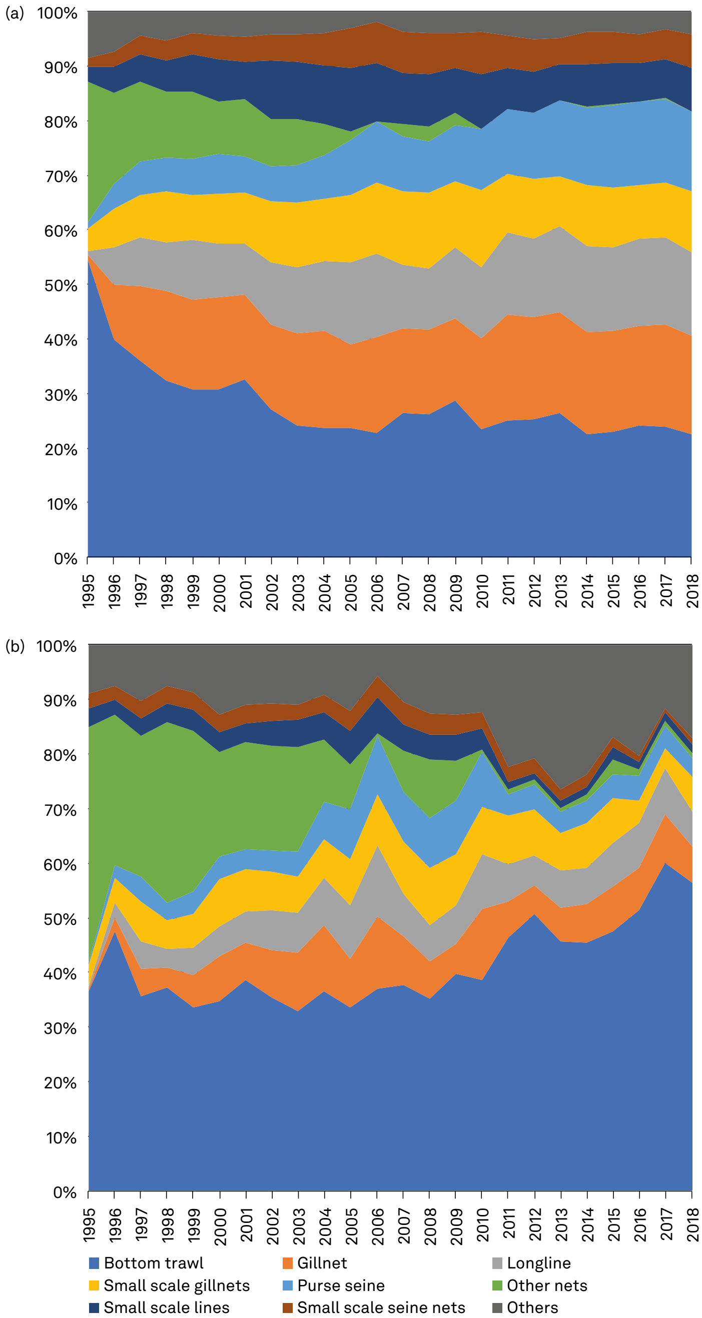


Figure 13: Gear types involved in the capture of Gadus morhua embedded in Swedish consumption (left) and estimates of discards associated with these captures, by gear type (right).

6.2.4 Limitations

The implementation of this enhanced fisheries extension is subject to the following limitations:

- Species and species group aggregations in Sea Around Us and FishStat, though fairly well aligned (particularly for larger fisheries/targeted species), do not match perfectly. This is primarily due to a combination of SAU estimates at a more disaggregated species level in some cases, and differences in species taxonomic classifications (e.g. species being named different things). For this gap analysis, we created a concordance (across >2600 species classifications) to ensure that all captures recorded in FishStat were associated with at least one equivalent classification within SAU at global scale. However, at the global level around 25% of catches in FSJ were not matched to an equivalent catch in SAU, although for the Swedish portion of the catch this ranges from ~10% to ~17% over the time series. Further work would be required to increase the accuracy of the concordance, particularly as matches vary for each individual reporting fishing entity.
- We have been made aware that in some cases Sea Around Us have more detailed information on gear types associated with discards which are assigned to a coarser gear classification in the landing data. The frequency with which this occurs in the dataset is unclear without detailed investigation (see Section 6.4.2). Additionally, there appear to be cases where discard estimates may vastly exceed stated landings. For example, for German captures by pelagic trawl in 2018 in SAU, only European sprat (*Sprattus sprattus*) is associated with any landings record (0.25 tonnes) whereas discards associated with pelagic trawling in 2018 are 1,959 tonnes. This results in an unrealistically high rate of discard. Further work would be required to systematically detect, and respond to, such cases, which have not been addressed in this initial gap analysis exercise.
- Sea Around Us data only provide information on marine fisheries and exclude captures or discards associated with, for example, mammals and reptiles.
- Across the fisheries results (capture and aquaculture) compiled in this gap analysis, we witness a significant drop in modelled consumption between 2004 and 2007. Initial exploration suggests that this is a consequence of the economic transactions as captured in the EXIOBASE MRIO structure; that is, a decrease in Swedish demand for products from the aggregated fisheries sector. The representativeness of this result to real-world demand for both capture and aquaculture production sources requires additional interrogation of the EXIOBASE dataset which sits outside the scope of this gap analysis. Further work is required to validate any indicative results presented, and recommendations to improve the allocation of fisheries production in MRIO models are also included below, see Section 6.4.2.

6.3 Aquaculture

6.3.1 Objectives of investigation in PRINCE 2

Within PRINCE 1 we made no attempt to provide additional information, beyond that already embedded in material footprint measures, about the link between Swedish consumption and products of aquaculture production. Within PRINCE 2 we sought to address this, via the utilization of FSJ data on the location, production type and species utilization underpinning aquaculture, and via scoping of the availability of data that might be utilized to extend the FSJ data to complement knowledge on the impacts of these production systems.

6.3.2 Impacts of aquaculture production

Global aquaculture production increased by 527% between 1990 and 2018 (from 13 to 82 million tonnes; FAO 2020a) and is an increasingly important component of fisheries products embedded in consumption activities. In Appendix 5 we summarize the findings of life cycle assessment and other studies which have explored the environmental impacts of aquaculture production. These reveal the particular importance of accounting for the nutrientloading/eutrophication potential of aquaculture production systems, with the feed composition, the technology used and the fish species all important determinants of this impact. A key environmental impact of aquaculture is the feed products used. However, these are already incorporated in MRIO accounts (through the consumptive use of products of fisheries or agriculture (in broader material accounts)) embedded in the fisheries sector present in the MRIO structure. Therefore, while more analysis of the upstream impacts of aquaculture feed is warranted, this was outside the scope of our analysis.

Our initial scoping of the research and data landscape surrounding aquaculture production is not comprehensive, but we did not identify any global datasets that would be directly suitable as the basis of an aquaculture extension of the PRINCE model. Datasets such as those developed in Lucas et al. (2020) or Huang et al. (2020) (see Appendix 5) offer some potential, but further work would be required to determine suitability. In the absence of readily applicable data linked to the environmental impacts, our results simply provide species and locations of production associated with the Swedish aquaculture consumption footprint, with a brief commentary on potential associated nutrient loading.

6.3.3 Methods

FAO FishStat provides aquaculture data in a similar format to that provided for capture production, with countries of production, species farmed, production location (i.e. broad oceanic/inland water area) and details of the production system type (freshwater, marine and brackish water) in terms of tonnes produced over a 1950–2019 time series. Per species production quantities, area and production system type can therefore be used to provide an extension sheet for the EXIOBASE model. As for capture fisheries, production records can then be assigned to the appropriate country or region within the “Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)” sector. Extension sheets were prepared for each year between 1995 and 2018.

6.3.4 Results

Figure 14 presents the total aquaculture-linked consumption footprint for Sweden, by source region. Consumption of products of aquaculture has increased, which is consistent with world trends. Swedish consumption of Swedish production has decreased in relative importance, with production from Norway being most important overall.

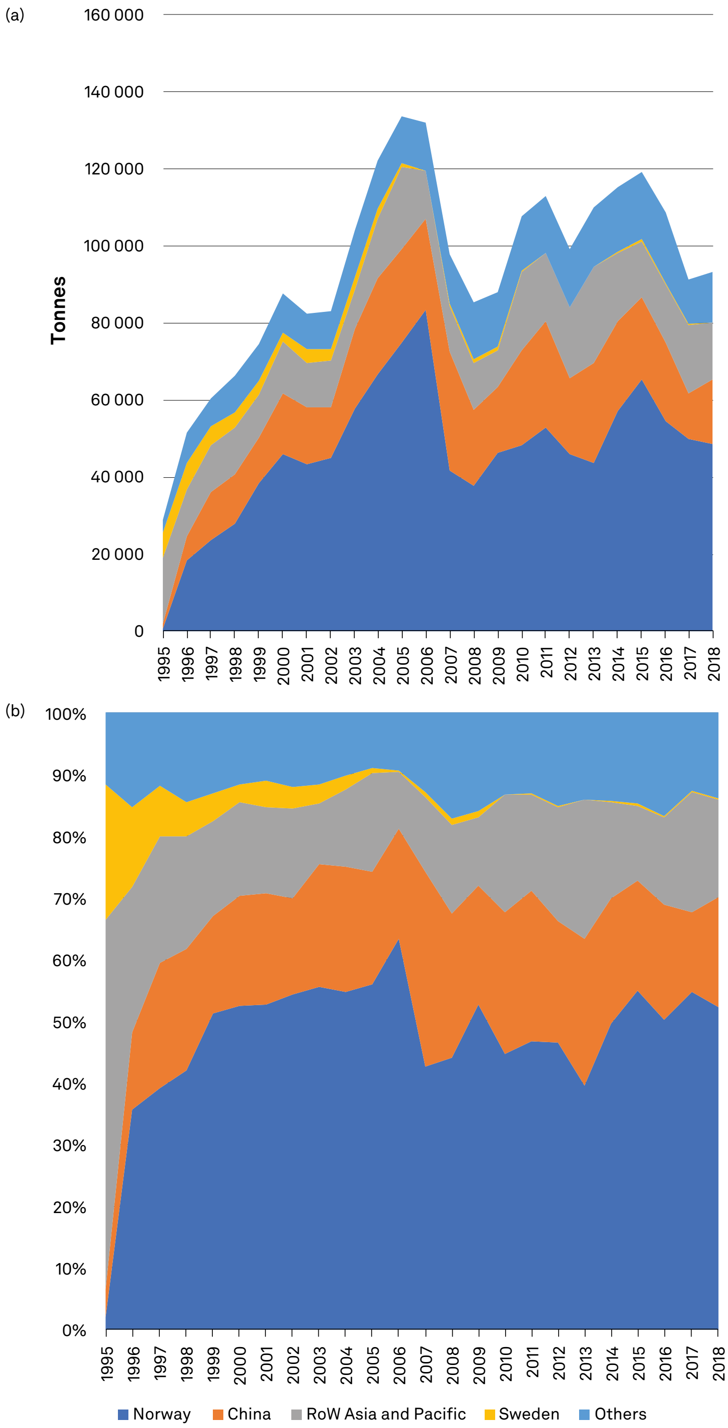


Figure 14: Source regions for products of aquaculture embedded in Swedish consumption. (a) absolute values; (b) relative values.

Figure 15 presents a species breakdown of the aquaculture footprint. The most important single species is Atlantic salmon (*Salmo salar*) followed by rainbow trout (*Oncorhynchus mykiss*), although the latter has decreased in relative importance over the time studied. Non-fish species such as algae/seaweeds and shellfish are also included in the account. Results reveal that Norway is a key source of the two most important species.

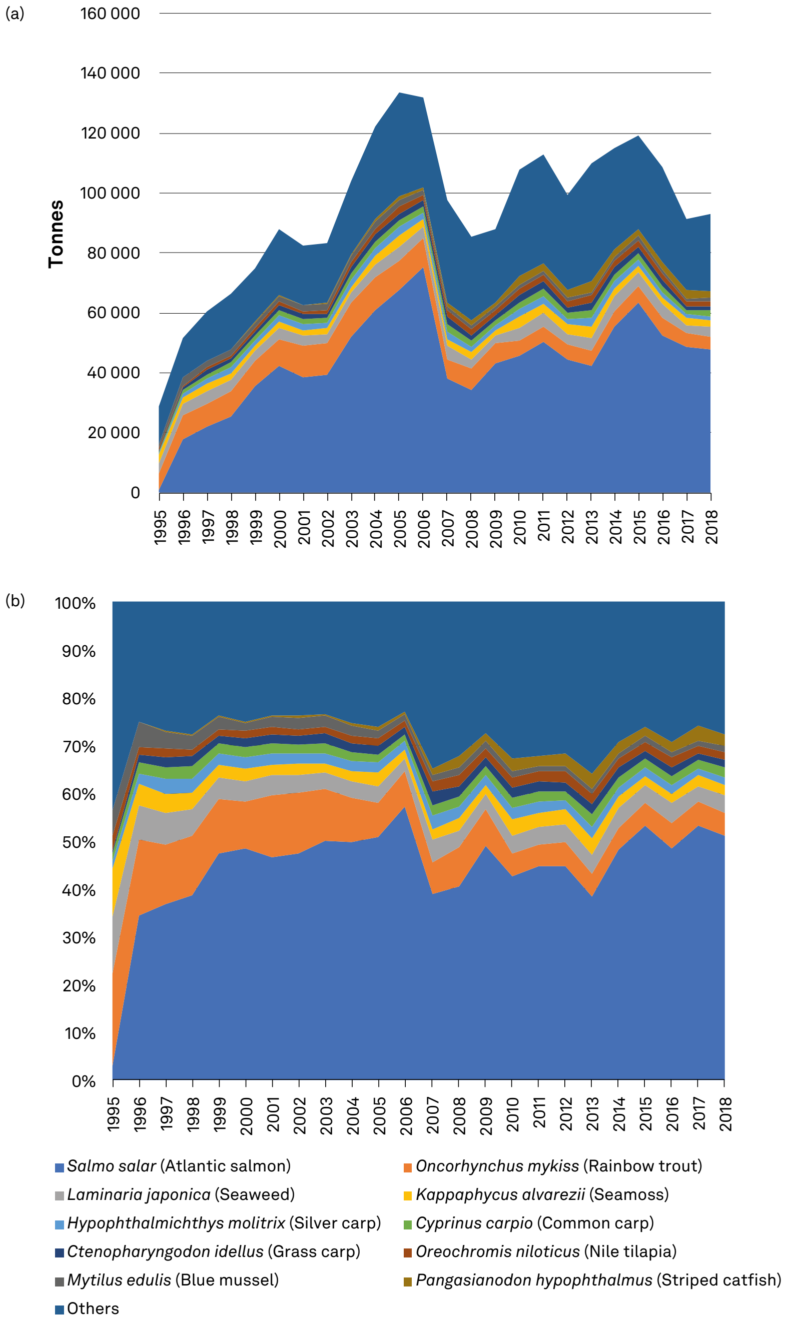


Figure 15: Species involved in aquaculture production embedded in Swedish consumption. (a) absolute values; (b) relative values.

Salmon and rainbow trout are both part of the Salmonidae family, and their production is associated with a global average of 48 kg phosphate (PO_4^{3-}) per tonne of live weight (Lucas et al., 2020; see Appendix 5), which is relatively high compared to other species-systems. The material footprint of these species embedded in Swedish consumption in 2018 was 48 481 tonnes, which is associated with a loading of 2 324 tonnes of PO_4^{3-}. Shrimps and prawns have an even higher global average load (78 kg PO_4^{3-} per tonne of live weight). However, the most important single shrimp/prawn species in the Swedish footprint is white-leg shrimp (*Penaeus vannamei*), with production of 1,984 tonnes linked to Swedish consumption in 2018 (and representing a total load of 155 tonnes of PO_4^{3-}).

6.3.5 Limitations

The implementation of this aquaculture extension is subject to the following limitations:

- At the time of writing, the results provide estimates of mass of production linked to Swedish consumption; additional data on associated environmental pressures would require further data compilation and harmonization.
- There is very limited information in the FishStat database about the technologies employed for production. While this might be inferred by analysis of the location, species and production system (brackish water, freshwater, marine), further investigation is required to ascertain technological systems identified as important drivers of impact in our initial scoping work.

6.4 Potential use in official statistics and next steps

6.4.1 Use in national statistics

Given the importance of fisheries products nutritionally and economically, the continued presence of unsustainable production, and their inclusion in international policy agendas, fisheries extensions to the PRINCE model would satisfy the relevance dimension of statistical quality.

The primary dataset used in the preparation of the fisheries extensions detailed here, and in the PRINCE 1 study, is FSJ, which is based on a compilation of statistics submitted by national agencies to FAO. It offers as robust an estimate of officially recorded global fisheries production as is likely possible without recourse to the original national statistical agencies. Furthermore, these data are updated regularly and in a timely fashion; compilation by FAO ensures comparability and relative accuracy (according to official sources), and they are openly available. These statistics are also those used where fisheries products have been included, for example in the PRINCE model as part of the material footprint. As such, this information on overall production volumes (for both capture and aquaculture production) is likely a good candidate for inclusion in official national consumption statistics. However, as mentioned above, we do observe an unusual result with a rapid decrease in observed consumption when our fisheries extension is applied to the EXIOBASE MRIO. The extent to which this reflects real-world behaviour would require additional validation before these extensions can be utilized for statistical purposes.

A limitation, however, relates to the fact that capture data is allocated to the country-flag on the vessel, and an assumption is made that this equates to the country of residence. While this assumption is also used where fisheries captures are encapsulated in aggregated material footprint estimates, further work is needed to assess the consequences of this assumption on results. It would also likely be difficult, or impossible, to make corrections for this given that no information disaggregated to vessel level is available in FishStat. Additionally, general improvements to fisheries statistics by data collators would reduce uncertainties associated with the significant proportion of catch which is resolved only to coarse (non-species specific) classifications.

Our extensions to capture statistics, based on the application of Sea Around Us data, show promise in enhancing consumption-linked understanding of the environmental damage associated with capture methods and, importantly, providing a more granular understanding of the discards associated with marine fisheries consumption. The SAU statistics are evidence-based and compiled via peer-reviewed methods. SAU provides a comprehensive, global, spatially resolved dataset which is also updated regularly (albeit with a lag; the latest update to 2018 was released in June 2021). As such, it is likely that their application would add value to any statistic associated with fisheries-linked consumption. Additional work is required to improve the concordance mapping undertaken for this gap analysis, for example to production country-level, and to check for any data discrepancies linked to the issue of occasionally differing catch method allocations for captures and discards (see also Section 6.2.4).

6.4.2 Potential developments and applications

As part of the PRINCE 2 project, a dedicated dialogue on the results of the fisheries gap analysis was conducted with members of Swedish organizations (Swedish EPA, Swedish Agency for Marine and Water Management and Board of Agriculture) and the UK policy organization, the Joint Nature Conservation Committee. Discussions centred on the following topics of interest linked to potential methodological considerations (and associated developments) or applications of this potential dataset to inform policy:

- **Enhancement of capture fisheries information to include data on stock status:** In addition to the impacts on the marine environment (via gear type) or non-targeted species (via discards), there is potential to integrate regional information on the status of the targeted stocks themselves (see “Next steps” below).
- **Exploration of enhancements to the economic allocations of fisheries products in the MRIO model**: Two potential enhancements were discussed: (a) the potential to utilize information from regional offices or satellite data from for example, Global Fishing Watch[22] to overcome country-flag limitations (see above); and (b) potential utilization of bilateral fisheries-product trade information in physical units (available from FAO FishStat) to improve consideration of fisheries-production linked trade prior to insertion into the MRIO structure.

[22] https://globalfishingwatch.org/

- **Exploration of additional environmental extension information**: Options exist to utilize information from, for example, life cycle assessment repositories, to explore whether and how additional characterization factors (for biodiversity loss, nutrient or chemical loading, greenhouse gas emissions) could be integrated alongside the species information provided by the fisheries extension.
- **Exploration of results in context of policy change:** There is potential to explore whether results from the consumption-based account for fisheries reflected changes in policy, for example shifts in gear type practices for capture fisheries or shifts in the utilization of marine vs. terrestrial feed inputs for aquaculture.
- **Comparative analysis of results with terrestrial food production systems:** There was interest in utilizing, for example, feed conversion ratio information, and potentially (with further enhancements to cover nutrient loading or greenhouse gas emissions) other impact data, to compare the environmental impacts of fisheries production with terrestrial (e.g. livestock) systems with a consumption-based lens.
- **Downscaling of nutrient loading data:** Potential was noted for using nutrient loading extensions for aquaculture to "hotspot" sources of concern that could then be explored further to identify specifically where production is likely to be taking place and what impacts this might be having in local environments.

6.4.3 Next steps

We identify the following steps that could be taken to improve upon and/or extend this work towards the development of a fisheries extension for consumption-based statistics:

- **Additional work on Sea Around Us integration:** Data for larger fisheries/most commonly targeted species align relatively well between SAU and FSJ datasets used in our analysis, but improvements to our concordance mapping (including attempts to automate matches via computer-coded matching processes), the detection and resolution of extreme estimates of discard rates, and associated sensitivity analysis would be beneficial.
- **Stock sustainability:** Further exploration of the potential to integrate stock-status information alongside capture statistics may allow other sustainability perspectives (i.e. whether or not fisheries are being managed to avoid depletion) to be integrated alongside our gear-type and discards-based assessments. A brief investigation conducted as part of this gap analysis has identified RAM Legacy and International Council for the Exploration of the Sea stock status datasets as potential data sources. Significant additional work would be required, however, to align these datasets with the resolution of production statistics provided by FAO FishStat.
- **Other metrics:** Other metrics relevant to fisheries production could also be considered. These include more detailed analysis of the greenhouse gas emissions associated with fishing methods. While greenhouse gas emissions were not included in this gap analysis (but are included, in relatively coarse terms in the greenhouse gas emissions associated with the PRINCE model's

fisheries sector) the additional detail provided for gear types may allow more accurate assessment of associated emissions. Furthermore, other relevant statistics such as the catch per unit effort could be explored, which again is facilitated by the more granular fisheries extensions provided by PRINCE. The impacts of fisheries are ultimately broad and therefore efforts to improve extensions would benefit from alignment with other activities aiming to develop indicators for seafood sustainability (e.g. Joint Research Centre, 2021). Data published after our scoping review (Gephart et al., 2021) are also indicative of the likely availability of improved datasets that may assist in the assessment of fisheries impacts and inter-comparisons across fisheries products and other protein sources.

- **Material allocations to EXIOBASE:** Currently, physical catch is allocated into a single sector within the country (associated with the fishing vessel flag) within EXIOBASE, meaning that the distribution of fisheries products is based solely on the economic transactions captured within EXIOBASE at sectoral scale. While (as described in Section 6.4.1) addressing potential discrepancies between vessel-flag allocations and country-residence is likely to be difficult, FSJ also provides detailed information on the trade of fisheries products in addition to fisheries production. These data could theoretically be used to track the movement of fisheries-linked products derived from captures in more detail, but they are not classified consistently with production statistics and would therefore require harmonization before use.
- **Aquaculture extensions**: A more extensive review of the availability of information linked to aquaculture production systems should be undertaken. This should focus on the technologies utilized in international production systems and associated nutrient loading or feed conversion ratios (FCRs). Given that technologies vary broadly internationally, while a simple extension to mass-of-production information could be undertaken via existing global FCR estimates (see Appendix 5), the development of a more specific dataset for application to FishStat production estimates would be beneficial.

7. Official statistics and new consumption-based indicators

Key messages

- Official statistics are produced according to internationally agreed-upon quality requirements.
- Statistics Sweden has the institutional capacity to ensure a foundation for the production and publication of official statistics according to the relevant quality requirements.
- The experimental time series produced in this study for pesticides, veterinary antibiotics and deforestation demonstrated the potential to be developed into time series for official statistics.
- For fisheries, biodiversity and HCP use further validation and development work is required before consideration for official statistics.
- Production and updating of new time series requires sufficient financial resources to be allocated to the environmental accounts group at Statistics Sweden.
- For land use and material footprint new data will become available in the next few years to make it possible to produce experimental time series in these areas.

7.1 Quality framework for producing official statistics

PRINCE 2 has investigated which other consumption-based indicators could be produced as official statistics. To ensure high quality, official statistics are governed by internationally agreed standards, for example United Nations Fundamental Principles of Official Statistics (United Nations, 2013).

Statistics in the EU are produced according to the European Statistical System Committee's guidelines, the European Statistics Code of Practice (Eurostat, 2018). The Code of Practice sets the standard for developing, producing and disseminating European statistics with the aim to raise the quality and enhance trust in the statistics. The Code of Practice is based on 16 principles that cover the institutional environment, statistical processes and statistical output, shown in Figure 16. For evaluating the PRINCE model and new consumption-based indicators we have focused on the principles in the statistical output which also overlap with quality criteria in the Swedish law on official statistics (2001: 99)[23]. Important aspects to consider regarding the institutional environment and statistical processes are also discussed.

Institutional environment	Statistical processes	Statistical output
• Professional independence	• Sound methodology	• Relevance
• Coordination and cooperation	• Appropriate statistical procedures	• Accuracy and reliability
• Mandate for data collection and access to data	• Non-Excessive burden on respondents	• Timelessness and punctuality
• Adequacy of resources	• Cost-Effectiveness	• Coherence and comparability
• Commitment to quality		• Accessibility and clarity
• Statistical confidentiality and data protection		
• Impartiality and objectivity		

Figure 16: Sixteen principles in the European Statistics Code of Practice.

7.2 An institutional environment for producing statistics

The institutional environment is the basis for credible and effective statistical production. There are 29 government agencies in Sweden that have been appointed to be responsible for official statistics within their respective areas. Statistics Sweden is both responsible for central coordination with and between other agencies with responsibility to produce official statistics and is also responsible for many statistical areas directly, including environmental accounts and sustainable development where the consumption-based indicators have been developed. As such, Statistics Sweden is, therefore, well managed according to the principles under institutional environment in the Code of Practice. This is further described in, for example, the Swedish law (2001:99) and regulation (2001:100) on official statistics, and Statistics Sweden's quality policy (Statistics Sweden, 2020).

For the PRINCE model, two principles from the Code of Practice are especially important: mandate for data collection and access to data, and adequacy of resources. Regarding mandate for data collection, the PRINCE model uses a coupled model approach combining national data with an MRIO framework. Swedish input-output tables are available to analysts at Statistics Sweden, but not outside the organization, since data at this detailed level are confidential. The coupled model currently uses data from EXIOBASE which are publicly available on Zenodo. For indicators where data are not produced in house at Statistics Sweden access to data is required.

[23] https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/lag-200199-om-den-officiella-statistiken_sfs-2001-99

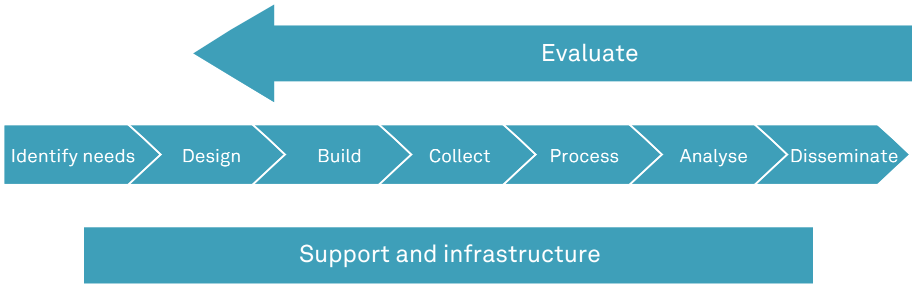


Figure 17: The Generic Statistical Business Process Model.
Source: United Nations Economic Commission for Europe (2019).

Adequacy of resources requires both the human, financial and technical resources to meet current statistical needs and that there are procedures in place to justify demands for new statistics in light of their cost. The PRINCE model is already used for producing official statistics and there are resources available for maintaining the model. External funding or increased grants will, however, be vital for extending the current model with additional indicators.

7.3 Statistical processes for producing indicators

Statistical processes are about using international standards, guidelines and good practices when producing statistics. The principles on sound methodology, appropriate statistical procedures and cost-effectiveness can be further demonstrated in the Generic Statistical Business Process Model developed by the United Nations Economic Commission for Europe (UNECE) and used at Statistics Sweden for producing statistics (UNECE, 2019) shown in Figure 17. The principle of non-excessive burden on respondents is not directly applicable to the current PRINCE model since it is based on already existing input data, although there might be new statistical needs for consumption-based indicators that can affect the burden on respondents in the long run.

Before statistics are produced, user needs must be analysed (see Figure 17). The need in the PRINCE 2 project came from the SEPA, which wanted to develop more indicators to follow up the environmental quality objectives. In the next steps the production is designed, built and tested followed by data collection and processing of the data (see also Figure 17). All this is represented in the PRINCE model where the methodology has been developed and tested over several years, first research and later in statistics production. In the analysis phase the statistical output is examined, including ensuring that the data are fit for the purpose for which they will be used. After each production cycle the model is evaluated and improvements are identified and planned for the next cycle. The PRINCE model can add new indicators in a cost-effective way since the model is already institutionalized at Statistics Sweden.

7.4 Assessing the quality of the statistical output from the PRINCE model

The Code of Practice and Swedish law on official statistics states that official statistics must meet a number of quality criteria, which are described in Table 3. This project has used these quality criteria for evaluating the PRINCE model in general and the indicators that can be part of the system of official statistics.

Table 3: Quality criteria for producing official statistics, evaluation of the PRINCE model.

Quality criteria	Description	Prince model
Relevance	The degree to which statistics meet current and potential need of the users.	The policy need for consumption based indicators to follow up Swedish environmental spill over effect is high, see Chapter 2. There is also institutional capacity to regularly evaluate user need of official statistics in Statistics Sweden's user council and yearly evaluation of official statistics.
Accuracy	The closeness of estimates to the unknown true value.	The PRINCE model is evaluated in all steps of the General Business Process Model i.e. input data, methodology, data computation as well as documentation of quality, accuracy and shortages in quality declarations of the official statistics. Official statistics produced with the PRINCE model are fit for purpose.
Timeliness and punctuality	The period between the availability of the information and the event or phenomenon it describes and the delay between the date of the release of the data and the target date.	The date of the release of the official statistics from the PRINCE model is communicated in the Statistics Sweden publishing calendar, is published without delays and as soon as possible regarding when source data for the PRINCE model are available.
Coherence and comparability	The adequacy of the data to be reliably combined in different ways and for various uses. The measurement of the impact of differences in applied statistical concepts, measurement tools and procedures where statistics are compared between geographical areas, sectoral domains or over time.	The PRINCE model is comparable over time and over sectoral domains such as industry and product. Time series breaks occur in national input data from Statistics Sweden's National Accounts input-output tables. This is documented and described for each indicator. There is also ongoing evaluation of comparability with different MRIO databases. Output from the PRINCE model can be combined with other data in a coherent way.
Accessibility and clarity	The conditions and modalities by which users can obtain, use and interpret data.	Official statistics from the PRINCE model are published in the statistical database at Statistics Sweden together with documentation on how the statistics are produced, quality declaration and "Statistical news".

Source: Regulation (EG) 223/2009[24]

Some of the quality criteria for official statistics can be achieved thanks to Statistics Sweden's institutional environment for producing official statistics, for example punctuality, accessibility and clarity. For other quality criteria such as accuracy and relevance there might be more variations and requirements for different indicators.

[24] EUR-Lex - 32009R0223 - EN - EUR-Lex (europa.eu)

A complementary and simpler characterization of quality in statistical output is that statistics should be fit for purpose (United Nations, 2021b). While the aim of statistics, and especially statistics marked as official, is to be as accurate as possible, they must also be set in relation to the purpose they should serve. Indicators based on MRIO models are needed because the footprint perspective is lacking in other already existing official statistics. As such they add an important dimension on the Swedish environmental spill over effects to meet current and potential needs of the users. Since they are also model-based statistics, they are in general best suited on a more aggregated macro level than for describing details.

The national input data in the PRINCE model are based on official statistics from Environmental Accounts and National Accounts. The quality of these statistics is considered very high. Production processes are also set up at Statistics Sweden for producing these statistics yearly in accordance with the Generic Statistical Business Process Model.

The global multiregional input-output model, EXIOBASE, was chosen because it includes most environmental indicators and has more disaggregation in products compared to many other models. One uncertainty regarding EXIOBASE, when it was selected, was the frequency in updates and revision policy of the model. Although there is no official publication schedule for new versions of EXIOBASE, the model has been updated and improved regularly since 2019 when consumption-based greenhouse gas emissions statistics were first published at Statistics Sweden. The project expects the model to be continuously updated since global user need and interest is still high.

The nature of the PRINCE model is such that other MRIO databases could replace EXIOBASE in the future, or results can be compared with other MRIO databases. It will be important to follow the work done by Eurostat and the Organisation for Economic Co-operation in the FIGARO project where EU input-output tables are being developed. The tables are fully based on official statistics, the project is publicly funded, and has a stated purpose to be updated yearly. Economic variables are already available and the aim is to extend them to include environmental pressures such as carbon dioxide emissions. Besides lacking environmental pressures, the tables also have lower sectoral details and greater number of years of time lag.

7.5 New consumption-based indicators as official statistics

For new indicators we have focused on the following quality criteria: relevance, accuracy, and coherence and comparability. We have also added the principles of access to data, adequacy of resources and statistical processes from the Code of Practice to the evaluation. The summary of this qualitative evaluation is shown in Table 4.

The general conclusion is that most of the new proposed indicators, given their relevance in policy evaluation, and maturity in data production can be produced as official indicators and included in, for example, follow up of the generational goal.

The experience from the gap analyses in PRINCE 2 suggests that time series for indicators for greenhouse gas emissions from deforestation, pesticides and veterinary antibiotic use are at a stage where they can be considered for production as official statistics. Of these, indicators for pesticides and veterinary antibiotics could be relatively quickly implemented in statistics production. Indicators on deforestation require more work to transfer research results to an institutionalized statistical process.

Experience in the gap analyses further suggests that time series for indicators for fisheries, HCP use and biodiversity require further evaluation and possibly methodological development before consideration as official statistics. For biodiversity some additional work remains regards scoping and prioritization of indicators given the complexity and taking into account the balance between complexity and producing indicators that can be used and understood in a wider context. For HCP use further validation and potential methodological development is required in light of discrepancies in input data and potential issues with the extrapolation procedure applied. For fisheries further validation work of the illustrative results is required.

Irrespective of the current status of the indicators considered in the gap analyses, methodologies for indicator production must be well documented, noting in particular uncertainties regarding model assumptions. Second, the level of aggregation for the indicators must reflect the underlying assumptions for producing the statistics. Some indicators are better suited for following trends and analysing distribution between domestic and imported impacts. This must be well documented with clear recommendations on how they should be used. Last but not least, the possibility for funding to produce these new indicators as official statistics must be explored since there are limitations to what can be produced within existing financial resources at Statistics Sweden.

Table 4: Evaluation of hazardous chemicals, pesticides, antibiotics, land-use change, biodiversity and fisheries based on quality criteria for official statistics.

Evaluation criteria	Hazardous chemical products	Pesticides	Antibiotics	Land use change	Biodiversity	Fisheries
Relevance	High user need for monitoring sustainable consumption in generation goal, environmental quality objectives and Sustainable Development Goals					
Accuracy	Time series has demonstrated potential discrepancies in geographical extrapolation in particular and requires further investigation.	Accuracy is evaluated and documented according to processes at Statistics Sweden. Limited to bought products. Data have high global coverage. Some model assumptions to fit EXIOBASE structure.	Accuracy is evaluated and documented according to processes at Statistics Sweden. Based on EU (and not global) data but EU data are most relevant. Model assumption leads to possible under-coverage.	Accuracy is evaluated and documented in research. Based on model assumptions. Cannot separate indirect/direct effects on land-use changes from different commodities; analyses by product should be done with caution. Measures risk rather than actual land-use change, and climate impact, which is documented and communicated.	Accuracy is evaluated and documented in research. Biodiversity is measured by a proxy and should be interpreted as biodiversity risk rather than biodiversity impact. Based on institutional data in combination with research results. Further evaluation is required in the Swedish context.	Certain modelling limitations, e.g. catch attribution by species, country-flagging of vessel. Also time series changes that require further validation work.
Coherence and comparability	Time series breaks that must be well documented and communicated to users. Ongoing work.	Time series breaks that are handled with replaced data. This must be documented and communicated.	Geographical extrapolation of available input data that must be documented and communicated.	Time series based on several data sources. No specific issues.	Input data updated yearly, based on historical data.	Input data updated annually. No specific issues.
Access to data	National input data are official statistics from environmental accounts and national accounts, with PRINCE model using EXIOBASE which is available to producers.	Institutional data with high coverage with PRINCE model which is available to producers.	Institutional data with PRINCE model which is available to producers.	Institutional data in combination with research which is available to producers. Ambition to update yearly.	Research data and institutional data which are available to producers.	Research data and institutional data which are available to producers.
Statistical processes	Using the GSBPM at Statistics Sweden.	Using the GSBPM at Statistics Sweden.	Using the GSBPM at Statistics Sweden.	Research, no production process in place at Statistics Sweden.	Research, no production process in place at Statistics Sweden.	Research, no production process in place at Statistics Sweden.
Resources	The PRINCE model can add new indicators in a cost-effective way since the model is already institutionalized at Statistics Sweden. Adding new indicators will, however, demand more resources than currently available, both human and financial, in order to develop and maintain them in the production processes.					

GSBPM: Generic Statistical Business Process Model

Our recommendation is that Statistics Sweden continue to develop indicators for veterinary antibiotics and pesticides and integrate them in the PRINCE model. When the PRINCE 2 project is finalized, Statistics Sweden must investigate the possibility for funding the production of these new indicators as official statistics since there are limitations to what can be produced within existing grants.

7.6 Other indicators

The potential to produce updated time series and official statistics for indicators not covered in PRINCE gap analyses was also assessed.

7.6.1 Material footprint

The material footprint is an indicator used to track progress towards Goal 12 in the Agenda 2030 global goals. The material footprint account aggregates all types of resources used, measured in tonnes (dry matter equivalent), including biomass, fossil fuels, metallic minerals and non-metallic minerals. In the initial PRINCE project, EXIOBASE data were used for both the Swedish domestic account of material extraction, as well as the calculation of material footprint multipliers used in the coupled model. Since the initial PRINCE project, EXIOBASE material data have not been updated, such that a new calculation using the coupled model using the same approach would not be feasible.

Material flow accounts are now prepared for Sweden, hence it would be possible to now use domestic production-related data for the Swedish component of the model, only relying on EXIOBASE for multipliers applied to imports. Consistency would need to be ensured between the treatment/categorization of Swedish data and EXIOBASE data for further implementation.

If EXIOBASE data were just used for multipliers, it would be feasible to use available projections of material usage from EXIOBASE, as multipliers are simply intensity values (reflecting changes in efficiency of production), rather than levels of demand for imports. As such, these multipliers generally change slowly over time, and are thus suitable to give estimates for short time series of updates of data. There is an update of material flow accounts under the UNEP Resource Panel work, and it is anticipated that this will flow through into EXIOBASE by the start of 2022.

7.6.2 Water use

The water use indicator was based on EXIOBASE data in the initial PRINCE project for both the Swedish domestic account, as well as the calculation of water use multipliers used in the coupled model. Water use data are not readily available in annual time series globally and are usually reliant on a mixture of data from the FAO and model output (such as from the WaterGAP model). Annual updates of the water use indicator are one of the more challenging indicators to address, and neither Statistics Sweden nor EXIOBASE has a current plan for updates here.

7.6.3 Land use

The land-use indicator in the first PRINCE project was also based on EXIOBASE data for both the Swedish domestic account and the calculation of land-use multipliers used in the coupled model. Land-use data are readily available in annual time series from the FAO, although some revisions were made to this data in the EXIOBASE dataset. The FAO data also need to be allocated to economic sectors, although due to the aggregation of the agriculture sector in the Swedish input-output table, most land use occurs in the agricultural sector.

Land-use data have been updated to 2015 in the EXIOBASE model, with projections since then. An update is currently under way for the land-use data, projected for the start of 2022.

7.6.4 Other air pollutants

Statistics Sweden produces air emissions accounts with a production perspective for a broad range of non-greenhouse gas air emissions, such as NOx, SOx and particulate matter. Time series for these substances have, however, not been updated in EXIOBASE but are projected. In order to use these data to produce official statistics it would be necessary to update EXIOBASE emissions with new physical data.

8. Future outlook

PRINCE 2 has offered the opportunity to take stock of the development of consumption-based indicators with respect to three intertwined strands, with a focus on the role that PRINCE 1 has played in these developments:

- the policy landscape
- the knowledge base
- the outlook for official statistics.

In all the areas worked on in PRINCE 2, evidence has been established for the strong connections between each of these three strands. Another common theme for all the work in PRINCE 2 is that for all the progress made so far for particular indicators, there is great potential for further progress.

The findings of the parliamentary commission on a target for consumption-based greenhouse gas emissions will be published in spring 2022. The outcome will influence the direction of development for the official statistics in the area. Already, given the scope of the inquiry, a need for methodological development exists to account for emissions arising from products exported by Sweden and to compare them rigorously with products exported by other countries. The proposed carbon-border adjustment for the EU is another current area where methodological developments for consumption-based greenhouse gas emissions could provide policy support.

Consumption-based data on tropical deforestation and associated greenhouse gas emissions are already influencing policy in the EU and beyond, and on the basis of the methodological developments made in PRINCE 2 have the possibility of being produced as official statistics. PRINCE 2 also demonstrated the possibility of producing coherent time series for consumption-based indicators in the fields of pesticides and veterinary antibiotics. Indicators in each of these areas have the potential to satisfy quality criteria for the production of official statistics. Hands-on production and updating of official statistics to the required quality can only be secured by making sufficient financial resources available for the purpose. Other indicators considered in the PRINCE 2 gap analyses on fisheries, biodiversity and HCP use require further evaluation and potentially methodological development before being considered for official statistics.

In order to update indicators in areas that were covered in PRINCE 1 but not PRINCE 2, for example land use and material consumption, updates to EXIOBASE would be needed. New data for land use and material footprint are also forthcoming in the next few years. When these data become available experimental time series can be produced and evaluated.

Finally, the key contribution of consumption-based indicators is that they connect environmental pressures with the economic exchanges that give rise to them. This observation suggests that the methods used to produce the indicators have a wider relevance in connecting any economic policy and plan with environmental pressures. It is suggested in light of this that a scoping exercise be performed to identify and evaluate new areas where the methods used in the PRINCE model can inform economic policy from an environmental perspective.

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Appendix 1: Environmentally extended input-output analysis and the PRINCE model

Scientific and statistical background of the model

Environmentally-extended input-output (EEIO) analysis is the methodological core of the PRINCE model. As documented more extensively in Brown et al. (2021), the method is scientifically well-established, dating back to the work of economist Wassily Leontief in the 1940s. The connection to environmental analysis was first explored in the 1960s. The 1990s saw a significant increase in interest in the method. Today EEIO analysis is a broad and dynamic field of research. The research has enabled analysis of a variety of environmental pressures from a consumption perspective for many countries, and a growing amount of economic and environmental data is becoming available for EEIO.

Key elements of the data necessary for EEIO are also standardized in international statistical manuals. The core economic data used in EEIO analysis, the input-output tables are codified in a chapter in the most recent edition of the United Nations Statistics Division's System of National Accounts (United Nations et al., 2009). EEIO methods also feature in the Applications and Extensions of the United Nations System of Environmental Economic Accounting (United Nations et al., 2009).

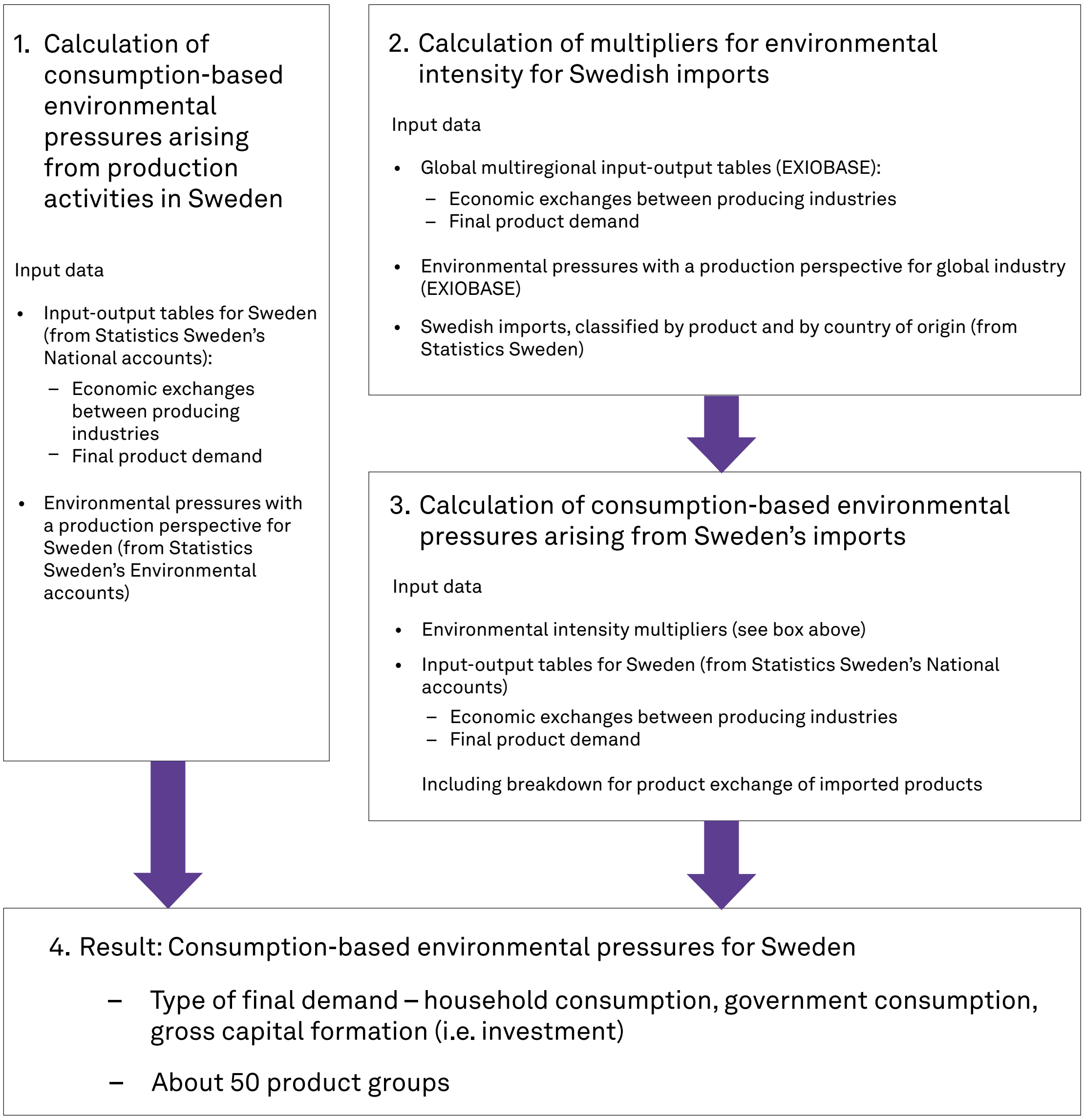

Figure 18: Schematic of the calculation process for the PRINCE model.

Summary of the PRINCE model

The PRINCE model uses a so-called coupled model approach, documented comprehensively in Wood (2018) and Palm et al. (2019). The approach derives from earlier work combining national statistical data within an MRIO framework in a so-called Single-country National Account Consistent approach (Edens et al., 2015). The original model was programmed in Matlab and is freely available on Github.[25]

Figure 18 summarizes the key calculation steps and input data in the model. As in box 1 in Figure 18, Sweden's consumption-based environmental pressures (e.g. emissions to the environment or resource use) arising from production in Sweden are calculated using Sweden's official economic data (i.e. input-output tables) and data on environmental pressures. Sweden's consumption-based environmental pressures arising from imports are calculated in two steps (box 2 and box 3). In the first step, shown in box 2, multipliers for the environmental intensity (i.e. environmental pressure per SEK of imported product) are calculated. The input environmental and economic data here come in the first instance from the global multiregional input-output database EXIOBASE. This is combined with official economic data on Sweden's imports from Statistics Sweden (see also box 2, Figure 18), classified by trading partner (i.e. exporting country). The final calculation to environmental pressures arising from Sweden's imports (shown in box 3, Figure 18) then uses the multipliers generated according to box 2 in conjunction with economic data for Sweden as shown in box 3 in Figure 18. A large part of Sweden's imports is used as intermediate inputs in Swedish industry, and the calculations summarized in box 3 are necessary to assign the environmental pressures embedded in these imports to the products that are finally consumed.

The resulting total environmental pressures (shown in box 4, Figure 18) are classified by the type of final demand (see also the box, "Definitions and terminology" below), and by product group. Sweden's official consumption-based statistics on greenhouse gas emissions, for example, present data for 50 product groups. The model is relatively simple to run for an input-output expert but is not designed for use by lay people. Model output, however, is relatively simple to understand and interpret through the use of interactive tools.

PRINCE's coupled model approach offers key advantages compared to other approaches. The use of a global MRIO to calculate environmental pressures due to imports is an improvement compared to the assumption that imports are produced according to the same economic structure and environmental intensities as domestic production. This assumption is nevertheless used by other statistical agencies producing consumption-based accounts, for example Eurostat and Statistics New Zealand (see Brown et al., 2021).

The coupled model approach is also advantageous compared to using a global MRIO directly, because it makes use of the high quality economic and environmental data for Sweden in the official statistics. It is also advantageous compared to attempting to directly embed the Swedish economic and environmental data directly into a global MRIO because it simplifies the calculations required.

[25] https://github.com/rich-wood/hySNAC

More information about the input data used in the PRINCE model and the macroeconomic balances at the centre of the calculations are shown in the boxes below.

Input data in the PRINCE model

Economic data for Sweden

The model currently uses Statistics Sweden's official input-output tables for Sweden classified according to 91 separate product groups. Such monetary input-output tables contain monetary data about what products are produced in a country, intermediate use of the products (i.e. use of products by industry to produce more products) and final use of the products (for household and government consumption and investment).

The model also makes use of Statistics Sweden's official statistics on the import of goods (Statistics Sweden, 2021b) and services (Statistics Sweden, 2021c). These data are important because they are classified by type of product that is imported, and by the exporting nation. Input-output tables do not give information about exporting nation, which is required to accurately calculate the emissions arising from the production of products that Sweden imports. Since these data are official statistics, they are updated regularly according to well-established quality criteria.

Data on environmental pressures from Swedish production

PRINCE 2 has focused on developing data sources for novel environmental pressures from a consumption perspective. In the current use of the model for official statistics on consumption-based greenhouse gas emissions, input data for greenhouse gas emissions from Swedish production are based on air emissions accounts, produced by Statistics Sweden's environmental accounts group. In the model, these data are also classified according to 91 separate product groups. As for Sweden's economic statistics these data are also official statistics and are updated regularly according to well-established quality criteria.

Economic and environmental data for the global economy

The PRINCE model currently uses the global MRIO database EXIOBASE as shown in Figure 18 above. In EXIOBASE, the global economy is classified according to 44 separate countries and 5 rest of world regions including other countries, giving 49 geographical areas in total. For each geographical area, the economy is classified according to 163 sectors. This relatively high sectoral resolution focuses on sectors significant for environmental pressures such as agriculture. EXIOBASE was developed in successive EU projects with the aim of providing an environmentally extended MRIO with high suitability for environmental analysis focused on the EU and its major trading partners (Stadler et al., 2018). It is well-documented (see e.g. Stadler et al., 2015), regularly updated and freely available online.

One further feature of the coupled model is that other MRIO databases could replace EXIOBASE in the future if so desired. For example, the European Commission and the OECD are working on institutionalizing the production of MRIO datasets through the FIGARO tables available from Eurostat, and the Inter-Country Input-Output tables available from the OECD. At the time of writing, however, the tables have relatively lower sectoral detail, less coverage of environmental extensions and greater number of years of lag time between the last available data and the current year.

Definitions and terminology

Consumption-based accounting is still a relatively new area for policy and research and a single unified terminology is yet to arise.

Many of the terms used relate to the macroeconomic principles at the core of the analysis, namely that the total demand in the economy is equal to the total production. In the national accounts, this principle takes the form of the following equation:

$Y+M = C+G+I+X$ Equation 1

Where Y is production in the domestic economy (i.e. gross domestic product), M are imports to the economy, C is household (private) consumption, G is public consumption, I are investments (including changes in inventories and net acquisitions of valuables) and X are exports.

Where:

Total supply = $Y+M$ Equation 2

And

Total final demand = $C+G+I+X$ Equation 3

The PRINCE model applies input-output analysis to calculate environmental pressures for the total final demand (the right hand side of Equation 1) using detailed information about supply and use in the economy and environmental pressures for the terms on the left-hand side of the equation.

Terminologically, it is interesting to distinguish the total final demand as shown in Equation 3 from the domestic final demand as follows:

Domestic final demand = $C+G+I$ Equation 4

As shown in Equation 4, the difference between domestic final demand and total final demand is that the latter includes exports.

The use of the term "consumption"

The term "consumption" is used with slightly different meanings in different contexts. On the one hand consumption is used as the opposite of production in an economy as a whole. Here production/consumption are used as alternatives to supply vs. demand for a whole economy.

The terms "private consumption" and "household consumption" are also regularly used, and refer to that part of the demand in the whole economy that arises from private households (denoted by C in Equations 1, 3 and 4 above). The terms "government consumption" and "public consumption" are used to refer to consumption by government at supranational, national and local levels (denoted by G in Equations 1, 3 and 4 above).

This report uses the term "consumption-based" environmental pressures to refer to environmental pressures arising due to domestic final demand in the economy (as shown in Equation 4). This is according to the way the term was used in the first PRINCE project and also more broadly among researchers, statisticians and analysts using EEIO to calculate environmental pressures.

Appendix 2: What is state of the art for incorporating biodiversity into consumption-based accounts?

IEEP (2021) categorizes biodiversity footprints in terms of (a) ecological footprints, such as land or forest area; (b) biodiversity footprints for those metrics which more directly estimate losses of biodiversity; and (c) ecosystem service footprints, which pertain to the impacts on the benefits that arise from nature. Here we consider (b) – those that specifically address biodiversity and allow assessment of heterogeneous impacts between *and within* ecosystems.

A number of studies have provided consumption-based accounts of biodiversity impacts at national level. These include those based on the known threats to species, on the species area relationship, and on mapped species ranges (Table 5).

Threats

Lenzen et al. (2012) linked country-wise species and threat data from the IUCN and BirdLife (BirdLife International, 2021; IUCN Red List of Threatened Species[26]) to commodities to demonstrate how consumer demand can threaten species in remote locations through international trade in commodities. The work is a useful development, clearly highlighting that threats accrue to particular species in particular places. However, this approach is difficult to downscale, as threat lists are compiled at a national level, making it impossible to account for their subnational spatial variation. This is vital, as biodiversity and commodity production both show considerable spatial variation. Moran and Kanemoto (2017) advance this work by adding spatial information on species ranges. This allows subnational biodiversity priorities to be accounted for, although the individual species ranges used to calculate priority areas are relatively coarse.

In both studies all threats and species are weighted equally, yet it is known that some commodity-species combinations will be worse than others. Moreover, the model and approach in this study uses financial data at country level, a further constraint to downscaling to finer scale impacts. Essl et al. (2012) also argue that the estimates of Lenzen et al. (2012) are too conservative, highlighting recent rises in trade volume that are not reflected in the threat assessments. They cite the 119%

[26] Version 2021-2: https://www.iucnredlist.org/

increase in volume of worldwide exports between 1990 and 2011 and, particularly, the rise in prominence of highly biodiverse producer countries (e.g. China, Brazil, India and Indonesia) as reasons to expect the impacts to be much greater. Moreover, non-threatened and even regionally threatened species are not included, yet far outweigh the globally threatened (Essl et al., 2012; Kitzes et al., 2017).

Species-habitat relationships

The species-area relationship (SAR) is one of the most widely used methods for estimating the biodiversity impacts of trade (Souza et al., 2015). The approach relies on the relationship between habitat availability and species richness, calibrated for different habitats and geographies: as habitat area decreases, we see a non-linear response in species loss. The related countryside SAR (cSAR) is based on the original SAR, but also accounts for the ability of species to persist in non-native habitat, rather than assuming complete hostility of converted land for native species. In studies by de Baan et al. (2013) and then Chaudhary et al. (2015), the cSAR is developed and used to quantify regional species loss from land-use change for vertebrates in six land-use types in 804 ecoregions. Chaudhary et al. (2015) calculate vulnerability scores per ecoregion based on the fraction of each species' geographic range contained within the ecoregion (i.e. a measure of range size rarity) and the IUCN assigned threat level of each species. Vulnerability scores were multiplied with regional species loss to estimate potential global extinctions per unit of land use. One shortcoming of this approach is the double counting of vulnerability based on range size criteria. Where a species is assigned a higher IUCN threat status due to range size, this will be incorporated again in the measure of range size rarity calculated for the study. Chaudhary and colleagues went on to use the cSAR to estimate loss of vertebrate species due to agricultural land use within each of the 804 terrestrial ecoregions. This includes taking the estimates of species loss from Chaudhary et al. (2015, 2016) a step further by combining them with high spatial resolution global maps of crop yields to calculate species lost per ton for 170 crops in 184 countries (Chaudhary & Kastner, 2016). This could then be linked with the bilateral trade data of crop products between producing and consuming countries from FAO, to calculate biodiversity impacts embodied in international crop trade and consumption. More recent work has been done to refine the method to consider impacts under different intensities according to their management regime (Chaudhary & Brooks, 2018).

The cSAR characterization factors are well suited to life cycle analysis approaches and generally well accepted as a method of "hotspotting" biodiversity risk, though not for fine scale decision-making (de Baan et al., 2013; Frischknecht et al., 2016; Gaudreault et al., 2020). An important feature of the method is that it accounts not just for current species losses, but also for the lag between habitat loss and extinctions; that is, it counts those losses that are expected in the future from species whose loss of habitat "commits" them to extinction (Kastner et al., 2021). The method has been adopted within the life cycle assessment framework LC-IMPACT (Verones et al., 2020) and applied to EXIOBASE (Bjelle et al., 2021) and also within the Stockholm Environment Institute's input-output trade analysis (IOTA) model in its application as an "experimental statistic" for the UK Government, as noted in Chapter 2 (Croft et al., 2021; https://commodityfootprints.earth/).

Alternatively, "species abundance" metrics can be used. These are based on species populations (rather than species richness) and rely on local species abundance data that are associated with a specific type of land use to infer impacts of future land-cover change (Molotoks et al., 2020). Species abundance metrics count the number of individuals of each species. Examples include the Biodiversity Intactness Index, which estimates how land-use changes affect the intactness of species' populations relative to undisturbed ecosystems (Newbold et al., 2016; Scholes & Biggs, 2005) and the similar Mean Species Abundance (Alkemade et al., 2009).

Species distribution models

Where site(s) of production can be mapped, a conceptually simple and intuitive method for assessing the land-use impacts of production on biodiversity is to consider the species ranges that overlap a site of production. Simplest of all is to use species range maps (extent of occurrence; they delineate the extent of the known, native distribution of the species) to count the number of species range polygons that overlap an area of production. Although spatially coarse, comprehensive data are curated and maintained for birds, amphibians and mammals, representing over 23 000 taxa (BirdLife International, 2021; IUCN Red List of Threatened Species[27]). These data have been used – in a very simple manner and in combination with spatialized agricultural distribution maps – to develop a "species hectare" metric of biodiversity risk, applied to Stockholm Environment Institute's IOTA model in its application as an "experimental statistic" for the UK Government (Croft et al.,2021; https://commodityfootprints.earth/).

A similar approach is taken by Kitzes et al. (2017), who calculate an "occupied bird ranges" metric, in which overlapping bird species ranges are summed to derive an estimate of biodiversity in a relatively unaltered state. Rather than overlaying these with crop production maps, they instead use mapped values of human-appropriated net primary productivity, as a proxy for the extent of habitat conversion, to mediate those values. Although relatively simple, a key advantage of this approach is that it is more sensitive to impacts than a measure of species extinction, potentially allowing risks to be identified and addressed earlier (Kitzes et al., 2017).

A study by de Baan et al. (2015) used habitat suitability models of mammal species. This considered the potential land-use effects on individual species to calculate "Area of Habitat", which were weighted by the species' conservation status and range size rarity. However, as for Chaudhary et al. (2015), this "double counts" vulnerability when restricted range size is used first for the threat level assessment by IUCN and then in these analyses to calculate the fraction of the species' range falling within the assessment unit. The work described the impacts of three major export crops but did not link through to trade and consumption databases.

A similar metric was developed by Durán et al. (2020), which measures impacts based on estimates of historical and current area of habitat (AoH). This method advances previous work by allowing species-specific impacts to be assessed, and attributing greater weight to species that have experienced greater historical habitat loss, and the parts of the AoH that fulfil different needs (e.g. breeding, migration,

[27] Version 2021-2: https://www.iucnredlist.org/

wintering grounds) separately. Its spatially explicit nature allows impacts to be attributed to land conversion for particular commodity crops and it was used to estimate species impacts of international soy bean trade through hybridized-MRIO analysis (Green et al., 2019). Mair et al. (2021) also recently developed the "species threat abatement and restoration" metric, which although not yet applied in a foot-printing context, shows promise (see also Section 3.5 on future developments).

There has been a large degree of progress across multiple fronts and, ultimately, there is no "best" option; the most appropriate metric(s) will be dependent upon the context. Multiple perspectives will give a more comprehensive picture of impacts (Crenna et al., 2020; Marques et al., 2021). The spatial heterogeneity of biodiversity means not only that its absolute value will vary from place to place – some areas are "richer" or have greater abundance of flora and fauna – but also that its composition will differ, which means that some areas will be more "irreplaceable" than others because of the species (or other features) that it contains (Baisero et al., 2021). This concept is an important one, particularly for minimizing species extinctions, as it not only identifies sites of high biodiversity, but also sites of unique biodiversity.

Table 5: Selection of studies that use a multiregional input-output approach to quantify the role of agricultural commodity trade in driving biodiversity loss. Adapted from Kastner et al. (2021).

	Coverage				
Example	**Temporal**	**Geographic**	**Commodity**	**Approach**	**Biodiversity loss embodied in trade**
Lenzen et al., 2012	2000	187 countries	15 909 sectors[a]	Attribution of ***biodiversity threats*** to industry sectors	• biodiversity threats used as a proxy for impacts on biodiversity • 30% of global species threats due to international trade
Chaudhary & Kastner, 2016	2011	184 countries	179 crops	***Countryside species-area relationship*** (cSAR) to related land-use area and impacts on species richness	• regional and global impacts on biodiversity measured as potential species extinctions • 17% of global biodiversity loss due to international trade
Kitzes et al., 2017	2007	129 regions	57 sectors	***Bird ranges and bird densities*** linked to a map of Human Appropriation of Primary Productivity and a map of land use	• impacts measured as occupied bird ranges and missing individual birds • 23% of occupied bird ranges and missing birds due to international trade
Wilting et al., 2017	2007	45 regions	48 sectors	Loss in ***mean species abundance*** (MSA) due to land use, urban infrastructure, roads, and climate change	• impacts on biodiversity quantified as loss of MSA • 16% of MSA loss due to international trade
Chaudhary & Brooks, 2019	2007	129 regions	Four land-use types (agric, pasture, urban, forestry)	***cSAR*** to related land-use area and impacts on species richness	• projected global species extinctions • 25% of global species extinctions due to international trade
Green et al., 2019	2000 –2011	Brazil (Cerrado)	Soy	Soy expansion maps linked with ***suitable habitat models***	• Impacts computed as a ''conservation score'' that captures the non-linear cumulative effect of historical habitat loss on the local persistence of a species
Marques et al., 2019	2000 –2011	49 regions	200 products	***cSAR*** to related land-use area and impacts on birds species richness	• global impacts on biodiversity measured as potential bird species extinctions • 22% of potential extinctions due to international trade in 2000 and 25% in 2011
Wilting et al., 2021	2010	162 EU regions, 14 other countries /regions	18 sectors	Loss in ***MSA*** due to land use, urban infrastructure, roads, fragmentation and climate change	• impacts on biodiversity quantified as loss of MSA
Bjelle et al., 2021	1995 –2015	214 countries	200 sectors	LC-IMPACT characterization factors of biodiversity impacts from land use (based on ***cSAR***)	• impacts on biodiversity quantified as potentially disappeared fraction of species • 19% of global PDF due to international trade in 1995 and 33% in 2015
Croft et al., 2021	2005 –2017	44 countries and 5 rest of world regions	162 crop/crop groups	IOTA (hybridized MRIO) to model impacts to final consumption. ***cSAR*** and ***species range*** maps (overlaid with commodity maps).	• Species richness-weighted hectares calculated by overlaying and summing mapped species ranges against hectares of crop. • Country and crop specific cSAR method also implemented (from Chaudhary & Kastner, 2016).
Cabernard & Pfister, 2021[b]	1995 –2015	189 countries	163 sectors	Provide an approach to combine information from MRIO methods to retain high sectoral specificity of EXIOBASE3, but increase spatial specificity by adding Eora26.	• Higher resolution raises the EU's water stress and biodiversity loss footprint by up to 20%. • One third of the EU's biodiversity loss footprint is induced in countries aggregated to Rest of World regions in EXIOBASE3.

[a] Note that some of the sectors are "equivalent", as different classifications are used in different countries but counted separately.

[b] Note that this study has only just been released and was therefore not included in the original Kastner et al. (2021) review.

Appendix 3: Spatialization and specificity

Biodiversity, in particular, is highly heterogeneous across space, and one of the key requirements for the accurate representation of biodiversity impacts in footprinting methodologies, therefore, is the spatialization of datasets. High spatial resolution to understand how biodiversity impacts are distributed across a production landscape is vital, yet missing or limited in many assessments (Cabernard & Pfister, 2021). This spatialization and situation of impacts in a landscape is aided at several stages, including by:

- disaggregating "Rest of World" regions to their constituent countries in consumption-based accounting models (Cabernard & Pfister, 2021)
- increased refinement in the representation of sectors – either by increasing the number of sectors in the model or by linking sectors to the commodities that they represent (Croft et al., 2018; Moran et al., 2016)
- use of fully physical MRIO-equivalent models (e.g. the FABIO model; Bruckner et al., 2019) or of hybridized-MRIO models in which information on the physical production and trade of commodities either complements or replaces information on financial transactions offered by traditional MRIO approaches (Bruckner et al., 2015; Croft et al., 2018, 2021)
- refining upstream connections of supply chain models to make links to subnational production areas (Croft et al., 2018; Godar et al., 2015)
- using maps of commodity production and expansion to refine the spatial extent of expected impacts (Croft et al., 2021; Durán et al., 2020; Green et al., 2020).

Appendix 4: Sea Around Us data

The Sea Around Us (SAU) dataset supplements officially reported statistics with interpolated estimates from other sources in an attempt to reflect the full picture of capture fisheries exploitation; the premise is that it is worse to put a value of zero for the catch of poorly documented fisheries than to estimate this catch, even if this is done roughly. A six-step approach implements this: 1) Baseline catch time series is collated from official FAO records, International Council for the Exploration of the Sea and national data; 2) Sectors not covered are identified via literature search and expert consultation; 3) Sources for missing data are identified via searches; 4) Data "anchor points" are developed for each missing data component; 5) Interpolation takes place between these anchor points; 6) A resultant time series is compiled of reported catches in Step 1 and the outcome of Step 5. Estimates of the gear used are derived by SAU from a combination of data in Step 1 and that compiled by expert input and review in Steps 2–5.

Within PRINCE 2, in order to associate gear type with the utilized (landed) component of capture fisheries, we use catch method (gear type) records from the *reported* component of the Sea Around Us dataset. These data are used to define – for each species (or species group) record, fishing entity and year – the distribution of the total catch of the species by catch method.

The process to construct the gear-type extension to landed (reported only) fisheries mass is as follows for each year in the time series and for each fishing entity (country):

- Aggregate SAU data across Exclusive Economic Zone and high seas fishing areas to provide total capture for each species/species group.
- Determine the species/species groups in FAO FSJ records that can be matched to SAU per fishing entity. In cases where there is no direct match at species level, a concordance list has been developed that allows matching between records (but see also Limitations, Section 6.2.4).
- For each matched record, calculate the proportion of total catch comprising each fishing gear by dividing SAU catch per gear by total catch.
- Multiply the corresponding FAO landing statistics by these proportions to provide estimates of FAO mass by gear type.

Sea Around Us also provides estimates of discards (see Zeller et al., 2018) – the unused component of fisheries capture activities – which mainly originate from industrial fisheries. In constructing the SAU dataset, a gear-specific discard rate is applied to landings (of all taxa) by particular gears to calculate a total discard amount per gear. A taxonomic breakdown of the total discards by that gear type then takes place in order to disaggregate the species estimated to have been discarded in association with the gear type. This means that discard estimates are associated with the gear type used and not the species targeted.

Estimates of discards across gear types require the calculation of a conversion factor between the total captures by gear (both unreported and reported components of captures are used to estimate discard quantities in the SAU dataset) and the associated discards. To achieve this, for each year and fishing entity:

1. The estimated discards by gear are summed across all species/species groups (see also Section 6.2.4 of the main report).
2. The total reported and unreported landings by gear are summed across all species/species groups.
3. Summed discards are then divided by summed catches to provide a gear-specific discard rate.

This discard rate can then be multiplied by the captures associated with the respective gear-type in the previously compiled gear-type extended FAO dataset, to estimate the total discards occurring in association with each capture activity.

The estimates of catch method and discards compiled are – within our environmental extension – associated with FishStat capture information that can be assigned to the appropriate country or region within the “Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)” sector. Extension sheets were prepared for each year between 1995 and 2018.

Appendix 5: Assessing the direct impacts of aquacultural production

In our scoping exercise of the environmental impacts associated with aquaculture, we were interested in assessing the availability of data that would support assessment of the direct impacts of agricultural production; that is, the site-linked impacts arising from the rearing of fish and other species in closed managed systems.

Life cycle assessment (LCA) of aquaculture provides a good platform for understanding how impacts have been conceptualized and incorporated into production system impact assessments. In a relatively recent review of 65 LCA studies (Bohnes et al., 2019), while feed production dominates impacts linked to climate change, acidification, energy use and net primary production use, it is eutrophication which is a key cause of concern linked to the farming process itself. The review also found that different aquaculture systems and technology components may exert considerably different environmental impacts, highlighting a requirement for understanding these with some specificity when trying to establish how impacts from source regions might vary within consumption profiles.

The review by Bohnes et al. (2019) identifies important biases in the underpinning studies relative to the geographic and species-level contributions to global aquaculture production. Approximately 50% of LCA studies are linked to European aquaculture systems, which make up just 3% of global production. Conversely, aquaculture systems in Asia make up 90% of global production, but only 24% of studies. Similarly, 42% of studies have focused on diadromous fisheries (e.g. salmonids), which represent only 7% of global production. Freshwater systems represent 60% of global production, but only a quarter of studies. As a result – and given the conclusion that technologies vary widely geographically – the studies reviewed are unlikely to be representative of the breadth of environmental impacts that might be experienced internationally.

The review does offer some important general conclusions from the studies covered, however. In particular, the farming technologies employed appeared to influence all impact categories considered (climate change, eutrophication, acidification, energy demand, water dependence, net primary production use) aside from acidification, and the feed conversion ratio (FCR) seems influential for climate change, eutrophication and energy demand. The FCR reflects the amount of feed needed per unit of animal weight gain, with nitrogen and phosphorus emissions from uneaten feed, and fish faeces, resulting in eutrophication identified as a critical component of aquaculture sustainability. FCR is influenced by feed composition, the technology used, the fish species and the mortality at the site (Pelletier et al., 2009). While the fish species harvested does influence impacts, the authors note that other parameters may also alter the impact results, with species' needs potentially varying between countries and/or technologies.

Ultimately, coarse estimates of FCR (or similar measures) could be likely obtained for broad aquaculture systems, which may still have some utility in understanding the overall pressures imposed by consumption of aquaculture products. For example, Fry et al. (2018) provide ranges of FCR for a variety of cultured species groups. Verdegem (2013) also concludes that the nutrient input (feed) to extraction (harvest) ratio can be much higher in freshwater aquaculture in comparison with marine and brackish water environments, with the harvesting of molluscs and aquatic plants often leading to negative nutrient loading (more is harvested than input) in contrast to finfish and crustaceans leading to net nutrient loading.

Bohnes et al. (2018) also highlight the importance of the development of national or sectoral studies in informing understanding of aquaculture sustainability. Yet of the 65 LCA studies reviewed, only six adopted a country-scale perspective, and only four focused on a whole sector. The authors highlight that LCA methodologies, which have traditionally been applied at product level, are not always directly applicable to large-scale systems; more research to enable the conduct of such studies is needed.

A recent, interesting, example of an LCA-inspired study at national scale exists for France (Lucas et al., 2021). First, the authors constructed an "original database of the origin of fisheries and aquaculture products", and then utilized FAO FishStat data for French production and Eurostat trade data for fisheries imports and exports, correcting manually based on expert knowledge and literature. This "database of origin" was then matched to three environmental indicators (climate change, eutrophication, and energy demand). The eutrophication potential (kg PO_4^{3-} eq/ton) takes into account the emissions of reactive nitrogen and phosphorus in the ecosystems of production. Characterization factors for eutrophication greenhouse gases and energy use were compiled from over 20 sources, but the database of these factors does not appear to be in the public domain. Results from this study, however, indicate the mean impacts at global level per species group (see Table 6).

Table 6: Estimates of climate-, eutrophication- and energy-linked indicators, at global level, for different aquaculture production systems. Reproduced from Lucas et al. (2021).

Global environmental indicators (/tons of live weight)			
	kg CO_2 eq.	kg PO_4^{3-} eq.	MJ
Demersal and benthic	2368	8	27,961
Shellfish	545	1	10,414
Pelagic	1155	3	17,917
Salmonidae	2143	48	33,283
Shrimps and prawns	10,344	78	34,446
Crustaceans (excl. S&P)	10,315	34	132,906
Freshwater fish	5370	33	19,731
Cephalopods	6094	14	47,953
Seabass and seabream	2909	65	45,147
Overall	2622	18	26,599

Also recently, Huang et al. (2020) have attempted to map the global, spatially distributed, application and utilization of phosphorus (P), compiling a dataset which details the phosphorus use efficiency (PUE) of different species farmed in selected locations and environments (marine and freshwater, farmed and captured species). Aquaculture farm system-level PUE estimates (defined as P harvested via fish biomass divided by P input via feed and fertilizer) have been compiled for a representative range of farm types, with 168 “culture-system” entries in total (based on 96 peer-reviewed publications). The PUE values span a wide range (1–167%; see Figure 19) and are associated with pond, tank, cages, recirculating and flow-through aquaculture systems across Australia, Bangladesh, Brazil, China, Czech Republic, France, Honduras, India, Ireland, Israel, Madagascar, Mexico, Poland, Saudi Arabia, Sweden, Thailand, United States and Viet Nam. While this database is not globally comprehensive, further extended work could ascertain whether estimates of PUE could be applied to FAO fisheries information within a consumption-based accounting framework.

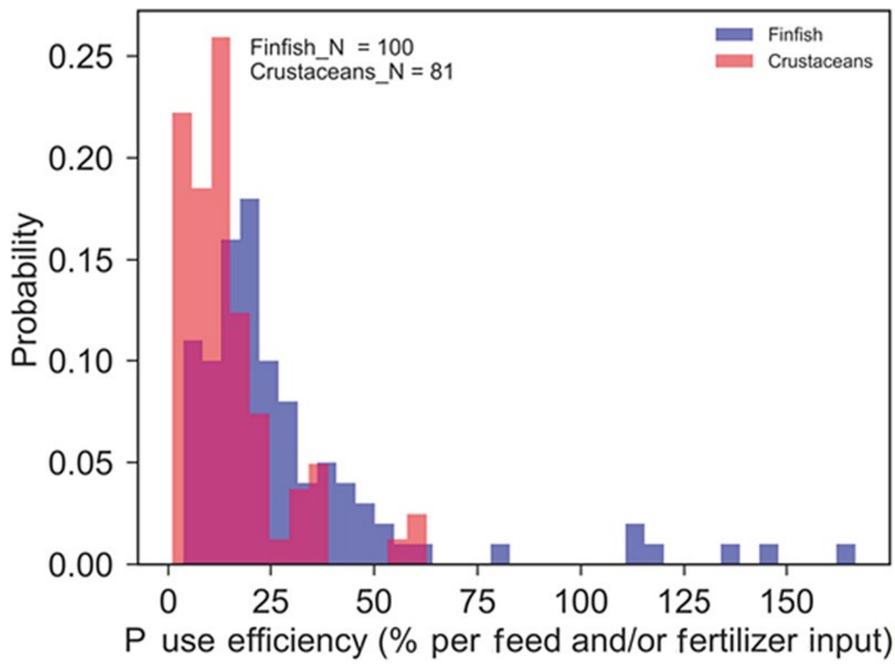

Figure 19: Distribution of culture-system level phosphorus use efficiency, split by finfish and crustacean systems. Reproduced from Huang et al. (2020) supplementary information.

Appendix 6: List of abbreviations

CPA	Classification of Products by Activity (a European standard statistical classification)
cSAR	countryside species-area relationship
EEIO	environmentally extended input-output
EMA	European Medicines Agency
ESVAC	European Surveillance of Veterinary Antimicrobial Consumption
FAO	Food and Agriculture Organization
FCR	feed conversion ratio
FSJ	FishStatJ
GSBPM	Generic Statistical Business Process Model
HCP	hazardous chemical products
IOTA	input-output trade analysis framework
IUCN	International Union for Conservation of Nature
LCA	life cycle assessment
MRIO	multiregional input-output
PRINCE	Policy Relevant Indicators for National Consumption and Environment
PUE	phosphorus use efficiency
SAU	Sea Around Us
SEPA	Swedish Environmental Protection Agency
WULCA	Water Use in Life Cycle Assessment working group

Appendix 7: Peer-reviewed scientific publications from PRINCE 1

Cederberg, C., Persson, U. M., Schmidt, S., Hedenus, F., & Wood, R. (2019). Beyond the borders: Burdens of Swedish food consumption due to agrochemicals, greenhouse gases and land-use change. *Journal of Cleaner Production, 214*, 644–652. https://doi.org/10.1016/j.jclepro.2018.12.313 (open access)

Croft, S. A., West, C. D., & Green, J. M. H. (2018). Capturing the heterogeneity of sub-national production in global trade flows. *Journal of Cleaner Production, 203*, 1106–1118. https://doi.org/10.1016/j.jclepro.2018.08.267 (open access)

Dawkins, E., Moran, D., Palm, V., Wood, R., & Björk, I. (2019). The Swedish footprint: A multi-model comparison. *Journal of Cleaner Production, 209*, 1578–1592. https://doi.org/10.1016/j.jclepro.2018.11.023

de Boer, B. F., Rodrigues, J. F. D., & Tukker, A. (2019). Modeling reductions in the environmental footprints embodied in European Union's imports through source shifting. *Ecological Economics, 164*, 106300. https://doi.org/10.1016/j.ecolecon.2019.04.012

Fauré, E., Dawkins, E., Wood, R., Finnveden, G., Palm, V., Persson, L., & Schmidt, S. (2019). Environmental pressure from Swedish consumption: The largest contributing producer countries, products and services. *Journal of Cleaner Production, 231*, 698–713. https://doi.org/10.1016/j.jclepro.2019.05.148

Joyce, P. J., Finnveden, G., Håkansson, C., & Wood, R. (2019). A multi-impact analysis of changing ICT consumption patterns for Sweden and the EU: Indirect rebound effects and evidence of decoupling. *Journal of Cleaner Production, 211*, 1154–1161. https://doi.org/10.1016/j.jclepro.2018.11.207

Moran, D., Wood, R., & Rodrigues, J. F. D. (2018). A note on the magnitude of the feedback effect in environmentally extended multi-region input-output tables. *Journal of Industrial Ecology, 22*(3), 532–539. https://doi.org/10.1111/jiec.12658

Nordborg, M., Arvidsson, R., Finnveden, G., Cederberg, C., Sorme, L. Palm, V., Stamyr, K., & Molander, S. (2017). Updated indicators of Swedish national human toxicity and ecotoxicity footprints using USEtox 2.01. *Environmental Impact Assessment Review, 62*, 110–114. https://doi.org/10.1016/j.eiar.2016.08.004

Palm, V., Wood, R., & Björk, I. (2019). The Swedish footprint: A multi-model comparison. *Journal of Cleaner Production, 209*, 1578–1592. https://doi.org/10.1016/j.jclepro.2018.11.023

Palm, V., Wood, R., Berglund, M., Dawkins, E., Finnveden, G., Schmidt, S., & Steinbach, N. (2019). Environmental pressures from Swedish consumption: A hybrid multi-regional input-output approach. *Journal of Cleaner Production, 228*, 634–644. https://doi.org/10.1016/j.jclepro.2019.04.181

Pendrill, F., Persson, U. M., Godar, J., Kastner, T., Moran, D., Schmidt, S., & Wood, R. (2019). Agricultural and forestry trade drives large share of tropical deforestation emissions. *Global Environmental Change, 56*(May 2019), 1–10. https://doi.org/10.1016/j.gloenvcha.2019.03.002 (open access)

Persson, L., Arvidsson, R., Berglund, M., Cederberg, C., Finnveden, G., Palm, V., Sörme, L., Schmidt, S., & Wood, R. (2019). Indicators for national consumption-based accounting of chemicals. *Journal of Cleaner Production, 215*, 1–12. https://doi.org/10.1016/j.jclepro.2018.12.294

Schim van der Loeff, W., Godar, J., & Prakash, V. (2018). A spatially explicit data-driven approach to calculating commodity-specific shipping emissions per vessel. *Journal of Cleaner Production, 205*, 895–908. https://doi.org/10.1016/j.jclepro.2018.09.053 (open access)

Schmidt, S., Södersten, C.-J., Wiebe, K., Simas, M., Palm, V., & Wood, R. (2019). Understanding GHG emissions from Swedish consumption: Current challenges in reaching the generational goal. *Journal of Cleaner Production, 212*, 428–437. https://doi.org/10.1016/j.jclepro.2018.11.060

Sörme, L., Palm, V., & Finnveden, G. (2016). Using E-PRTR data on point source emissions to air and water: First steps towards a national chemical footprint. *Environmental Impact Assessment Review, 56*, 102–112. https://doi.org/10.1016/j.eiar.2015.09.007

West, C. D., Hobbs, E., Croft, S. A., Green, J. M. H., Schmidt, S. Y., & Wood, R. (2019). Improving consumption-based accounting for global capture fisheries. *Journal of Cleaner Production, 212*, 1396–1408. https://doi.org/10.1016/j.jclepro.2018.11.298

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New methods and environmental indicators supporting policies for sustainable consumption in Sweden

Final report – PRINCE phase 2

The second phase of the PRINCE project has summarized and built further on the achievements of the first phase of the project. PRINCE has already influenced policy processes, such as the investigation of a goal for consumption-based greenhouse gas emissions in Sweden, the development of data for monitoring the UK 25 Year Environment Plan and supporting the development of deforestation strategy for the European Union.

Gap analyses in the second phase of PRINCE have produced experimental time series for consumption-based indicators for deforestation-related greenhouse gas emissions, veterinary antibiotics and pesticides, that are judged to satisfy criteria for official statistics. The second phase also developed similar experimental time series for hazardous chemical product use, biodiversity and fisheries which require further methodological development before they can be considered for official statistics.

There is still potential for increased policy uptake for consumption-based approaches.

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