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Towards indicators of the global environmental impacts of UK consumption: Embedded Deforestation

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SEI Stockholm Environment Institute

Summary

The Outcome Indicator Framework for the UK Government's 25 Year Environment Plan calls for the development of an indicator to measure the "overseas environmental impacts of UK consumption of key commodities." This report describes the work undertaken to date and the work planned to take place over the coming months in order to release this indicator as an experimental statistic following completion of the project in August 2021. It is planned that this will feed into Outcome Indicator Reporting for 2022.

- Preliminary results for deforestation embedded in UK consumption of crop-driven agricultural commodities are presented in Appendix 1. UK consumption of agricultural commodities (excluding livestock) is estimated as responsible for 20,196 ha of tropical deforestation in 2017; a 42% decrease compared to 2005. Results are also presented for the total land area used to grow this same selection of agricultural crops consumed within the UK, the total GHG emissions from deforestation and the total tonnes of embedded production for UK consumption.
- The methodological approach that has been selected for indicator calculation is described in Appendix 2. This is based on combining multi-regional input-output modelling with physical production and trade data and a deforestation dataset, to determine where impacts from UK consumption are taking place and which commodities are causing this impact.
- Additional results are presented in Appendix 3. These break down the total deforestation, land use, GHG emissions from deforestation and tonnes of embedded consumption to show the breakdown of the ten most significant commodities. For example, the three commodities contributing most to total deforestation from UK consumption are estimated to be oil palm, soy and maize. Following project completion in August 2021, such results will be presented on an interactive dashboard to allow for greater interrogation of the data.
- A technical outline of future work planned can be found in Appendix 4. This includes the development of additional impact metrics and the proposed QA process prior to release as an experimental statistic.

Contents

1 Introduction

This report is a research output describing progress to date on the development of a suite of indicators showing the global environmental impacts of UK consumption. The main report describes the processes being undertaken, including the project background, structure, input from both a steering group and a wider stakeholder group, considerations of alignment with the existing UK Carbon Footprint and development of a dataset for the indicator.

- Appendix 1 presents a draft indicator, associated with consumption of crop-driven agricultural products, for the UK's material footprint, land use footprint, embedded deforestation impacts and embedded greenhouse gas (GHG) emissions from deforestation between 2005 and 2017. This will be used to obtain feedback for improvements before the full release of an experimental statistic at the end of the current project. The experimental statistic will also include additional impact metrics such as biodiversity or water stress and will aim to extend the scope beyond agricultural commodities.
- Appendix 2 presents the technical documentation explaining the methods behind the data presented.
- Appendix 3 gives additional information on impacts that were calculated but not included in the headline results, as they go into greater detail than an indicator typically would. This includes a breakdown of the source of impact by commodity. Following project completion, such results will be presented on an interactive dashboard separately from the indicator, which is better suited to identifying countries and commodities of interest than static graphs.
- Appendix 4 gives a technical outline of future work planned.

2 Background

2.1 Policy context

Around 50% of direct UK food supply is met from production in other countries (Defra 2017). The UK is also heavily reliant on imports for many other commodities, such as minerals and fuels. Imports embedded within composite products (such as palm oil as an ingredient in cosmetics) are more difficult to trace, but also make up a substantial proportion of UK consumption. Therefore, addressing the sustainability of UK consumption of commodities grown overseas is at least as important as that of commodities grown in the UK.

Globally, consumption of commodities is a major driver for loss of natural habitats and degradation of ecosystem services, such as biodiversity, resilience to hazards, and climate change mitigation and adaptation. For example, 9-14% of global annual GHG emissions come from the gases emitted and sequestration potential lost when land is converted for food and fibre commodity production (reviewed in Harris *et al*. 2020). The issue has been highlighted recently in multiple high-profile reports, such as the National Food Strategy, the Dasgupta review and zero drafts of the Convention on Biological Diversity's post-2020 framework.

The Government's 25 Year Environment Plan recognises the need to better understand the UK's contribution to such impacts. It sets out a series of indicators to track delivery of progress. One of these indicators (K1) relates to the "overseas environmental impacts of UK consumption of key commodities" and is designed to enable government to measure the risks and impacts associated with UK consumption. This publication aims to report on the approach that will be taken to measure against this headline indicator and present preliminary results for agricultural commodities.

2.2 Previous work

In 2018/19, Defra contracted JNCC (the Joint Nature Conservation Committee) to begin work on the development of an indicator of the "overseas environmental impacts of UK consumption of key commodities" for use in the 25 Year Environment Plan's annual Outcome Indicator Framework reporting. Two approaches, both of which were internationally peer reviewed, were explored. One project, contracted to Route2 (a sustainability consultancy), investigated best practices in the field of measuring consumption impacts (Route2 and Carbon Smart 2019). This project used a type of trade modelling known as multi-regional input-output (MRIO) modelling that allows impacts (e.g. deforestation, land use) to be broken down by i) the country of origin impacted by UK consumption, and ii) the commodities causing the greatest impacts (e.g. most deforestation). The other project investigated if the proportion of imports that are certified as being sustainable, originally proposed against this indicator of the 25 Year Environment Plan, could be developed into a feasible and effective method (Harris *et al.* 2019). It concluded that this would not be an appropriate indicator to use, as certification data is not included in official trade data (so calculation is not possible) and differences between certification standards make comparisons complex. Therefore, the former approach was taken forward for subsequent work.

In 2019/20, JNCC carried out additional work to assess the robustness of the approach proposed by Route2. This work validated the method and concluded it had potential to elucidate powerful relationships and metrics, provided certain limitations are well-communicated and understood. A roadmap was produced based on this work and based on consultation with external experts. This recommended the 25 Year Environment Plan indicator should:

- be based on a hybrid MRIO approach. This builds on the basic MRIO approach proposed by Route2 by also including physical production and trade data, allowing for a greater commodity and country resolution (i.e. the data can be broken down into individual commodities, such as palm oil, instead of just aggregated sectors, such as oilseeds – and results can be provided for all countries instead of leaving some countries aggregated into 'rest of world' regions).
- generate several separate metrics of sustainability (e.g. water, soils, biodiversity, habitat conversion, habitat degradation, GHG emissions, etc.).
- be developed in a phased approach, whereby an experimental statistic is developed after the first year, but work continues for the subsequent three years to improve the indicator and produce a final version.

3 Indicator development process

The current project runs from December 2020 to August 2021. The final output will be the release of an experimental statistic that can be used in the 25 Year Environment Plan Outcome Indicator Framework's annual reporting from 2022. It will also feed into the UK Biodiversity Indicators. This interim output presents preliminary results up to March 2021 (Appendix A). The project is managed by JNCC, with analyses carried out by contractors Stockholm Environment Institute (SEI).

3.1 Steering group engagement

The project is supported by a steering group of currently twelve representatives from six different Defra teams. The group meet at project milestones to provide input on key decisions, such as feedback on project planning, prioritisation of research direction (e.g. the range of commodities and impact metrics to include) and data visualisation.

3.2 Stakeholder engagement

Many stakeholders would form part of the longer-term user base for an indicator once developed. The project is, therefore, also engaging with a wider stakeholder group, including representatives from industry, non-governmental organisations (NGOs) and more widely across Government departments.

In February 2021, a workshop convened these stakeholders to provide input to an indicator. The aim was to report on total environmental impacts from UK consumption, categorised by the production countries in which the impacts take place and the commodities/sectors driving the impact, for use in 'hot-spotting' areas and commodities of highest risk. The workshop sought views from the wider stakeholder group around:

- potential secondary use cases for the indicator, beyond the 25 Year Environment Plan.
- priorities from potential end users around the impact metrics (e.g. deforestation, water stress, biodiversity) that should be selected.
- potential end user preferences for improvements that focus on widening the range of commodities that can be analysed, or the geographic resolution of a smaller number of specific commodities at the point of production, using sources such as Trase.

Many potential use cases were identified, including macro-scale decision making, proving the credentials or progress of a sector, and complementing current reporting procedures. Stakeholders saw biodiversity, land use, deforestation and GHG emissions from deforestation as the highest priority impact metrics to be developed. There were mixed opinions on whether implementing a broad or a narrow approach regarding improvements to commodity data would be of most use, with stakeholders recognising the advantages and disadvantages of each approach.

Two further engagement events are planned between April and August 2021, to gather feedback on data visualisation options and to better understand how the draft indicator is interpreted.

3.3 Consideration of alignment and consistency with the UK Carbon Footprint and UK Material Footprint

Leeds University already compile an MRIO based indicator about two aspects of the UK's consumption impacts, in the form of the UK Carbon Footprint and the UK Material Footprint. The project recognised the potential for alignment as it could be useful if other environmental indicators developed in this body of work are produced in a consistent and comparable way with existing UK indicators. In particular, this project is producing a material footprint of its own, on which the impact metrics are based, and a GHG emissions from deforestation indicator (an aspect of GHG emissions not currently included within the UK Carbon Footprint). The project team, therefore, met with those who work on the UK Carbon Footprint in February 2021 to discuss potential alignment opportunities.

However, the nature of the UK Carbon/Material Footprint does not allow for a detailed breakdown in terms of commodities and countries of origin, unlike the indicator developed under this project. For example, carbon emissions linked to agricultural commodities are presented at an aggregate 'agricultural' sector level, which cannot be broken down into specific commodities such as soy, wheat, palm oil, etc., and geographic resolution is limited to that of the MRIO. This is because the GHG/Material footprints aim to quantify the overall pressure that the UK is exerting, whilst the work within this project aims to understand in greater detail the location of impacts and their associated drivers, to inform action. As understanding countries and commodities of impact is key to many of the current indicator's use cases across both the steering group and the stakeholder group, it was decided that in this case alignment would not be immediately beneficial. GHG emissions are also less sensitive to spatial heterogeneity compared to impacts such as deforestation and biodiversity.

It should therefore be flagged that the results from these two indicators will not be directly comparable. They are not in the same format, and they also use separate methodologies. However, the project team will keep channels of communication open with Leeds as future use cases may emerge where direct harmonisation in approaches is useful. One such use case would be in an instance where the land-use emissions estimates resulting from the work conducted for this report could be considered as a 'supplement' to UK GHG accounts (which currently do not include LULUCF (Land Use, Land Use Change and Forestry) emissions).

3.4 Development of a draft indicator

Work undertaken within the project so far has led to the development of a draft indicator, presented in Appendix 1. This hybridised MRIO data from Exiobase with commodity specific data from the Food and Agricultural Organisation (FAO) and deforestation specific data from Chalmers University of Technology (Pendrill *et al.* 2020).

- Exiobase was chosen as the MRIO dataset used in the UK GHG and Material Footprint accounts, which also has the advantage of high sectoral resolution (although low country resolution; see Appendices).
- FAO was chosen as a comprehensive source of international production statistics with associated bilateral trade information that can be readily ingested into the modelling framework.
- The Pendrill *et al.* (2020) dataset offers comprehensive coverage of the agricultural commodity drivers of deforestation in tropical and sub-tropical regions.

All datasets are also regularly updated. The methods used in SEI's Input-Output Trade Analysis modelling framework were adopted to combine these data and are described in more detail in Appendix 2, based on peer reviewed methods described in Croft *et al.* 2018.

4 Next steps

Over the coming months, the project team will:

- organise two further stakeholder engagement sessions with the objectives described in section 3.2;
- make use of the draft indicator presented in Appendix 1 to understand how it is interpreted and can best be communicated;
- model additional impact metrics such as biodiversity and water stress;
- expand results to include more than agricultural commodities;
- identify any surprising results and use literature and independent data sources to identify reasons behind them;
- develop an interactive dashboard to present more detail than the static indicator;
- prepare for the release of refined results as an experimental statistic following project completion in August 2021, including undertaking an external review. It is expected

that this will feed into 2022 reporting for the 25 Year Environment Plan Outcome Indicator Framework.

Future work is described more fully in Appendix 4, including details of additional quality assurance processes and methodological refinements that will need to be carried out on the preliminary results presented in Appendix 1.

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Appendix 1 – Draft indicator

1. Introduction

This draft indicator shows the global environmental impacts of UK consumption of agricultural commodities (currently excluding livestock) between 2005 and 2017. This publication is an interim output and results are expected to change at the point of release in August 2021, following methodological refinements and inclusion of livestock and non-agricultural commodities. Impacts of UK consumption considered in this current version include:

- the agricultural commodity linked embedded tropical deforestation
- the resulting land use change related GHG emissions
- the agricultural commodity linked land use footprint
- the agricultural material footprint.

Whilst the output acts as an economy wide indicator covering total UK consumption of agricultural commodities, the data can also be broken down by commodity and the country where the impacts occur.

2. Key results

UK consumption of agricultural commodities in 2017 was responsible for an estimated 20,196 ha of agriculture driven (currently excluding livestock) tropical deforestation worldwide: a decrease of 42% since 2005 (Figure 1b). This is associated with an estimated total land use footprint of 15.28 million ha, representing a decrease of 29% over the same period (Figure 1a). The deforestation estimate shows the total area of forest converted for production of agricultural commodities, whereas the land use footprint shows the total area of land required for production, including both recently and land that has been used for production historically.

Deforestation linked to 2017 consumption activities led to a total of 12.76 million tonnes of land use change related CO_2 emissions (Figure 2), 36% of which related to peat drainage and the balance of which related to the loss of both above and below-ground biomass, and organic carbon in the soil.

UK consumption of agricultural commodities in 2017 had an estimated total material footprint of 103.38 million tonnes, a decrease of 23% compared to 2005 (Figure 3).

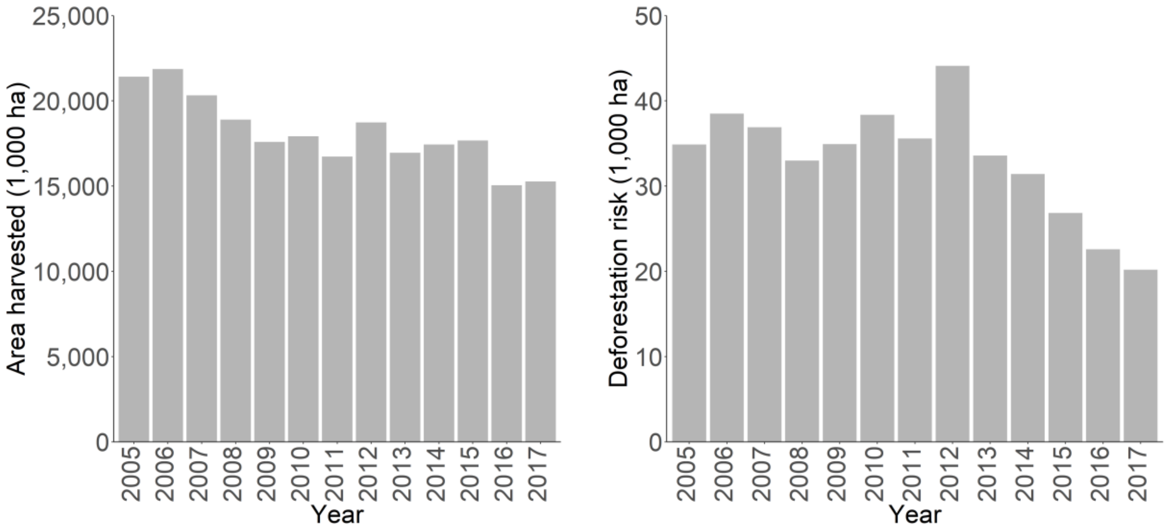
In 2017, the preliminary results show countries where UK consumption was responsible for the most tropical deforestation were Indonesia (5,482 ha), Brazil (3,550 ha) and Myanmar[1] (1,354 ha, Figure 4). The UK-consumed commodities causing the highest rates of global tropical deforestation were oil palm (5,496 ha), soybeans (3,084 ha) and maize (1,809 ha, Figure 5). Both the top three countries and top three commodities are responsible for over 50% of total deforestation risk attributable to the UK.

Footprints seem to show consistent decreasing trends. However, there are some potential anomalies in the dataset which require additional investigation, notably the observed spike in UK-linked deforestation in 2012 and the large decrease in land use and material dependency between 2015 and 2016. Explanatory causes may include changes in the production system, differences in yearly trade or inter-sectoral transactions as represented in

[1] Results from Myanmar have slightly lower confidence and may reflect (at least in part) an underlying trade data issue which will be investigated in the next phase of the project. See Appendix 4 for more details.

the data sources (such as rapid change in domestic or overseas production dependencies), or artefacts in the source data. The slight downwards trend in the material footprint suggests that some, but not all, of the explanatory cause is a reduction in total consumption of these commodities. The fact that the deforestation footprint is decreasing at a faster rate than the land use footprint suggests that an increasing proportion of production is taking place on historically converted rather than newly converted land.

The presence of oil palm fruit, soy and coffee as key sources of UK deforestation risk is common to other assessments, but the preliminary data reveals UK linkages to other supply chains (such as beans, cassava, paddy rice) which are not often considered as 'deforestation risk' materials. These supply chains warrant further investigation to understand e.g. which sectors of consumption are linked to these estimated impacts.



(a) Total area harvested (1000 ha) resulting from the consumption of agricultural commodities in the UK.

(b) Risk of global deforestation (1000 ha) resulting from the consumption of agricultural commodities in the UK.

Figure 1. a) Total area harvested (1000 ha) and b) risk of global deforestation (1000 ha) resulting from the consumption of agricultural commodities in the UK, 2005 to 2017.

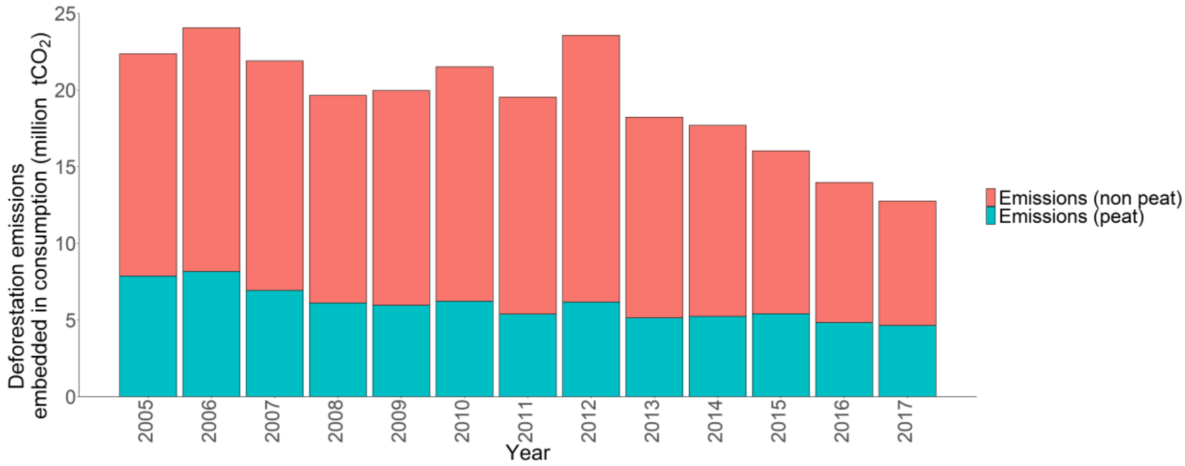


Figure 2. Total deforestation-related emissions (tCO2) embedded within UK consumption. Teal line includes emissions due to peat drainage, and the red line excludes emissions due to peat drainage.

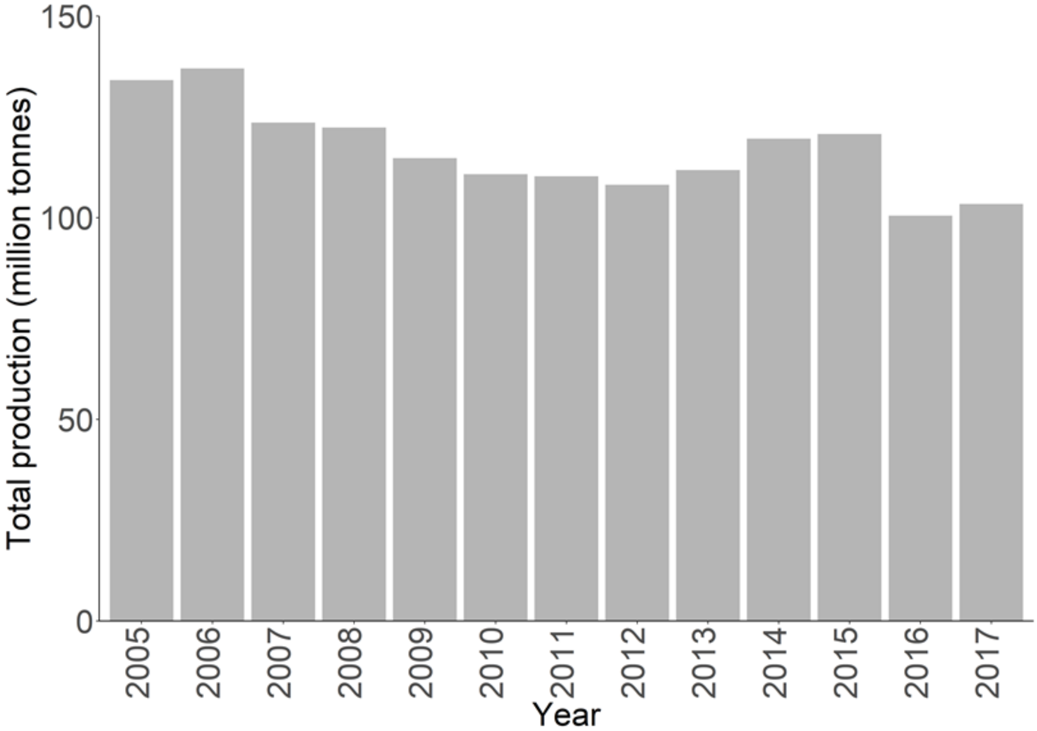


Figure 3. Total agricultural production (tonnes) embedded within UK consumption.

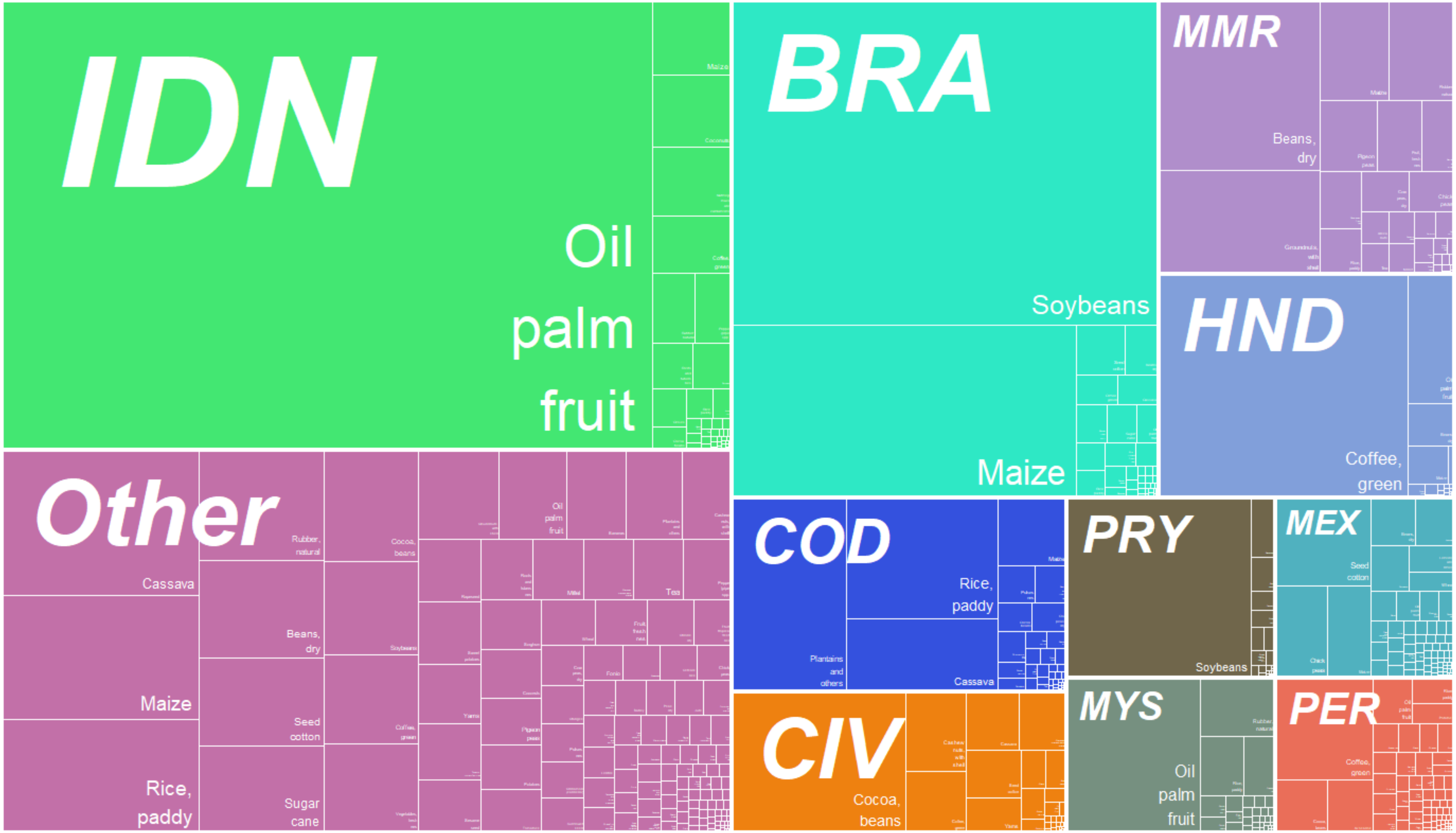


Figure 4. The composition of the UK deforestation footprint by source country (top ten plus 'other') and commodity in total for 2017. Size of block is proportional to footprint. Coloured blocks represent source country (IDN = Indonesia, BRA = Brazil, MMR = Myanmar, HND = Honduras, COD = Democratic Republic of the Congo, CIV = Ivory Coast, PRY = Paraguay, MYS = Malaysia, MEX = Mexico, PER = Peru). This is a representation of one way in which footprint data can be visualised and will be possible to explore more thoroughly in an upcoming interactive dashboard.

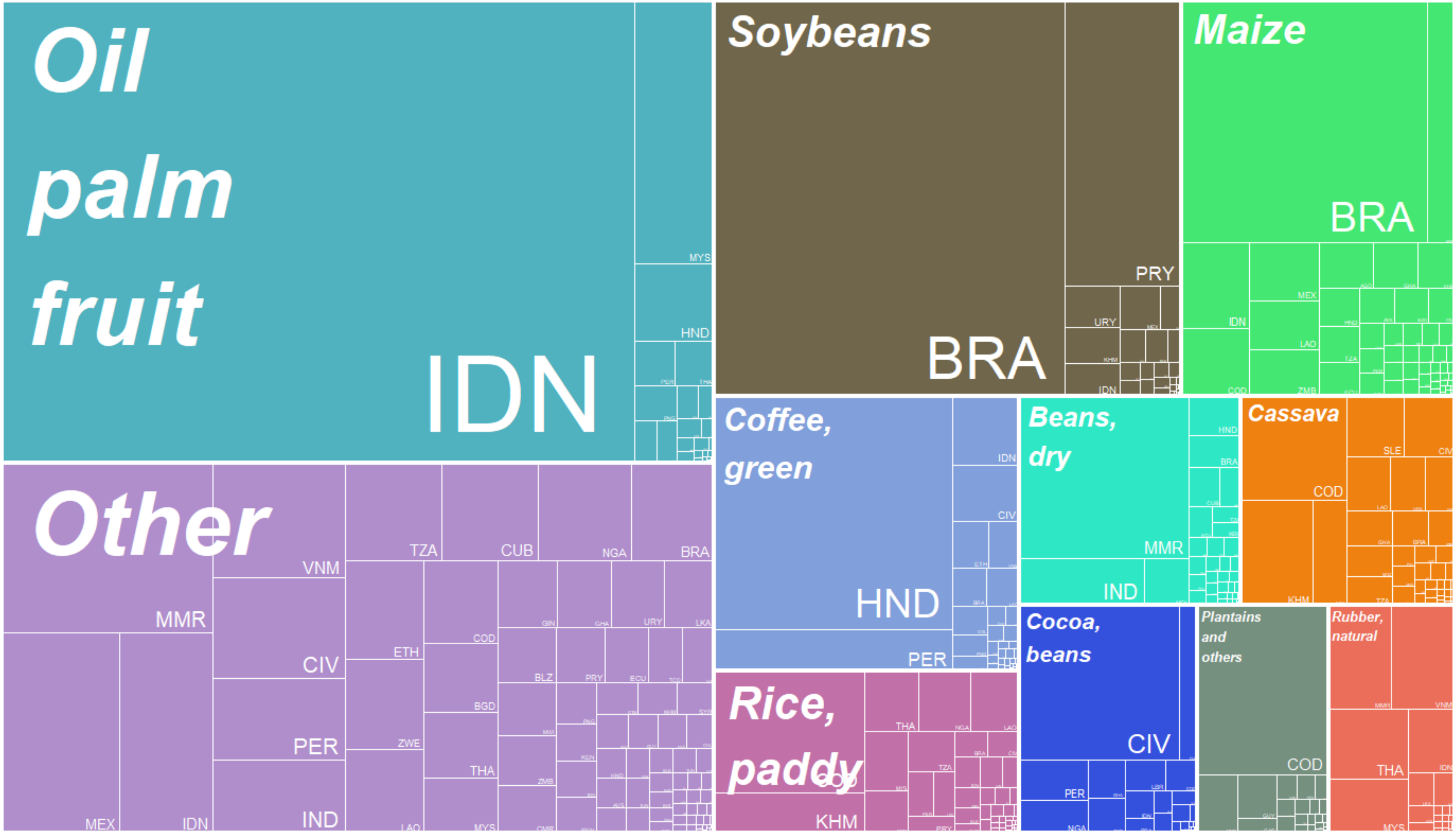


Figure 5. The composition of the UK deforestation footprint by commodity (top ten plus 'other') and source country in total for 2017. Size of block is proportional to footprint. Coloured blocks represent deforestation footprints per commodity. Country codes are based on ISO 3166-1 alpha-3 codes.

3. Indicator description

The full methodology for this indicator can be found in the technical documentation[2]. The method is based on MRIO modelling used to model global trade flows through tables representing the monetary inputs and outputs across different countries and their commercial sectors (e.g. oilseeds, cattle farming, paddy rice, etc.). The MRIO data used for this indicator was from Exiobase (an MRIO database). The Exiobase dataset was selected to increase alignment and consistency with other UK footprint accounts (the UK GHG and Material Footprints) and due to its considerable temporal coverage. As well as this, it allows for data to be broken down into a high number of different sectors compared to other MRIO datasets (although country data are more aggregated).

The MRIO data was hybridised with physical data from the Food and Agricultural Organisation, using the Stockholm Environment Institute's IOTA (Input Output Trade Analysis) model (Croft *et al*. 2018). This step allows for a higher resolution breakdown of commodities (e.g. palm oil, soybeans, etc., instead of just oilseeds) and of countries of origin than MRIO data would alone, and allows trade - in physical units - at commodity level to also be included before this data is integrated into the MRIO framework. This gives the footprint results at a greater level of product-specificity than a standalone MRIO-based account. The Food and Agriculture Organisation Statistics were chosen for use because they are a comprehensive set of global production statistics, collected from official national statistics of each country, which can be easily incorporated into the modelling framework.

To determine deforestation and CO_2 emissions from deforestation, data from Chalmers University of Technology linking deforestation and commodity production (Pendrill *et al*. 2020) has been used to proportionally attribute UK deforestation impacts based on the volumes of each commodity the UK consumes within each production country (for example, if the Pendrill dataset links x ha of deforestation in that country with the production of a particular commodity, and the UK consumes y % of that commodity produced in that country, then it is assumed that the UK is responsible for y % of those x ha). This deforestation dataset was selected as it provides data on deforestation in tropical and sub-tropical regions and its associated agricultural commodity drivers, with comprehensive coverage.

Due to data availability, currently the data reflect the situation pre-25 Year Environment Plan, from 2005 to 2017. It is expected that annual updates will be possible, with 2018 data planned for release in 2022 if dependant data sources are updated as expected and funding for upkeep of the indicator allows.

4. Relevance

The Government's 25 Year Environment Plan has set out a series of indicators to track progress. One of these indicators (K1) relates to the "overseas environmental impacts of UK consumption of key commodities" and is designed to enable government to measure the risks and impacts associated with UK consumption of key commodities. The full list of indicators in development can be found in the 25 Year Environment Plan Outcome Indicator Framework.

5. Background

This draft indicator was calculated by the SEI under a project managed by the Joint Nature Conservation Committee and contracted by Defra for developing an indicator for the 25 Year Environment Plan. It builds on data from the Norwegian University of Science and

[2] Appendix 2 in this report.

Technology's (NTNU) Exiobase trade model and deforestation data from Chalmers University of Technology (Pendrill *et al*. 2020). It also builds on previous work including a proof of concept study which recommended MRIO as the approach to use for this indicator (Route2 and Carbon Smart) and a separate study investigating an alternative approach which was not recommended to be taken forward (Harris *et al*. 2019). The JNCC have also produced an entry-level guide introducing people to the area of sustainable production and consumption more generally, which may be of interest to anyone wishing to learn more (Hawker *et al.* 2020).

6. Caveats, limitations, and uncertainty

For accurate interpretation of the results presented within this document, it is necessary to understand the following caveats:

- Data tracing all commodities exactly back to their countries of origin are not publicly available. Whilst based on empirical statistics, the outputs produced by this indicator derive from modelling so should be considered as estimates rather than exact countries of origin.
- Only the country of origin, and not the exact location of origin, can be obtained from the current version of the indicator as only national scale data were used. This means impacts are based on average production practices per country, not the actual impacts at the exact location the product came from. This could be improved by using sub-national data in subsequent iterations of the indicator.
- Because data linking impacts to trade are compiled at national level, any action by the UK in specific regions will be 'averaged' across the full global supply chain. Therefore, it will be hard to differentiate UK action from the actions of other consumer nations. The indicator will be more responsive to multi-national action than to UK action specifically.
- The deforestation figures used within this indicator are tropical and sub-tropical only and relate only to agricultural crop products. Additional products (beef and wood) are covered in the Pendrill *et al.* dataset, which will be included in the next data release. These will add additional deforestation to the UK footprint estimate and are likely to be important commodity-drivers.
- Double-cropping activities that may in some cases affect the harvested area indicator have not been accounted for but estimates of deforested areas are capped at total agricultural expansion.
- The data presented here are based on a fundamentally different approach to the UK Carbon Footprint or the UK Material Footprint. The results presented here are therefore not comparable to the existing Carbon and Material Footprints and should be viewed separately.
- Data lags in international trade statistics mean that data is only available in the current release up to 2017. Care should also be taken in analysing trends over time which can reflect complex changes in production volume, trade distributions, estimated inter-sectoral demands and final consumption expenditure.
- Use of different MRIOs as the underlying dataset (for example GTAP rather than Exiobase) could lead to differences in results. The project team intend to undertake intercomparison work to understand the degree to which model assumptions and choices affect overall results.
- The presence of oil palm and soy as key sources of UK deforestation risk is common to other assessments, but the preliminary data reveals UK linkages to other supply chains (such as beans, cassava, paddy rice) that are not often considered as 'deforestation risk' commodities in other publications. These supply chains warrant further investigation to understand e.g. which sectors of consumption link to these estimated impacts.

In many of the countries where soft commodities are driving rapid impacts, the UK represents a small proportion of the total demand. However, understanding and reducing UK impacts can help show international leadership and set an example for other countries to follow. It also provides better opportunities to work with producer countries and to work multi-laterally with other consumer countries.

As initial, draft results, additional notes and caveats are included in Appendix 4.

7. Weblinks and further information

Datasheets giving raw results behind the graphs presented in this report are available from the JNCC Resource Hub: https://hub.jncc.gov.uk/assets/709e0304-0460-4f83-9dcd-3fb490f5e676

- JNCC-Report-681-Datasheet-Commodity-Results.csv – https://hub.jncc.gov.uk/assets/709e0304-0460-4f83-9dcd-3fb490f5e676#JNCC-Report-681-Datasheet-Commodity-Results.csv

- JNCC-Report-681-Datasheet-Producing-Country-Results.csv – https://hub.jncc.gov.uk/assets/709e0304-0460-4f83-9dcd-3fb490f5e676#JNCC-Report-681-Datasheet-Producing-Country-Results.csv

- JNCC-report-681-Datasheet-Results-Total-Annual.csv – https://hub.jncc.gov.uk/assets/709e0304-0460-4f83-9dcd-3fb490f5e676#JNCC-report-681-Datasheet-Results-Total-Annual.csv

Appendix 2 – Technical documentation

A2.1 IOTA methodological information

A2.1.1 Background

The footprint results are produced from a specially updated version of SEI's Input-Output Trade Analysis (IOTA) modelling framework (Croft *et al.* 2018).

Traditional production and bilateral trade statistics detail production quantities of commodities and their flows from country to country. However, the 'point of import' viewpoint that such data provides can be, and often is, quite different from that obtained from 'final consumption' profiles that aim to understand the dependencies of products associated with the final purchases and consumption of materials and services. This is especially true for commodities with long and complex supply chains, where consumption of the commodity is indirect and embedded within other consumption activities (for example most soy is "consumed" as feed within meat products).

MRIO approaches overcome this limitation of physical trade data by offering a representation of the entire global economy, which captures the full breadth (all sectors) and depth (all tiers of the supply chain from point of production to point of consumption) of global supply chains. MRIO detail financial transactions between different sectors of the economy, and final purchases from the economy for consumption. Standard MRIO methods allow for consumption activities to be linked not just to outputs associated with direct purchases, but also all up-stream outputs throughout the entire supply chain. This means that footprints of consumption can be linked to points of origin of raw commodity production, regardless of how many trade, processing or utilisation steps there are between these points of origin and the final consumption.

However, traditional MRIOs offer this breadth and depth at the sacrifice of resolution. This applies to both geographic and commodity fidelity. Whilst physical data will detail commodity-specific production and country-to-country trade, typical MRIO representations will cover purchases between (often broad) economic sectors and a mix of countries and geographic regions. Not only does this limit the resolution of results, but it can be especially problematic when looking at impacts which can be highly heterogeneous within sectors and regions.

IOTA is an environmentally extended hybridised MRIO model. IOTA's hybridised approach attempts to overcome the limitations of both approaches by adopting a modelling framework comprising a hybrid of commodity- and country-specific physical production and trade data with the sector- and regional- level representation of the global economy offered by MRIOs (MRIOs contain some countries and some rest of world regions aggregating countries). The result is a model that links individual commodity production, resolved to country level, via commodity-specific country-level trade flows and the sector/regional financial flows, to final consumption behaviour at the MRIO regional-level. That is, it retains the production-end resolution of commodity and country specificity but allows for full length supply chain modelling through to final consumption activities, and thus a better understanding of specific production footprints driven by final demand. Environmental extensions allow for any production-linked impacts to be likewise linked through to consumption.

A2.1.2 Physical production and trade data

The country-level commodity-specific data are taken from FAOSTAT. Production data is sourced from the "Production - Crops" dataset, and bilateral trade data from the "Trade - Detailed Trade Matrix" dataset. The main source of FAOSTAT trade data is official country statistics compiled by UNSD and Eurostat.

A2.1.3 MRIO data

In this work, IOTA utilises the EXIOBASE 3.8.1 MRIO (https://zenodo.org/record/4588235). EXIOBASE comprises 44 countries plus five rest-of-world (ROW) regions, and 163 industries.

A2.1.4 Implementation

Re-exports

Bilateral trade data often contain records pertaining to the re-export of goods; that is the report of exporting a good that has previously been imported. This is problematic since such records are not providing a direct link between point of origin and destination, and instead contain records e.g. A -> B and B -> C, when the information that is desired is the resolved flow A -> C. This issue is resolved by running the production and trade data through an algorithm which takes countries' supply (production + imports) into account and reassigns exports accordingly to estimate their true origin. Supply constrains possible exports, and so the system fully resolves whilst preserving total inputs (e.g. all production), and forbids the exports of goods from a country which does not have sufficient supply (be it domestic production or imports from other countries) to meet, i.e. the whole system is balanced (see Croft *et al*. 2018 for more technical detail).

Concordance of FAO countries and commodities to EXIOBASE countries/regions and sectors, respectively

The re-export algorithm provides a best estimate of where (at the country level) a country's production of a commodity has been distributed to after all trade activity associated with the raw commodity has been conducted. To align this with the MRIO database, all of the countries in the FAO data need to be concorded to EXIOBASE's countries and regions. This is a one-to-one mapping for countries within the MRIO, and an aggregation of countries for the ROW regions. This allows the country of origin to country of destination results from the re-export algorithm to be transformed into a country of origin to MRIO country/region of destination array.

Likewise, to understand which sectors within the MRIO database the production of a given commodity is associated with (which is important for allocation within the MRIO; see below), the FAO commodities need to be concorded to appropriate producing sectors within the MRIO database. In some cases this is a one-to-one mapping (e.g. "Rice, paddy" within the FAO database maps to the "Cultivation of paddy rice" sector within EXIOBASE), but typically it is an aggregating process (e.g. "Barley", "Maize", "Rye", "Oats" etc. all map to the "Cultivation of cereal grains nec" sector).

Hybridisation of FAO-derived re-exports data and EXIOBASE MRIO database

The concorded results of the re-export algorithm provide the MRIO countries/regions to which each countries' traded production of a given commodity needs to be allocated. However, each country/region within the MRIO comprises multiple sectors across which this needs to be further allocated. This is done by taking the relative expenditure by sectors within an importing country/region on outputs of the concorded sector responsible for the production. Below is an example of this allocation process (note "Country B_c" in the example below could be a country or region within the MRIO database):

Example

From re-exports results:

> Country A exports X tonnes of Commodity Y to Country B

Concordance relationships:

> Country A concords to Country A_c
> Country B concords to Country B_c
> Commodity Y concords to Sector Y_c
> (i.e. Sector Y_c is the sector associated with production of Commodity Y)

Concorded results:

> X tonnes of Country A's production of Commodity Y allocated to Country B_c

Disaggregation of Country B_c's allocation to sectors:

> Take relative expenditure by all sectors within Country B_c on outputs from Sector Y_c, and distribute concorded results proportionally

After this process, the production of a given commodity within a given country has been allocated to the importing countries/region and sectors within the MRIO.

Calculation of “physical L matrix”

In traditional MRIO methods, the L matrix (or Leontief inverse/”total requirements” matrix) allows the calculation of all financial outputs required across the entire economy (all sectors in all countries/regions) for the purposes of enabling a given sector within a given country/region to produce a unit of output. By allocating the physical quantities of traded commodities to the appropriate sectors of import (see above), a “physical L matrix” can be constructed which allows the estimation of the amount of these physical flows embedded in the final consumption from different sectors within different countries or regions. This means that final consumption within a given country can be linked back to the country within which its component commodities were produced.

This is achieved by normalising the sector allocations by total sector monetary outputs (i.e. converting the total allocations into intensities, e.g. unit mass of commodity per unit value of output) and multiplying the monetary L matrix. A unique matrix is constructed for each individual commodity.

Compiling results for final demand

Multiplying the “physical L matrix” for a given commodity by the final demand vectors for a consuming country/region (the UK in this case), calculates the physical quantities of that commodity embedded within this final demand. This process works by taking the value of purchases from a given sector in a given country/region, and accounting for all required outputs from all other sectors for the given sector to meet this demand. By way of the “physical L matrix”, these “outputs” take the form of physical flows of the commodity associated with each possible point (i.e. country) of production.

Applying indicator metrics

The indicator metrics are transformed into per-unit-mass intensities. This is done by taking e.g. total deforestation linked to a country’s production of a given commodity in a given year and dividing this by total mass produced of that commodity in that country/year. This is then simply applied as a scaling factor to the embedded production (mass) results to convert these mass-flow results into results for the different indicator metrics in their appropriate units.

A2.2 Environmental metrics: tropical deforestation and associated emissions

A2.2.1 Overview

The initial environmental extensions/metrics developed for the first release of this UK indicator framework are based on a dataset which contains estimates of tropical deforestation embodied in the production, exports, imports and consumption of agricultural and forestry commodities by country, year, and commodity, in the time period 2005-2017. The data is an update on the results presented in Pendrill *et al.* (2019a, b), using a land-balance model to attribute deforestation across 135 countries in the tropics and subtropics to expansion of cropland, pastures and forest plantation and the commodities produced on this land.

A2.2.2 Methodological summary

A detailed description of methods for this extension can be found in Pendrill *et al.* (2019a, b; which should also be referred to for detail of the more granular treatment of deforestation in

Brazil and Indonesia in comparison to other included countries). A visual summary of the source data and methodology is provided in Figure 6.

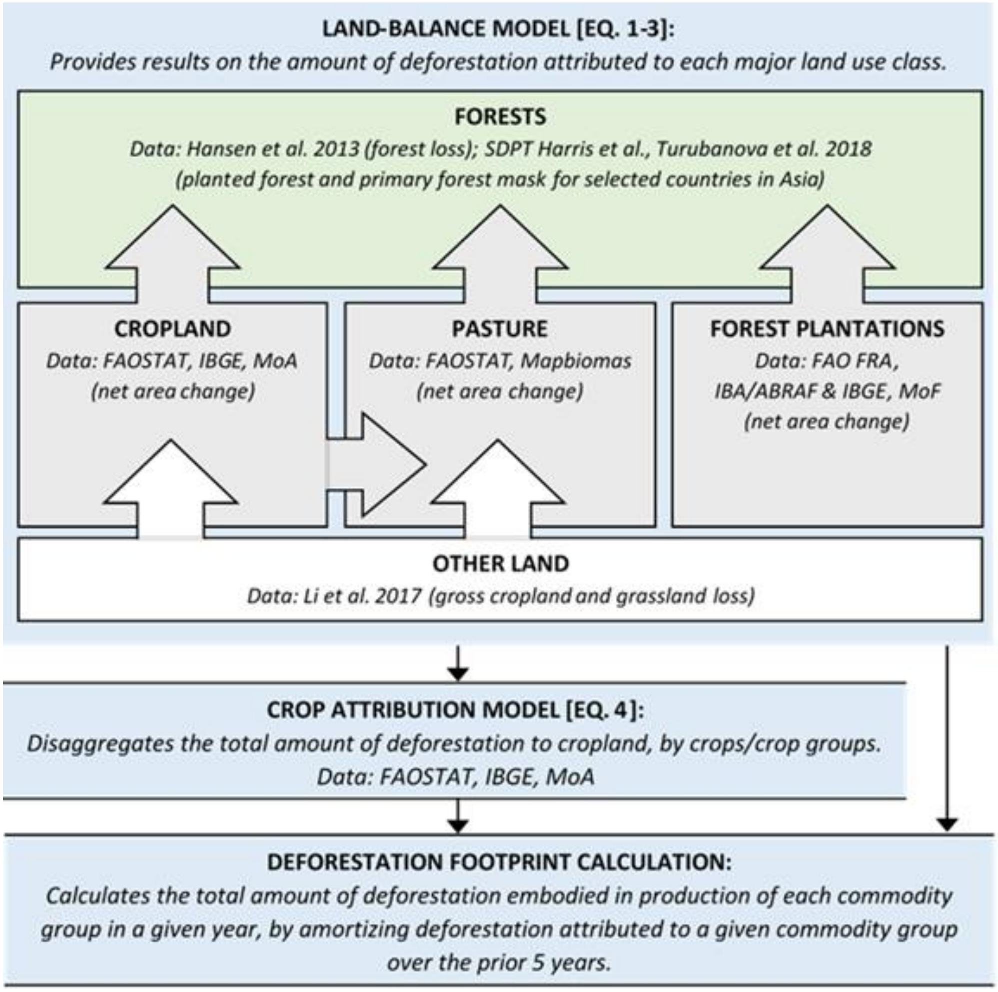


Figure 6. Overview of the main steps of the analysis linking deforestation to agricultural and forestry production as well as the main data sources used for the analysis. Revised from Pendrill *et al.* 2019a to reflect latest updates to dataset; provided by and reproduced with permission of Florence Pendrill).

Observed forest loss, from remote sensing data (from GLAD/Hansen - at 30 m resolution, with a threshold of 25% canopy cover used to define forest, and complete loss per pixel defined as 'forest loss'), is attributed to agricultural and forest commodities using a relatively simple land-balance model implemented at national scale (apart from for Brazil and Indonesia, where it is implemented at subnational scale). In this land-balance model, cropland expansion (data for which is sourced from FAO, except Brazil and Indonesia which use national statistics) takes place first into pastures (in cases where there is gross pasture loss), and then into forests (where there is gross forest loss), an assumption which is deemed to robustly reflect typical landscape dynamics. In essence, in the model, forest loss is attributed across expanding cropland, pasture and forest plantations proportional to their area increase. Forest loss attributed to cropland expansion is then further attributed to individual crops or crop groups in proportion to their relative expansion in harvested area (data also from FAO, except Brazil and Indonesia which use national statistics). Forest loss attributed to pasture is linked to cattle grazing for meat and, to a lesser extent, leather production. Note that, whilst data on forest loss is spatially specific (as it is derived from remote sensing data), attribution to individual crops/crop groups is conducted non-spatially based on overall planted areas and not the physical location/expansion of specific crops (data on which is not globally available at this stage).

A2.2.3 Deforestation data

Deforestation occurring in one year is not linked immediately to commodity production in another, because a transition period which can span several years between clearance and resource production is typical. To account for this, the change in area of cropland, pastures and plantations over a three-year period following forest loss is used in the attribution step. This effectively accounts for 'lag time' between initial conversion of land and subsequent conversion to productive use in order to adequately identify which land uses drive the deforestation.

Furthermore, because land may be productive many years following conversion (and thus production in subsequent years can be validly attributed to previous land use change), an amortization period of five years is adopted, meaning that the total amount of deforestation embodied in production of a given commodity in a given year is calculated as the total deforestation attributed to the land use producing that commodity in the five previous years, divided by five. This amortization step ensures that 'responsibility' for the original conversion is distributed equally over a number of subsequent years of production (which is a practice commonly applied to other metrics, including those used e.g. in greenhouse gas inventories).

A2.2.4 Emissions data

Carbon emissions from deforestation are estimated by quantifying the changes in carbon stocks resulting from forest loss and subsequent land use, considering above-ground biomass (AGB), below-ground biomass (BGB) and soil organic carbon (SOC). A separate component of the data adds emissions associated with the drainage of peatland. Estimates of above-ground carbon loss are derived geospatially by combining forest loss data with estimates of carbon stocks prior to forest loss (in the year 2000), compiled at 30m resolution. Carbon loss is attributed only to forest loss (which means that, where carbon loss may have taken place due to earlier degradation, it is possible over-estimates are present). BGB estimates are more uncertain but follow a typically adopted approach of assuming a fixed ratio between AGB and BGB. In this dataset, vegetation-specific ratios are adopted following 2006 IPCC guidelines. Stocks of AGB and BGB in resultant land uses (crops, pastures and plantations) are based on existing literature (discussed within Pendrill *et al.* 2019b). SOC estimates are estimated from a tropical meta-analysis (see Pendrill *et al.* 2019b). Emissions estimates are attributed to commodities in the same way as deforestation rates (i.e. a commodity attributed 10% of deforestation will be attributed 10% of emissions).

Emissions from peatland drainage (excluding Indonesia) are based on a single study which provides country-level data on carbon emission from peatlands drained for agriculture and forestry for the years 1990 and 2008 (see Pendrill *et al.* 2019b for full details), which allow emissions per unit of land drained to be estimated (note that there is some requirement for interpolation and extrapolation to achieve this, with an assumption made that the share of cropland occupying peat/non-peatland remains constant over time). Estimates for Indonesia (which accounts for nearly two-thirds of tropical peatland carbon) are based on more specific, province-level data (see Pendrill *et al.* 2019b for full details).

A2.2.5 Data update plans

An update of the Pendrill deforestation dataset for the year 2018 is currently planned. The authors are looking for opportunities to ensure that continued data updates are possible, including via collaborative opportunities under the Trase programme which has just secured funding for a further five years. Annual updates (or as soon as the underlying datasets are updated) are therefore considered likely.

A2.2.6 Source

This dataset is managed by the University of Chalmers, Sweden. The key contact points are Florence Pendrill and Martin Persson. Both are active collaborators with the SEI York team.

The data are available, open source at: https://zenodo.org/record/4250532. Publications using this data (including as applied within the UK indicator framework) should properly reference this resource (and associated papers).

Current citation: Pendrill, Florence, Persson, U. Martin, & Kastner, Thomas. (2020). Deforestation risk embodied in production and consumption of agricultural and forestry commodities 2005-2017 (Version 1.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.4250532

A2.2.7 Application in IOTA framework

The project team use the attribution data from the Pendrill dataset. This allows the production linked deforestation and emissions estimates to be added directly into the IOTA framework (to FAO production categories) which are then translated, via the modelled trade-and-consumption system, into footprint indicators (see above for methods; for units refer to results sheets). The following notes are relevant to the application of this dataset in IOTA:

- The raw data is already classified into FAO production categories. The project team have created a library to ensure the correct matching where any alternative product namings are used (which occurs in a handful of cases). One crop (Guarana, produced only in Brazil) in the Pendrill dataset is not associated with any FAO production/trade data and is, therefore, not included in the footprint.
- At this stage, the project team have not incorporated any emissions linked to beef cattle or forest products into the results, because the preliminary results presented here focus on agricultural products only. The project team envisage that the data will expand to include beef and forest commodities (from plantations) when final results are released as an experimental statistic, which involves the integration of additional data into the existing methodology. The authors of the deforestation dataset split deforestation associated with cattle production between meat and leather in a 19:1 ratio (95% meat, 5% leather). This is based upon Brugnoli and Kral (2012) and Gac *et al.* (2014) and, when beef cattle is implemented, the project team intend to maintain this split to avoid introducing additional assumptions. FAO data, however, suggests a 96:4% split, and therefore this split could be adjusted (albeit with minimal impact on results).
- Due to the amortisation approach adopted in the deforestation dataset, plus a difference in the FAO production dataset timestamps used in the preparation of the deforestation data, a small number of entries for commodity-linked production have no associated production within the current FAO dataset. This means that this impact cannot be applied and attributed within the IOTA framework described above. The project team ignore any deforestation which cannot be directly attributed to production.
- Sudan appears as “Sudan” throughout the Pendrill time-series (2005-2017), but within FAO production and trade data is listed as “Sudan (former)” for 2005-2011, and “Sudan” and “South Sudan” for 2012-2017. This raises issues of allocation, complicated further by the fact that a significant portion of data for South Sudan within the FAO dataset is listed as “not available” (suggesting it is unknown, rather than taking 0 value). As such, impacts metrics associated with Sudan are currently not allocated within the results. These are small for deforestation, but the project team aim to review how to include Sudan in the next phase of the project.

References

Brugnoli, F. & Kral, I. (2012) Life Cycle Assessment, Carbon Footprint in Leather Processing. UNIDO: Available at: https://leatherpanel.org/sites/default/files/publications-attachments/lca_carbonfootprint_lpm2012.pdf [Accessed: 16/04/2021].

Gac, A., Lapasin, C., Laspiere, P.T., Guardia, S., Ponchant, P., Chevillon, P. & Nassy, G. (2014) Co-products from meat processing: the allocation issue. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector: Available at: https://www.ifip.asso.fr/sites/default/files/pdf-documentations/gac2014-iclca-2.pdf [Accessed: 16/04/2021].

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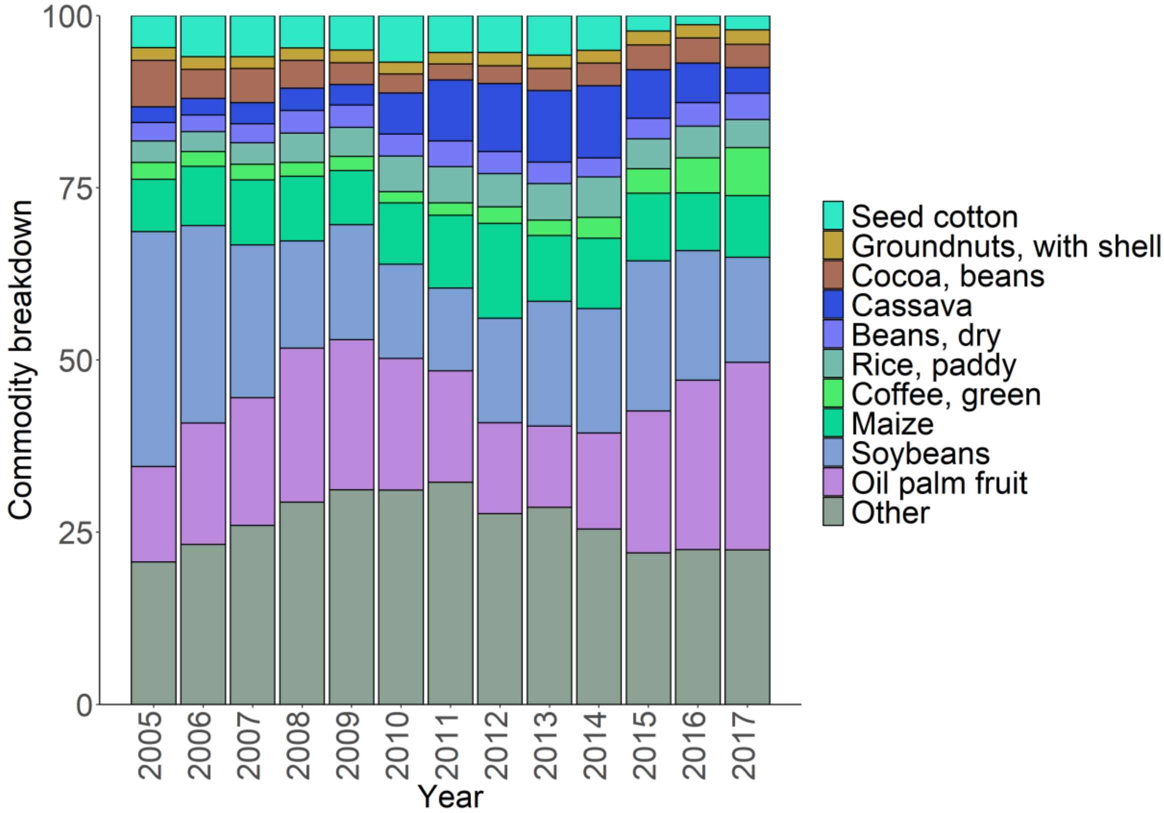
Pendrill, F., Persson, U.M., Godar, J. & Kastner, T. 2019a. Deforestation displaced: trade in forest-risk commodities and the prospects for a global forest transition. Environmental Research Letters, 14(5), p.055003. Available at: https://doi.org/10.1088/1748-9326/ab0d41 [Accessed: 16/04/2021].

Pendrill, F., Persson, U.M., Godar, J., Kastner, T., Moran, D., Schmidt, S. & Wood, R. 2019b. Agricultural and forestry trade drives large share of tropical deforestation emissions. Global Environmental Change, 56, pp.1-10. Available at: https://doi.org/10.1016/j.gloenvcha.2019.03.002 [Accessed: 16/04/2021].

Appendix 3 – Additional draft results

Project results also break down the source of the impact by commodity and by country. Following project completion, such results will be presented on an interactive dashboard, which is better suited to identifying countries and commodities of interest than static graphs. However, for this draft report, static graphs showing the breakdown of the most significantly impacting commodities have been included.

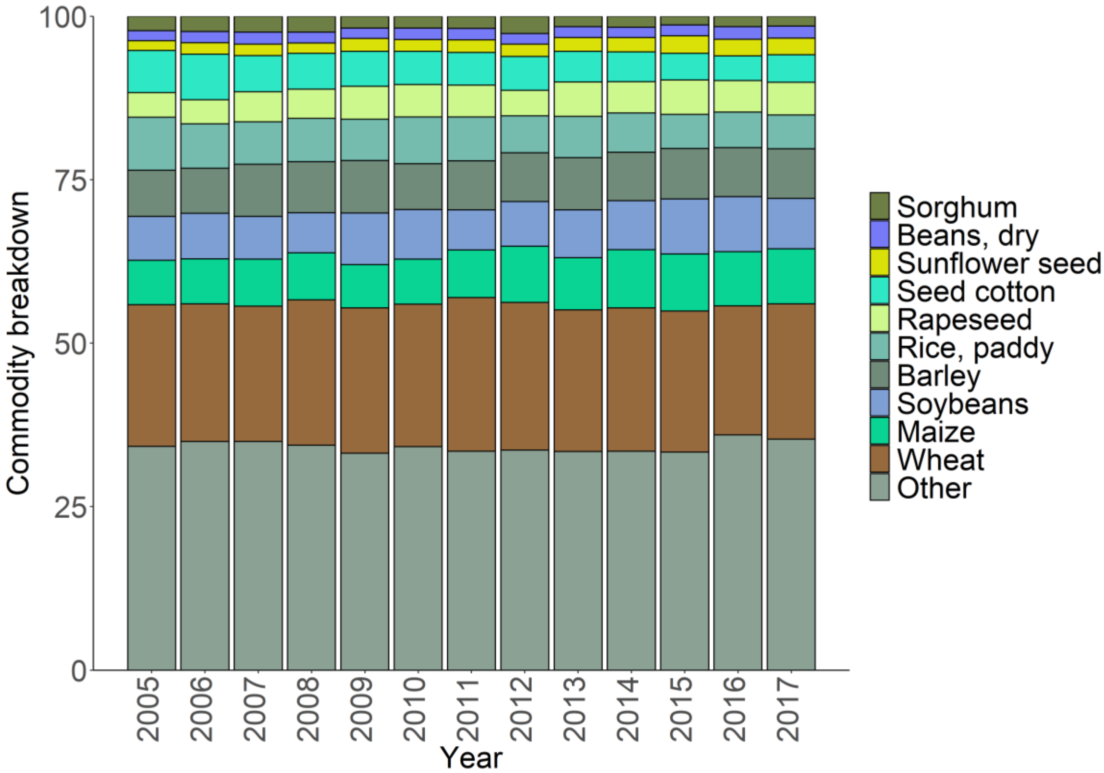
Overall, oil palm and soybeans have the biggest impact on deforestation risk across the years, although in some years the impacts from maize are similar (Figure 7). The most significantly impacting commodities remain reasonably similar between 2005 and 2017, but with some noticeable changes (for example an increase in cassava between the years 2011 and 2014).



(c) Deforestation risk embedded in consumption.

Figure 7. Deforestation risk (ha) embedded within UK consumption broken down by commodity. The order in which the commodities appear in the graph match the order in the legend; e.g. seed cotton is the top block in every year.

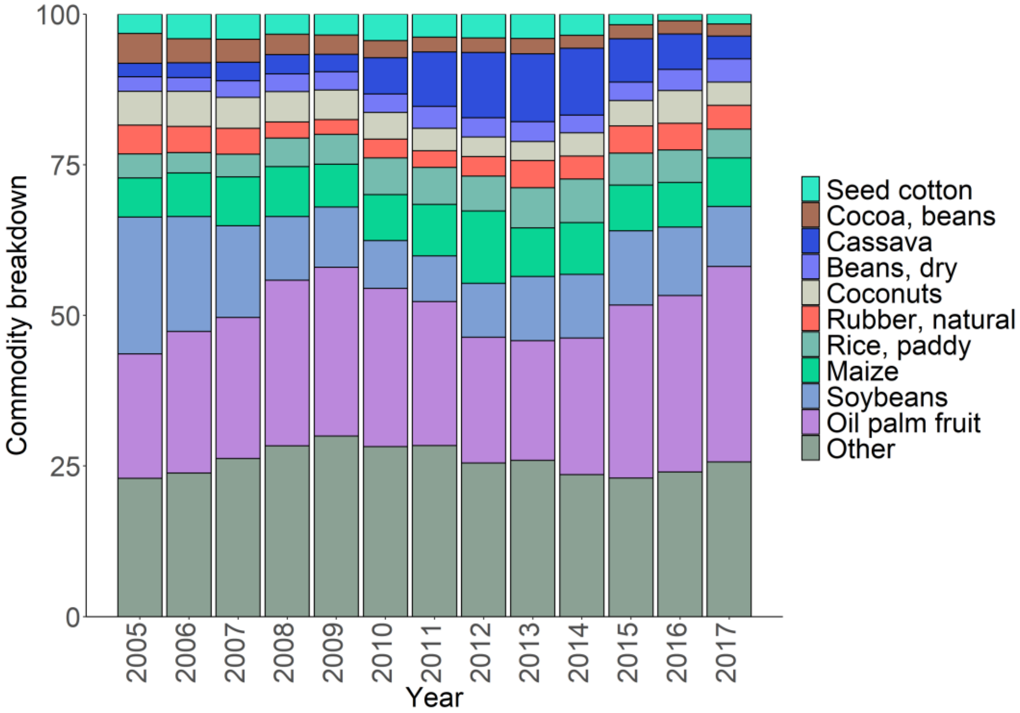
When area harvested is taken into account rather than deforestation risk, wheat becomes the commodity with the highest value and oil palm is not even in the top ten (Figure 8). This illustrates the importance of analysing deforestation separately. The area harvested commodity breakdown remains very consistent across the time series studied.



(b) Area harvested embedded in consumption.

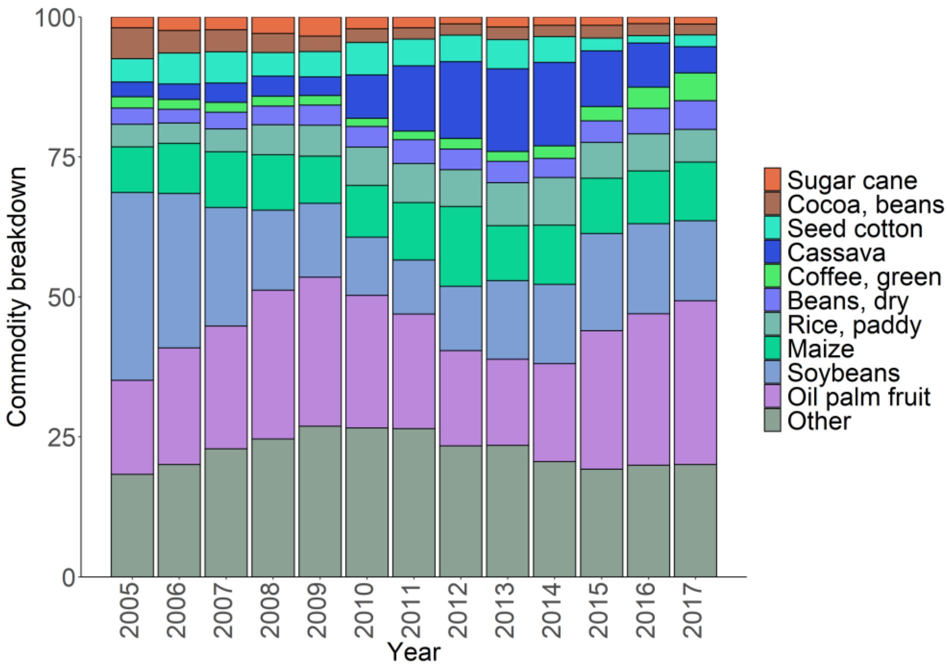
Figure 8. Area harvested (Ha) embedded within UK consumption broken down by commodity. The order in which the commodities appear in the graph match the order in the legend; e.g. sorghum is the top block in every year.

For GHG from deforestation, oil palm is once again the most significant commodity (Figures 9 and 10). There is some difference between the commodity breakdown when including and excluding emission from peatland drainage. For example, coconuts and rubber are within the top ten commodities when including emissions from peatland drainage, but not when excluding it.



(d) Deforestation emissions (inc. peat) embedded in consumption.

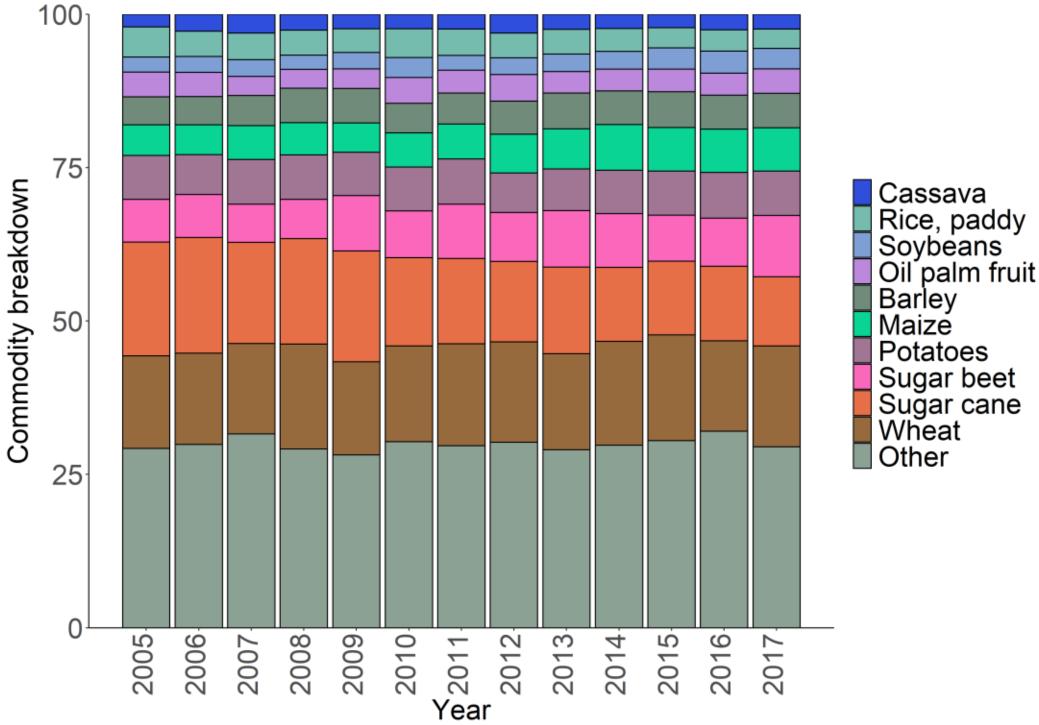
Figure 9. GHG emissions (tonnes of CO_2) from deforestation (including peat) embedded within UK consumption broken down by commodity. The order in which the commodities appear in the graph match the order in the legend; e.g. seed cotton is the top section in every graph.



(e) Deforestation emissions (excl. peat) embedded in consumption.

Figure 10. GHG emissions (tonnes of CO_2) from deforestation (excluding peat) embedded within UK consumption broken down by commodity. The order in which the commodities appear in the graph match the order in the legend; e.g. sugar cane is the top section in every year.

In terms of material footprint, the commodities the UK imports the most of are wheat and sugar (Figure 11).



(a) Total production embedded in consumption.

Figure 11. Material footprint (tonnes of production) embedded within UK consumption broken down by commodity. The order in which the commodities appear in the graph match the order in the legend; e.g. cassava is the top section in every year.

Appendix 4 – Future work

A4.1 Expansion of commodities and indicators

In addition to the coverage of commodities and indicators presented above, the project team plan for the upcoming experimental statistic to include the wood product and beef deforestation data which is present in the Pendrill *et al.* (2020) dataset but has not been integrated to date. The project team also intend to explore the integration of mining and fisheries production into the IOTA framework, along with the extension of indicators to include water and biodiversity. These additions will be scoped out in the next phase of work.

A4.2 Quality assurance process

These results represent the first step in a longer process to developing a fully-fledged suite of consumption indicators for the UK. Whilst largely built upon existing and established components (which have undergone various stages of peer review and quality assurance), the complete integration and implementation within this work is an on-going process of experimentation. Whilst internal checks have been performed consistently throughout the different steps and stages of the codebase to ensure e.g. quantities are being conserved, totals match, consistencies of formatting, etc., it remains for all code and methods to undergo code review and checks to assert correct and proper execution, and for results to be properly scrutinised and understood.

Additionally, the project team intend to explore alternative implementations of some model assumptions (see below) and, following this work, scrutinise emerging results against comparable statistics and these modelling assumptions/implementations to understand (to the extent possible) differences between results.

The project team intend for the experimental indicator and associated methods to be externally peer reviewed following the completion of this future phase of work.

A4.3 Use of import data vs export data

Trade data typically come in two forms: export records and import records. Whilst in theory these should be equal and opposite (i.e. what Country A reports it exports to Country B should match what Country B reports it imports from Country A), for a number of reasons this very often is not the case. For example, this may be due to a lack of national statistical collection, differences in the reporting of destination / origin in customs records, time lags, differences in reference periods or human error. As such, typically a choice is made as to whether to use one form or another, and there is not a clear "correct" choice. It is often the case that one form of reporting can better capture certain flows than the other. For consistency, and to avoid overcomplication of methods in this work, export data has been chosen (as it always has in IOTA). A consequence of this choice is that approximately 19% of countries (typically, but not always, smaller or lower-income nations) are not represented by the trade component of the input data. This effectively means that the "hybridisation" step in IOTA is not capturing the trade of commodities *from* these countries, but only production *in* and/or trade *to* (depending on the production and trade landscape). Consequently, a larger component of the downstream supply chains involving these countries are modelled by the MRIO component of IOTA. This isn't necessarily problematic *per se*. (it depends on economic transaction data which still captures the trade flows), but for countries where representation within the MRIO database is limited to that of one of the four ROW regions (as there are in EXIOBASE), this results in the sub-optimal situation of an entire commodity supply chain being represented by sectoral flows and aggregated regions. Typically, these countries are relatively small, so do not represent the most critical to capture from an overall trade perspective.

There are options available to try to circumvent this issue. The simplest option is to run two sets of results out, one using each of the import and export datasets. Whilst this will provide two sets of comparable results, which collectively capture all available reported trade, it does not really address the problem; rather it is providing two sets of results with elements of limited coverage.

A better solution is to use a hybrid of both the import and export datasets; combining them to construct a more comprehensive and complete representation of the commodity trade. There are numerous options by which this could be tackled, but is an area requiring extra consideration and attention in a future release and is a high priority for future development and improvement of the IOTA model.

The project team intend, therefore, to explore this hybridised approach for the next iteration of the modelling framework presented here and conduct intercomparison of results.

A4.4 MRIO choice

Within this work, the EXIOBASE MRIO database has been used. The choice of EXIOBASE was primarily motivated by a combination of a desire to increase alignment and consistency with other existing indicator work (e.g. the UK Carbon Footprint and UK Material Footprints), and EXIOBASE's considerable temporal coverage. However, other MRIO databases are available and could be utilised within this work. Each MRIO has its relative strengths and weaknesses. For example, in comparison to EXIOBASE, the GTAP database (which to date has been used within IOTA) offers lower temporal resolution, a higher time lag and lower overall sectoral resolution, however it has significantly higher geographic resolution and superior sectoral resolution across agricultural commodities and sectors.

Whilst comparisons have been performed in the literature across different MRIOs, results from each implementation and application are affected and influenced differently by the choice of MRIO. Similarly, whilst each of the main MRIOs are well documented, reviewed and understood, the choice of MRIO within a modelling framework remains a source of uncertainty and variability on final results. Implementation across, and comparison between, different MRIO databases could provide a range of final results, and the relative variability could be useful from both the perspective of further informing MRIO choice, and also providing relative levels of confidence and certainty across different components and elements of outputs.

An example in these initial results which illustrates where the indicator framework may benefit from further work to address aspects summarised in A4.3 and A4.4 relates to the appearance of Myanmar as a key risk area (see Appendix 1). Myanmar does not appear as a reporter in the FAO trade data and therefore has no exporter data. In this instance, it would be appropriate to check 'import' records from countries sourcing from Myanmar and aim to integrate such records into the bilateral trade component of IOTA. Furthermore, within the EXIOBASE MRIO, Myanmar is classified under the "RoW Asia and Pacific" regional aggregation (which comprises 61 countries). This means - for inter-sectoral monetary transactions modelled by the MRIO component within the version of IOTA implemented here (which uses EXIOBASE) - Myanmar's interactions with the rest of the world will be 'smoothed' out across the transactions in this wider region. In contrast, the GTAP MRIO resolves Myanmar alongside only one other country (East Timor), and thus retains more granular treatment of the monetary interactions that Myanmar has with the rest of the world (and hence also the UK). In the interim results presented here, Myanmar emerges as representing a significant component of the UK's deforestation risk (the UK's consumption accounts for just over 1% of domestic deforestation in 2017 in Myanmar according to our initial results). The project team would expect this percentage to vary with alternative implementations, given the explanations above, but the magnitude of any change is impossible to pre-empt.