Measuring the impacts on global biodiversity of goods and services imported into the UK

Final Report

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Contents

Glossary of terms

Biodiversity: Variability among living organisms which includes diversity within species, between species and of ecosystems. Biodiversity is often used as an indicator of the health of ecosystems.

Carbon footprint: A measure of the greenhouse gas emissions associated with a defined population, system or activity; often incorporating emissions which are directly or indirectly released during an activity or use of a product and accumulated over the life stages of a product or service. The carbon footprint of a nation refers to the direct and indirect emissions associated with all products and services consumed by a population.

Consumption-based accounting/approach: An assessment of (environmental) impacts associated with the consumption of goods and services by the end consumer.

Ecological footprint: A standardised measure of human demand on the Earth's ecosystems, representing the amount of biologically productive land and sea that is required to satisfy human consumption and assimilate waste materials.

Ecosystems services: Humankind derives many benefits from organisms and natural environments; these are known collectively as ecosystem services.

Environmental extension: In relation to *Input-output* analysis*;* a data extension to an *Input-output* model that links units of production to associated environmental data.

Environmental indicators: Measures that provide insight into the state of the environment. In this project we directly link environmental indicators to the *MRIO-Physical use model* which are likely to be important drivers of biodiversity loss such as land use, water use, and fertiliser use.

Exports: The sale of goods and services from one country to other markets. See also *Imports* and *Re-exports*.

FAO: Food and Agriculture Organization of the United Nations; a key source of international data on production and trade of agriculture, forestry and fisheries products.

Final demand: Demand for a processed or unprocessed good, or service, by the end consumer(s). See also *Intermediate Demand*.

Financial data: Data represented in monetary quantities. Within this project, the *GTAP* trade data is financial. See also *Physical data*.

GTAP: Global Trade Analysis Project; a network of research and policy makers conducting analysis of international policy issues. Supplies the GTAP database on which the *MRIO* model demonstrated in this report is based.

Imports: Goods and services that are bought from other countries. See also *Exports*.

Industrial sectors: Within economic datasets, businesses are classified into groups which represent activities which are deemed to be similar. Purchases and sales between all sectors of an economy make up the *Intermediate demand* component of *Input-output* models.

Input-output (IO): In economics, an input-output model represents the interdependencies between different components of an economy and provides a comprehensive picture of the flows of goods and services within an economy in a given year.

Intermediate demand: Demand by industry for raw materials or products of other industry components of the economy. See also *Final demand*.

MRIO-physical use model: The model format used in this project which combines *Financial data* in an *MRIO* with *Physical data* on production and trade. It allows the worldwide *Supply chain* of goods and services to be captured whilst retaining detailed product-level production information.

MRIO: Multi-regional Input-Output; An *Input-output* model which, in addition to representing flows between components of the economy within a country, represents trade flows between economies of different countries and/or regions of the world.

Origin of production: The location where production of a product occurs (and where associated impacts on biodiversity are likely to take place).

Physical data: Data represented in quantities of mass (or other physical units). Within this project, physical data is used for information on quantities of production and, where possible, country-level trade. See also *Financial data*.

Physical use table: A table of production and trade of a particular product in physical units which can be joined to *MRIO* financial data to form an *MRIO-physical use model*.

Re-exports: Re-exports consist of foreign goods that are exported in the same state as imported (i.e. without processing within the country).

Supply chain: The network of the supply and demand of goods and services between *Industrial sectors* of the economy and final consumers.

UK demand: *Final demand* for goods and services by UK consumers. This includes goods and services produced in the UK and overseas. It excludes any *Intermediate demand* by UK industry that is exported to other countries to satisfy their *Final demand*.

Water footprint: An indicator of freshwater use, consisting of green (precipitation-based water use), blue (irrigation-based water use) and grey (water required to dilute pollution) components.

i. Executive summary

The UK relies on a range of imported goods and services to satisfy demand, which may cause pressure on biodiversity and ecosystems beyond the UK's borders. The recent and continued liberalisation of global trade and resulting complex network of supply chains means that this impact is difficult to trace. *The overall aim of this project is to provide a methodology for linking UK imports of all goods and services to geographically-defined impacts on biodiversity in a consistent and repeatable manner and to generate a database of these results.*

To fulfil the project objectives, an assessment framework has been developed to provide information on the direct and indirect links between consumption in the UK and environmental impacts that occur due to production in other countries. A global trade model that retains product-level production detail and quantitative links to associated environmental impacts has been development to allow top-down assessment of potential impacts. This model facilitates the selection of priority commodities and regions which can then be investigated in more detail using a case-study approach.

On the recommendation of experts attending a project workshop, the project and its outcomes focus on analysing the impact of consumption on potential drivers of biodiversity loss (rather than impacts to individual species). The assessment framework therefore includes environmental extensions associated with production activities that incorporate indicators of land use, water use and scarcity, and fertiliser use, along with potential impacts on threatened species identified within biodiversity databases such as the IUCN Red List and WWF's Global 200 Regions. The model makes no attempt to account for management or mitigation strategies aimed at reducing these threats, although these are considered in the case studies which form the final stage of the assessment framework.

Figure i.1 visualises an example of model output for production of soyabean in different countries in terms of total land area requirements necessary to fulfil UK consumption (including both direct consumption by the final consumer and soyabean embedded in processed products along the supply chain; for example soyabean embedded in animal feed which is then accounted for within meat consumption). A case study of soyabean production in Brazil (the location with the highest land requirement for UK demand) conducted as part of the project reveals that production of soyabean occurs mainly in the cerrado (tropical savannah) and has the potential to threaten a number of species via drivers such as land use change, soil erosion and chemical pollution (in the form of fertiliser and pesticide application).

The framework lends itself to industry-specific analysis and exploration of policy options: The potential impacts of over 200 agricultural products (and many other products of non-agricultural systems e.g. mining, forestry and fisheries) can readily be investigated using the model and, in addition to presenting results for total UK consumption, a breakdown of consumption impacts resulting from demand from specific industrial sectors can be derived.

The approach presents a new perspective on the global impacts of UK consumption, which is potentially highly powerful for undertaking a wide analysis of potential drivers of biodiversity loss in producing regions, and simultaneously assessing a variety of different commodities in a consistent, comparable and repeatable manner. The inclusion of supply chain impacts and retention of the origin of production within the international database is a fundamental step forward in understanding the potential holistic impacts in one country associated with consumption in another. Once areas of particular importance have been identified, and potentially monitored over time, completing the assessment with more detailed locally-specific datasets (as demonstrated within the case studies) represents a valid and powerful mechanism for analysing the potential impact that UK consumption is having on overseas biodiversity.

Figure i.1. Land requirements for soyabean in different countries to satisfy UK demand in 2007. Units: hectares (ha). Total world soyabean land used to satisfy UK demand is estimated at 1,270,000 ha. If grown in the UK, this production would require approximately 20% of total UK crop land (based on FAO 2007 statistics).

Of the products analysed so far, we can begin to get an impression of where in the world consumption in the UK could, without adequate mitigation, place greatest pressure on resources, land use, water and biodiversity. High-level comparisons between the impact of UK demand and the availability of goods produced or land area required on an international per capita basis demonstrate that the UK places a larger pressure compared to that available per person globally for some products, and smaller for others.

To assist the future adoption of the framework in policy analysis, we make the following recommendations:

- Assumptions underlying the methodology should be assessed further, and further effort and investment made in improving existing datasets and utilising additional trade, production, biodiversity and ecosystem services, and management and mitigation data.
- A greater number of products should be explored, and in combination, in future analyses to build up a more complete picture of the impacts, and aggregated impacts, of UK consumption overseas.
- In order to make an assessment of the likely relative effects of UK consumption within a global consumption context, the framework should be employed to investigate the impacts of consumption from non-UK countries.
- Options to produce timeseries data, conduct scenario analysis using the methodology, and potential downscaling of the model to local-, individual- or business-consumption levels should be explored. Extension of the methodology to a wider range of indicators would allow analysis of potential biodiversity impacts within a wider socio-economic and environmental setting.
- More extensive case studies should be developed to act as a knowledge base within the assessment framework. These should be conducted where possible in collaboration with governments and experts in the regions under study.
- The framework should be further developed for application as a national 'Global Impacts' indicator suitable for assessment of Convention on Biological Diversity targets.

ii. Extended summary

ii.1. Background

The UK relies on a range of imported goods and services to satisfy demand, which may cause pressure on biodiversity and ecosystems beyond the UK's borders. The recent and continued liberalisation of global trade and resulting complex network of supply chains means that this impact is difficult to trace. *The overall aim of this project is to provide a methodology for linking UK imports of all goods and services to geographically-defined impacts on biodiversity in a consistent and repeatable manner and to generate a database of these results.*

We have addressed this challenge by linking two distinct research streams: the analysis of trade pathways and supply chains of goods and services; and identification and analysis of production systems and their impacts based on geographically-specific and biodiversity-relevant information. Combining these research streams involves overcoming issues with data-availability (for trade, production, and biodiversity impacts); the assessment of complex supply chains; calculation of the environmental impacts of goods and services consumed; identification of the origin of production of the goods consumed; and collation of local-level information regarding the potential significance of production impacts in a particular region, along with management and mitigation efforts.

The project was initiated with a review of other studies that have aimed to link the consumption of goods and services (particularly agricultural products) to external biodiversity impacts (or the potential drivers of biodiversity loss). These included: virtual land use calculations, material flow analyses, environmentally-extended input-output analyses and ecological footprinting approaches. A variety of trade quantification methods is matched by an equal variety in the biodiversity indicators used. Some have applied specific biodiversity indicators such as genetic diversity or relative species richness and others have linked trade data to broader information on ecoregions or biogeographical realms. With such variation in methods and indicators across existing studies, a key part of this project has been the selection of appropriate biodiversity indicators and supporting datasets.

The full report follows the structure of the research project, firstly considering the production activities that might lead to biodiversity loss. The most likely direct and pertinent drivers in this case are habitat change, overexploitation and pollution. Several primary resource-use sectors were confirmed as those most likely to involve production activities that result in biodiversity loss: agriculture, fisheries, forestry, and energy and mining. Secondly, methods for tracking the international supply chains of goods and services from producer to consumer were explored in order to estimate the impacts associated with consumption. From this initial research a framework was developed to link UK imports to geographically-defined impacts on biodiversity. This framework is explained in the report and the results of its implementation are presented. The report concludes with recommendations for developments or improvements at each stage of the assessment framework, followed by extensions and further applications of the work.

ii.2. Assessment framework, approach and methods

The assessment framework developed in this project follows a three stage process for selecting and investigating the potential impacts that consumption in one country has on biodiversity in another. The three stages for assessment are as follows:

Stage 1: Use of an international trade model to trace supply chains and physical flows through the economy from producer to consumer; identifying the level of production required to satisfy consumption and the location and potential impacts of this production.

Stage 2: Selection of a particular commodity to investigate further.

Stage 3: A case study approach, providing detailed information about the biodiversity and impacts of production in a selected location.

A diagram of this assessment framework is shown in Figure ii.1, followed by a description of the method applied to provide the necessary data and information at each stage of the framework.

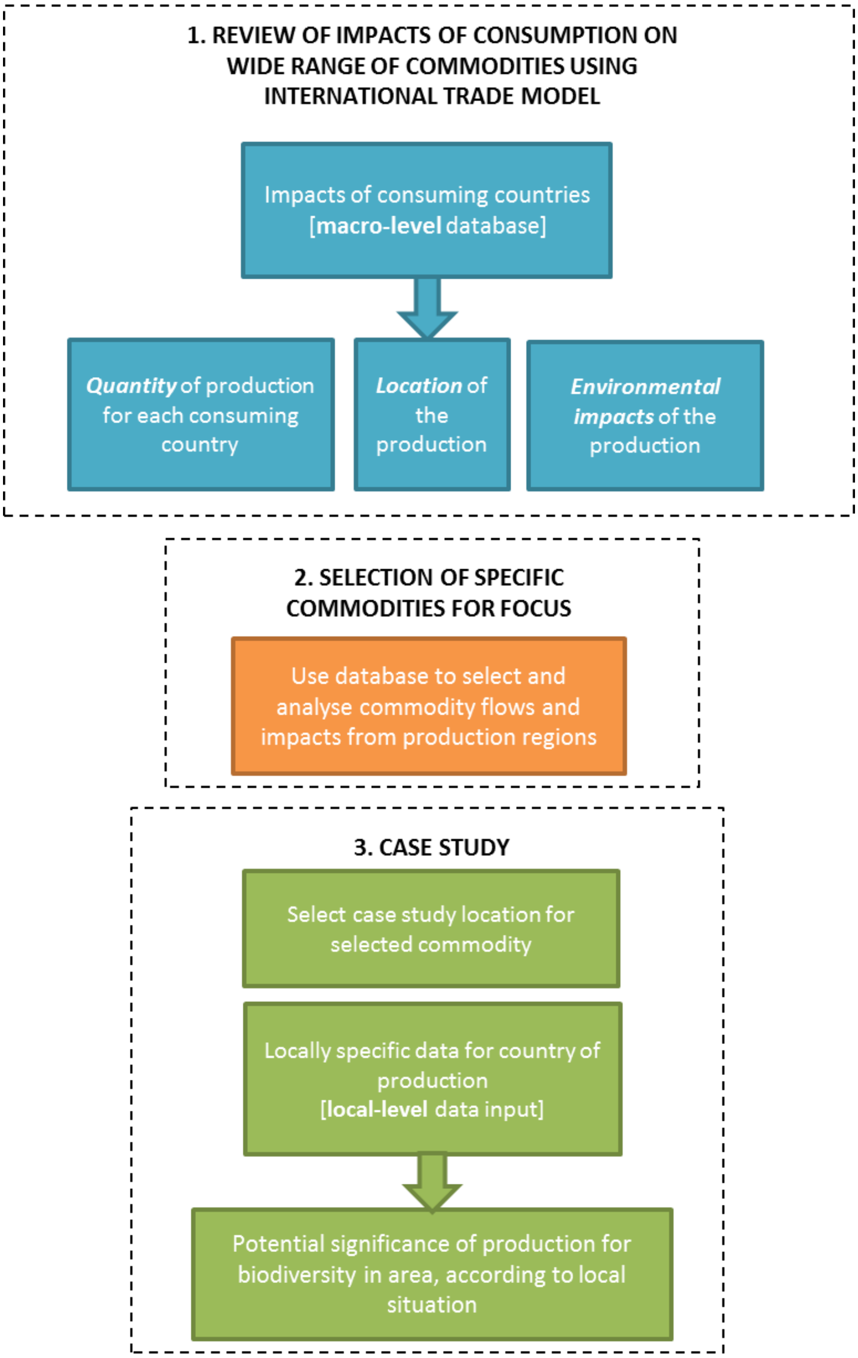

Figure ii.1. Overview of the assessment framework developed for the project.

ii.2.1. Stage 1: International trade model and the impacts of consumption

ii.2.1.1. Estimating impacts of consumption

Consumption data and production data are both often collected and reported by governments in economic and environmental accounts, along with data on the imports and exports to and from a country. However, to calculate the environmental impacts associated with consumption of a good or service all of the product inputs must be traced along the supply chain and combined with estimates of the number of products consumed. These data are rarely comprehensively provided in standard government statistics so need to be calculated. Techniques such as process life cycle analysis can be completed to estimate the impacts of individual products, but due to the variety and complexity of supply chains and the number of products this approach is very product-specific, difficult to implement at the national scale and cannot capture the full supply chain network. Macro-level assessment models are therefore employed to estimate impacts of all the goods and services consumed at the national scale. This provides consistency across product groups and includes full supply chains within a model of the whole economy, but estimates impacts to the aggregate product-group level rather than the individual product level.

Macro-level models have been used to generate ‘consumption-based environmental accounts’ which estimate the environmental impacts associated with all consumption wherever the impact occurs (domestically or abroad). These complement the territorial (or production) approaches commonly provided in environmental accounts. A good example of their use is in greenhouse gas emissions accounts, where consumption-based and territorial emissions can be compared (see for example, Peters et al. 2011). Similar methods have also been applied for other environmental impacts such as land use or water and they are often collectively termed ‘footprint’ or ‘consumption-based’ indicators. Many studies have demonstrated how this consumption-based approach can be successfully implemented at the national and international level to track flows of pollutants or resources from the point of production to the end consumer, but they also have a number of recognised limitations that are particularly relevant to this project on biodiversity impacts; these are listed below:

1) They report the quantity of pollutant or resource use flows from producer to consumer, but with no information about the local conditions and therefore severity or significance of the resource use at the local level. (This limitation is less significant where the impacts are global in the case of greenhouse gas emissions, but are very important when considering environmental impacts such as water use or biodiversity where impacts will vary depending on local conditions);
2) Only aggregated product-group information is provided and there is therefore a lack of specific commodity-level detail relevant to local-level production systems;
3) Information on the country of origin of commodity production is often lost when total consumption-based impacts are estimated;
4) Financial rather than physical data are relied upon to determine the movement of goods and services along supply chains.

The first limitation is related to the overall aims of the project and addressed by applying the developed assessment framework, i.e. linking macro-level trade flow data and consumption-based environmental accounts with local-level information about the origin of production. The second, third and fourth limitations are related specifically to the first stage of the framework; tracking international supply chains and modelling consumption-based impacts of a number of commodities simultaneously. The next section describes details of the method commonly used to develop consumption-based indicators and how the limitations of this approach are addressed within this project.

ii.2.1.2. Methods for calculating consumption-based impacts

The macro-level assessment model used for many consumption-based indicators is known as 'environmentally-extended input-output analysis'. Input-output tables contain data on the inputs and outputs of an economy, most often in financial terms. They are based on empirical data collected over a specific time period (usually a year) and regularly published by national statistics agencies for economic analysis. They show the interactions between industrial sectors of the economy and the consumption of products by the final consumers – mainly householders and the government sector (but also for export and other areas of expenditure such as capital investment). The input-output approach is therefore very suitable for tracing pollutants and resource use through the economy to the end consumer.

On a global scale, efforts have been made to combine input-output data for different countries and track financial flows between all of their industrial sectors in single models called 'multi-regional input-output (MRIO) models'. These models provide a suitable basis for tracking global supply chains and have greater ability to trace complex supply chains than standard trade statistics, which often identify only the country of last shipping rather than the origin of production or raw material extraction.

There are a number of international trade databases that provide the necessary source data for developing MRIO models, and a database developed by the Global Trade Analysis Project (GTAP) was identified as the most suitable for this project[1]. Using this database we generated an MRIO model containing data on the financial flows between 57 industrial sectors and 129 countries and/or regions of the world, representing global economic activity[2].

To track environmental impacts within the model, as opposed to solely financial flows, environmental information such as energy requirements, resource use or pollutants of each industrial sector must be added to the model. Once this is complete the model is termed an 'environmentally-extended input-output model' and can be used to estimate the environmental impacts (or footprint) of a nations consumption.

For this project we have combined financial input-output data from GTAP with a detailed matrix of commodity production and trade of commodities in physical units, which we have termed an 'MRIO-physical use model'. This method addresses the final three limitations described above: providing greater commodity level detail than in financial accounts alone (over 200 commodities compared to 57 aggregated product-groups in the financial model); giving production data in physical units by

[1] This decision was based on data coverage, availability, accessibility and consistency of publication. For assessment of other trade data and multi-regional input-output models see Section 2.2.1 in the full report.

[2] GTAP is a global database describing bilateral trade patterns, production, consumption and intermediate use of commodities and services. Bilateral trade, transport and protection data are used to characterize economic linkages among regions and individual country input-output tables account for inter-sectoral linkages within those countries (Narayanan et al. 2012).

country of origin and maintaining this detail through to the output stage, allowing the user to identify both the full supply chain impacts of the product consumed and the origin of production; and using some physical trade data (rather than solely financial) to trace flows through the supply chains.

The organisation of this MRIO-physical use model is shown in Figure ii.2. The box titled 'financial model' represents financial flows between the sectors in the global economy. The columns show the purchases of one sector from other sectors (e.g. the 'oil seeds' sector buys inputs from the machinery sector or the insurance sector; the 'value added' section represents expenditure on other inputs such as labour). The rows in the financial model indicate where that sector sells its outputs; either to another industrial sector or to final demand (the end consumer). Buying and selling can be either domestic or international (i.e. between sectors or consumers in the same country or other countries) and data is available for 57 industrial sectors and 129 countries/country groups.

The box titled 'physical-use table' can include information on the production and trade between countries of over 200 commodities for 236 countries in physical (rather than financial) units. The physical table contains data at a more detailed commodity level than the financial model (e.g. 'palm oil' and 'soyabean' rather than an aggregated group 'oil seeds').

Once the initial structure of the model is set up with the financial and physical datasets, a set of standard equations[3] can be used to conceptually reallocate the physical production from the industrial sector to the final good that is consumed at the end of the supply chain. The production and any associated environmental impacts or inputs (such as land, fertilizers or water) are traced along the global supply chains through various stages of processing, aggregated and then allocated to the good at the end of this supply chain. This is combined with information on the number of goods and services consumed within an economy and a total estimate of the impacts of consumption is derived.

For this project a number of different environmental datasets and indicators are linked to the production activities to provide information on environmental impacts that have the potential to drive biodiversity loss. The report includes an overview of these indicators and datasets, which can broadly be divided into those which can be explicitly and quantifiably linked to physical units of production (such as land, fertiliser and water requirements) and those which can only be linked semi-quantitatively or qualitatively (such as information from the IUCN Red List or WWF Ecoregions).

[3] Leontief equations, see Miller & Blair (2009)

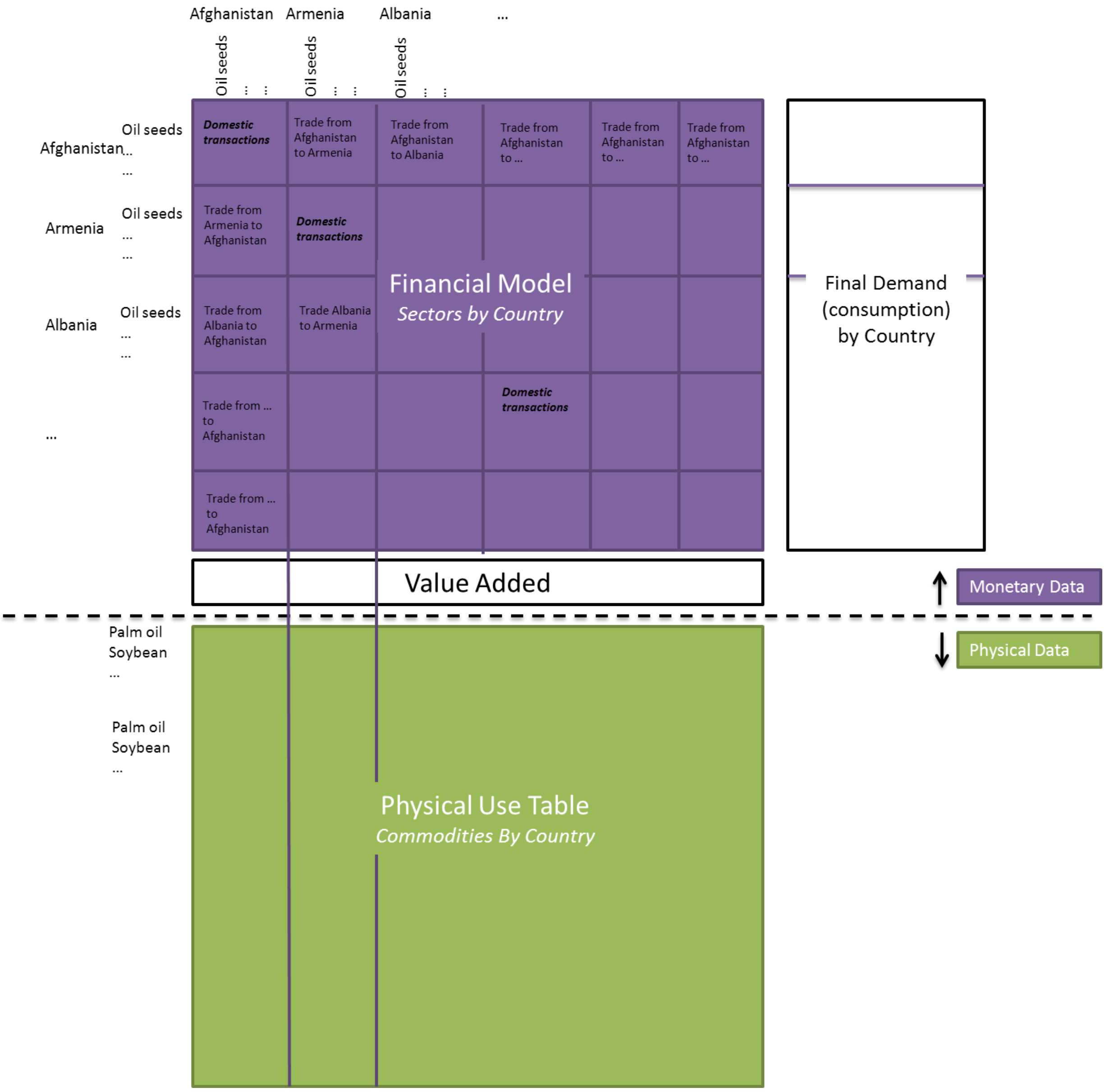

Figure ii.2. Diagram of the structure of the MRIO physical-use database, adapted from Ewing et al. (2012).

ii.2.2. Stage 2: Selection of specific commodities for further analysis

The MRIO-physical use model can generate data on the international production of over 200 commodities for consumption in 129 different countries. In addition, five environmental extensions are quantitatively linked to this production – land use, water use (green, blue and grey[4]) and fertilizer application, and four sources of biodiversity information (see Sections 5.2 and 6.1 of the main report for discussion of the limitations of these datasets) are also linked to the country of production within the database (IUCN Red List of Threatened Species[5], Bird Life International Important Bird Areas[6], IBAT's Key Biodiversity Areas and Alliance for Zero Extinction sites[7], and WWF

[4] See http://www.waterfootprint.org (accessed 25/03/13) and Section 2.2.3.2 of the full report.
[5] http://www.iucnredlist.org/ (accessed 25/03/13)
[6] http://www.birdlife.org/action/science/sites/ (accessed 25/03/13)
[7] https://www.ibat-alliance.org/ibat-conservation/login (accessed 25/03/13)

Global 200 regions[8]). This information can be used to select commodities and locations of interest for a more detailed analysis of impacts at the local level within the case studies.

It is impractical to present the information for over 200 commodities in one report so a number of priority products were selected by the steering group for analysis and presentation: bananas, bauxite, coffee, cocoa, cotton, hardwood (non-coniferous industrial roundwood), oil palm fruit (palm oil), rice, shrimp[9], soyabean, sugarcane and wheat. This project is primarily concerned with UK consumption, so results are presented for the full supply chain impacts of the goods and services consumed by residents in the UK (wherever in the world they are produced), identifying the origin of production of each commodity and the associated environmental impacts in that region.

The flexibility of the model means that results can be recreated for many other commodities and other countries' consumption in a straightforward manner. This approach also has the advantage of providing comparable, consistent and repeatable results across many products using the same model.

ii.2.3. Stage 3: Case studies and local-level biodiversity information

The role of the in-depth case studies is to give further detail and additional weight to the outputs from the model, presenting local and commodity-specific information that cannot be included within a global trade model system. They give an indication of the potential significance that each of the environmental impacts may have for biodiversity in a particular country, adding a level of detail not available in standard footprint assessments.

Due to project time constraints it was not possible to produce an in-depth analysis for all of the priority commodities selected in Stage 2. Consequently, only two case studies are presented in the report: one for soyabean and another for shrimp, with recommendations that further case studies be completed for products and countries of particular interest highlighted from the model outputs in Stage 1.

The case studies were developed by members of the research team with relevant expertise using academic literature, publications from international sources such as the UN or the World Bank, government statistics, non-governmental organisations such as WWF, and publically available datasets. The information collected includes the impacts of a variety of local activities on biodiversity such as: chemical fertilizer use in local areas, farming methods, soil erosion, crop selection and deforestation. This is presented along with background data on potential drivers of change in the region such as international investment, domestic and international commodity markets, changing farming practices, and national and regional policies for management and mitigation.

Collection of the data and information presented for the case studies were limited by the time constraints and the expertise of the research team. Whilst some initial links to local partners were identified during the project any future case studies may benefit the use of collaborative partnerships with stakeholders and sourcing of other local data sources.

[8] http://wwf.panda.org/about_our_earth/ecoregions/ecoregion_list/ (accessed 25/03/13)

[9] Shrimp is not considered further in this summary as, due to data limitations, it uses a model variation. Full details are presented in the full report.

ii.3. Results: Demonstration of the assessment framework for UK consumption

This section provides an example of the outputs from implementing the overall assessment framework. In accordance with the framework stages presented above, this section is also split into three parts:

Stage 1: Application of the MRIO-physical use model for assessment of the environmental impacts of UK consumption overseas, for a range of commodities.

Stage 2: Select of a commodity and location of production for in-depth analysis.

Stage 3: Collection and analysis of locally specific information for the commodity and location selected in Stage 2, combined with top-down data from Stage 1 for assessment of potential biodiversity impacts of consumption.

ii.3.1. Stage 1: MRIO physical-use model outputs

To demonstrate the additional benefit of using an MRIO model to track the impacts embedded along the full supply chains of all goods and services consumed (as opposed to just monitoring the direct trade of raw materials or finished products) it is useful to compare the model outputs with standard import, export and resource consumption data that is publically available in databases such as FAOStat[10].

Table ii.1. shows the UK domestic supply[11] data extracted from standard production and trade datasets for each product/crop[12], alongside the total production that takes place globally to satisfy UK demand[13] for all goods and services calculated by the MRIO-physical use model. All data is for a baseline year of 2007.

[10] http://faostat.fao.org/ (accessed 25/03/13)

[11] 'Domestic supply' is production, plus imports (and change in stocks), minus exports. Values for 'change in stocks' are available and included for agricultural products, but are available in the data for Industrial Roundwood and Bauxite.

[12] **Note:** The two product lists in this table differ in their coverage. For example 'coffee' in the FAO list in the left-hand side includes green coffee, roasted coffee and coffee extracts. FAO do not apply an MRIO model to trace raw materials from production to consumption, so when looking at domestic supply to the UK they include some raw materials in groups with more processed products. For the MRIO analysis only the raw production material is required as an input into the model (in this case 'coffee, green') and this is then traced through the entire supply chain and processing stages and allocated to the final consumer, so the production of 'coffee, green' to satisfy UK demand includes demand along the supply chain for more processed coffee products, not solely 'coffee, green'. The figures presented are therefore only comparable in the sense that they demonstrate the different approaches taken to accounting for product consumption, and should not be used for direct comparison or to interpret the accuracy of either approach.

[13] **Note:** In this text, table and all subsequent tables when showing total production or total land use 'for UK demand' or 'UK final demand' these terms refer to demand for all goods and services in the UK by householders and government, and for capital investment. These represent the consumers of the final product, rather than the requirements of an intermediate/ processing industry which then sells the product on, which is termed 'intermediate demand'. Any impacts of intermediate demand are embedded within the supply chains and allocated to the final consumer. For example, purchase of meat products may include soyabean in the supply chain, and this embedded soyabean production/impact is captured within the MRIO-physical use model.

<table>
<tr><th>FAO Product Description</th><th>Domestic Supply to the UK. Sources: Agriculture and forest: FAO; Bauxite: BGS/UN Comtrade</th><th>Total production that takes place globally to satisfy UK demand for all goods and services*</th><th>Units</th><th>Commodity analysed in the MRIO model</th></tr>
<tr><td>Bananas</td><td>939,489</td><td>871,778</td><td>tonnes</td><td>Bananas</td></tr>
<tr><td>Cocoa Beans[14]</td><td>278,798</td><td>134,382</td><td>tonnes</td><td>Cocoa beans</td></tr>
<tr><td>Coffee[15]</td><td>160,819</td><td>116,597</td><td>tonnes</td><td>Coffee, green</td></tr>
<tr><td>Sugar (Raw Equivalent)[16]</td><td>2,076,272</td><td>14,651,373</td><td>tonnes</td><td>Sugarcane</td></tr>
<tr><td>Soyabean Oil</td><td>366,379</td><td rowspan="3">3,410,798</td><td rowspan="3">tonnes</td><td rowspan="3">Soyabean</td></tr>
<tr><td>Soyabeans</td><td>809,992</td></tr>
<tr><td>Soyabean Cake</td><td>2,536,574</td></tr>
<tr><td>Palm Oil[17]</td><td>594,733</td><td>1,701,053</td><td>tonnes</td><td>Oil palm fruit[18]</td></tr>
<tr><td>Rice (Paddy Equivalent)[19]</td><td>569,435</td><td>3,310,057</td><td>tonnes</td><td>Rice, paddy</td></tr>
<tr><td>Cotton Lint</td><td>1,966</td><td rowspan="4">1,490,580</td><td rowspan="4">tonnes</td><td rowspan="4">Seed cotton</td></tr>
<tr><td>Cottonseed Cake</td><td>124</td></tr>
<tr><td>Cottonseed Oil</td><td>2,306</td></tr>
<tr><td>Cottonseed</td><td>76</td></tr>
<tr><td>Wheat</td><td>13,851,884</td><td>15,641,990</td><td>tonnes</td><td>Wheat</td></tr>
<tr><td>Industrial Roundwood (non-coniferous)</td><td>197,568</td><td>10,356,966</td><td>cubic metres</td><td>Industrial Roundwood (non-coniferous)</td></tr>
<tr><td>Bauxite[20]</td><td>44,465</td><td>5,093,063</td><td>tonnes</td><td>Aluminium ores & concentres</td></tr>
</table>

Table ii.1. Comparison of 2007 data from the MRIO model and standard production and trade databases, by product. Asterisk (*) represents data from model output.

In comparison with standard trade data, the model provides a different perspective on the quantities of product consumption and trade. Differences are particularly apparent for those goods that are embedded in the supply chains of other products and not consumed as a raw material. For example, despite sugar being tracked as a processed product in FAO data (as 'sugar, raw equivalent') and indicating that over 2.5 million tonnes is for domestic supply in the UK, the MRIO data suggests that there are much higher quantities of sugarcane required for UK domestic demand (14.6 million tonnes) when all sugarcane embedded in all products is considered (this also excludes sugar sourced from sugar beet – which has not been analysed within this project - so total embedded sugar is likely

[14] FAO Classifications: 61 Cocoa beans, 662 Cocoa Paste, 665 Cocoa powder and Cake, 666 Chocolate Prsnes
[15] FAO Classifications: 656 Coffee, green, 657 Coffee Roasted, 659 Coffee Extracts
[16] FAO Classifications: 158 Cane sugar, raw, centrifugal, 159 Beet sugar, raw, centrifugal, 162 Sugar Raw Centrifugal, 164 Sugar Refined, 168 Sugar Confectionery, 171 Sugar flavoured
[17] FAO Classification 257 Palm oil, 1276 Fatty Acids, 1277 Res. Fatty Subs
[18] Palm Kernels and Oil of Palm
[19] FAO Classifications: 27 Rice, paddy, 28 Rice Husked, 29 Milled/Husked Rice, 31 Rice Milled, 32 Rice Broken, 34 Starch of Rice, 38 Rice Flour; nutrient data only: 33 Rice gluten, 35 Bran of Rice
[20] Bauxite is not listed in the FAO dataset and data is instead sourced from the British Geological Survey and UN Comtrade.

to be higher still). This situation is similar for rice, seed cotton, oil palm fruit, industrial hardwood and bauxite.

Table ii.2 and Table ii.3 show the total production and land requirements to satisfy UK demand for each product in more detail, comparing the UK requirement from the MRIO-physical model to total world production and total world land area harvested for that production[21] .

	Production			Land Area		
	Production that takes place to satisfy UK demand for all goods and services (tonnes)*	**Total world production; FAO, 2007 (tonnes)**	**Percentage of total world production required to satisfy UK demand**	**Land area required to satisfy UK demand for all goods and services (ha)***	**Total land area harvested; FAO, 2007 (ha)**	**Percentage of world harvested land area required to satisfy UK demand**
Bananas	871,778	89,191,386	0.98%	41,562	4,683,550	0.89%
Cotton	1,490,580	73,551,789	2.03%	732,444	33,410,494	2.19%
Wheat[22]	15,641,990	612,611,392	2.55%	3,073,557	216,705,177	1.42%
Soyabean	3,410,798	219,676,859	1.55%	1,269,774	90,127,528	1.41%
Sugarcane	14,651,373	1,620,593,131	0.90%	251,938	22,809,305	1.10%
Rice	3,310,057	657,149,812	0.50%	694,355	155,137,979	0.45%
Oil palm fruit	1,701,053	193,126,508	0.88%	95,727	13,953,854	0.69%
Cocoa	134,382	3,883,052	3.46%	299,774	8,637,643	3.47%
Coffee	116,597	8,140,198	1.43%	159,659	10,626,475	1.50%

Table ii.2. Production and land requirements to satisfy UK demand, by crop, compared to total world production and land areas harvested. Asterisk (*) represents data from model output.

	Units	Total production that takes place to satisfy UK demand for all goods and services*	Total world production	Percentage of total world production required to satisfy UK demand
Industrial Roundwood (Non-coniferous)	cubic metres	10,356,966	632,132,047	1.64%
Bauxite	tonnes	5,093,063	213,148,398	2.39%

Table ii.3. Production to satisfy UK demand, for non-coniferous industrial roundwood and bauxite, compared to total world production. Asterisk (*) represents data from model output.

To consider the impact that UK demand places on production and land use compared to global availability we have compared the production and land used to satisfy UK demand per person to the production and land use availability globally per person (Figure ii.3). The ratio of UK demand to

[21] The figures in Table ii.2 are for primary products only. The FAO figures displayed are the production of the primary product (e.g. 'oil palm fruit'), which doesn't include any derivative/processed products. This table compares production of the primary product recorded by FAO, with the consumption of that primary product either directly or embedded within any goods and services consumed in the UK from the MRIO-physical use model.

[22] Wheat is the only crop listed in Table ii.2 with harvested land in the UK. Data from the MRIO-physical use model suggests that 1.36 million hectares of UK land are used to produce wheat for direct and indirect UK consumption; domestic production therefore accounts for approximately 44% of the UK's total land requirements for the wheat it consumes either directly or in processed products.

world production indicates whether demand for goods and services in the UK requires greater or lesser amount of production and land than provided on a per capita basis globally. For example, the data shows that the UK places a greater demand on production for cocoa and wheat than world average availability (3.8 and 2.8 times more respectively), but less for rice.

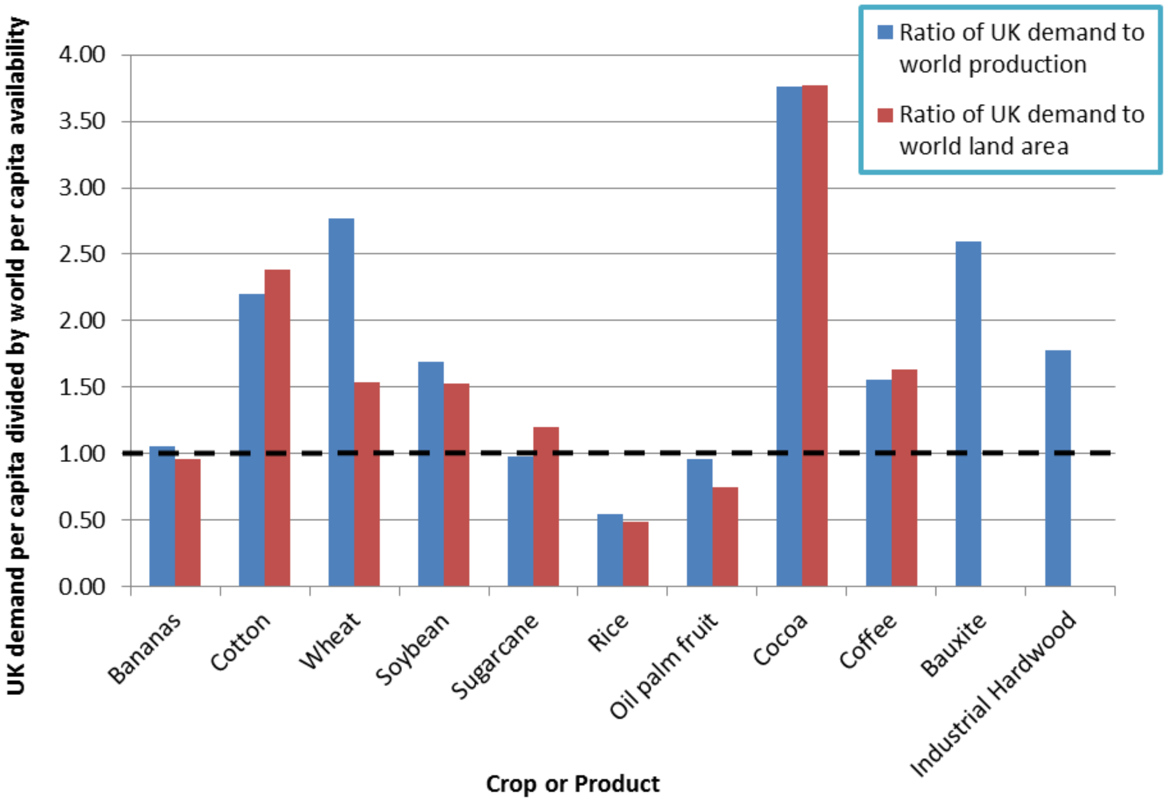

Figure ii.3. Global production and land requirements to satisfy UK demand per capita, compared to total world production and land use availability per capita.

ii.3.2. Stage 2: Selection of a commodity for further analysis

Soyabean was selected by the project steering group as a focus for analysis and therefore the remainder of this summary demonstrates the outputs from the MRIO-physical use model for soyabean (results are available in the full report for the other products listed in Table ii.2). These outputs are then used to select a country of soyabean production for focus in the in-depth case study. Environmental impacts are associated with commodity production in each of the 236 countries in the physical-use table. Although a full list of impacts is available in the database generated by the model, many of these countries do not produce the particular commodities listed and others only produce very small quantities. The results are therefore presented for the top countries of production for UK consumption.

The ability for the MRIO-physical use model to retain the country of origin of production (which is often excluded or aggregated in standard footprint results; see Section ii.2.2.1) is demonstrated in Table ii.4 which shows the top ten country origins of soyabean production used to satisfy UK demand for goods and services. Maintaining this level of detail allows analysis of the potential pressure that UK demand places on specific ecosystems and natural resources in particular countries. This can then be used to inform selection of case studies to assess impacts in more detail within the overall assessment framework.

Country of soyabean production/impact origin	Soyabean production that takes place to satisfy UK demand for all goods and services (tonnes), 2007*	Percentage of world soyabean production for UK demand that occurs in the specified country	Total soyabean production per country (tonnes), FAO 2007	Percentage of total country production that is used to satisfy UK demand for all goods and services
Brazil	1,417,268	42%	57,857,200	2.4%
Argentina	1,097,365	32%	47,482,800	2.3%
USA	549,625	16%	72,857,700	0.8%
Paraguay	89,298	3%	6,000,000	1.5%
China	88,054	3%	12,725,147	0.7%
Canada	52,730	2%	2,695,700	2.0%
India	37,636	1%	10,968,000	0.3%
Ukraine	22,700	1%	722,600	3.1%
Italy	10,547	<0.5%	408,491	2.6%
Uruguay	7,903	<0.5%	814,920	1.0%

Table ii.4. Production of soyabean in different countries used to satisfy UK demand for goods and services. Asterisk (*) represents data from model output.

The country with the largest soyabean production used to satisfy UK demand is Brazil, with 2.4% of the total country production being exported directly or used via supply chains to final consumers in the UK. Argentina is a second in terms of production; with 2.3% of the total production of soyabean in Argentina going to final consumers in the UK. Together these two countries produce around 74% of the total soyabean required for UK demand.

Similar analysis can also be completed for land requirements, where ranks may differ from the production perspective due to differences between crop yields in different areas. For soyabean the global land requirements to satisfy UK demand for all goods and services are shown in Figure ii.4. (maps for other environmental impacts are provided in the full report) and data are provided in Table ii.5. The top ten list is very similar to production for UK demand, demonstrating that the effect of yield differences is generally outweighed by the size of total soyabean output. DPR Korea (North Korea) appears in the top ten for land requirement, but is number eleven in production, swapping places with Italy in the top ten list.

Figure ii.4. Land requirements for soyabean in different countries to satisfy UK demand. Units: hectares (ha).

Country of soyabean production/impact origin	Soyabean land area harvested to satisfy UK demand for all goods and services (ha), 2007 *	Percentage of total soyabean land use for UK demand that occurs in the specified country	Total soyabean land area harvested in country (ha), FAO 2007	Percentage of total country harvested land area that is used to satisfy UK demand for all goods and services
Brazil	503,767	40%	20,565,300	2.4%
Argentina	369,341	29%	15,981,300	2.3%
USA	195,831	15%	25,959,200	0.8%
China	60,574	5%	8,753,868	0.7%
Paraguay	35,719	3%	2,400,000	1.5%
India	30,471	2%	8,880,000	0.3%
Canada	22,916	2%	1,171,500	2.0%
Ukraine	18,318	1%	583,100	3.1%
DPR of Korea	5,980	<0.5%	300,000	2.0%
Uruguay	3,555	<0.5%	366,535	1.0%

Table ii.5. Land requirements for soyabean in different countries to satisfy UK demand. Asterisk (*) represents data from model output.

These data on land use are useful to give an indication of the potential impact of UK demand across the world and the possible countries to target when considering resources embedded in goods and services consumed in the UK. For example, total world soyabean land used to satisfy UK demand is estimated at approximately 1,270,000 ha. If this soyabean was grown in the UK, its production would require approximately 20% of total available UK crop land which is estimated at 6,131,000 ha (based on FAO 2007 statistics). Of this 1,270,000 ha, 40% is actually attributed to production of soyabean in Brazil.

To add to this information on land use, the following environmental extensions are also included in the database:

- Green, blue and grey water use (with links to a measure of water scarcity) per country.
- Rate of fertilizer application per crop per country (nitrogen, phosphorus and potassium).
- IUCN Red List species threatened by production system in each country.
- Important Bird Areas threatened by production systems in each country.
- WWF Global 200 Regions threatened by production systems in each country.
- Key Biodiversity Areas and Alliance for Zero Extinction sites present in each country.

The database resulting from the MRIO-physical use model provides results at the country level for each of these environmental extensions and how inputs such as fertilizer use or blue water extraction may affect biodiversity at the local level is then considered within the detailed case study on a country-by-country basis as the impacts will vary by locality. The database gives an overview of the potential magnitude of impacts resulting from production for UK consumption and helps to select commodities and regions for further investigation, and the detailed case studies give an indication of the likely significance of these impacts. The summary data for water use for soyabean are shown in Table ii.6.

Water is a good example of why it is important to retain country of origin information and then consider the water availability at the local level; a country may have a high blue water requirement for soyabean production, but if it is a relatively water abundant area then this may not have a significant impact on biodiversity in the region. Water scarcity data are shown in Table ii.7. Information on water scarcity is available on a monthly basis at a major river basin level and we have developed this data source to provide complementary information for comparison against crop blue water footprints. To generate data relevant at the country level, river basins are allocated to the countries that they cover (for the purposes of this study, no weighting was applied to account for the percentage of the basin falling within each country). We condense the monthly information on water scarcity into a single value which specifies the number of water basins within that country which face 'extreme' water scarcity over the course of the year. We have defined extreme water scarcity as basins which experience three or more months of severe water scarcity (which occurs when the monthly blue water footprint exceeds 40% of natural run-off; see Section 2.2.3.2 in the full report for further details). For the basins which experience extreme water scarcity, we also specify the mean number of months under severe scarcity, the total (combined) area of water basins facing extreme scarcity, and the proportion of this area compared to the total basin area assigned to that country. The analysis for soyabean in Table ii.7 indicates that, for soyabean production for UK demand, of the top ten blue water users the USA, China, India and Iran are the countries most likely to encounter water scarcity issues.

Country of primary product production/ impact origin	Blue water use for growing soyabean for UK final consumption (000 m^3)	Country of primary product production/ impact origin	Green water use for growing soyabean for UK final consumption (000 m^3)	Country of primary product production/ impact origin	Grey water use for growing soyabean for UK final consumption (000 m^3)
USA	50,766	Brazil	3,091,730	Brazil	21,266
China	21,926	Argentina	2,297,424	China	19,220
Argentina	5,830	USA	857,606	Argentina	12,522
France	2,081	China	224,433	India	5,464
Italy	1,380	Paraguay	222,558	USA	5,274
Brazil	1,179	India	159,664	Ukraine	3,211
India	847	Canada	75,539	Paraguay	1,552
Indonesia	648	Ukraine	65,966	Canada	1,470
Iran	598	Uruguay	24,593	France	1,136
Romania	164	DPR of Korea	17,897	Viet Nam	577

Table ii.6. Water requirements for soyabean production to satisfy UK demand. All data are model outputs.

	Blue water use for growing soyabean for UK final consumption (000 m^3) *	Number of basins in country that face extreme water scarcity	Mean number of months of severe scarcity for basins that face extreme scarcity	Total area of basins in country facing extreme water scarcity (km^2)	Proportion of total water basin area in country facing extreme water scarcity
USA	50,766	11	7.09	1,661,546	18.93%
China	21,926	10	5.70	5,050,178	48.81%
Argentina	5,830	1	4.00	154,330	3.84%
France	2,081	1	3.00	21,499	3.42%
Italy	1,380	0			
Brazil	1,179	3	3.00	125,712	1.09%
India	847	12	5.83	3,318,524	86.50%
Indonesia	648	1	3.00	15,146	3.29%
Iran	598	2	4.00	862,914	100.00%
Romania	164	0			

Table ii.7. Blue water requirements for soyabean production to satisfy UK demand and scarcity measure for each country. Asterisk (*) represents data from model output.

Fertilizer data were extracted from FAO FertiSTAT[23] providing information on the application rates of nitrogen, phosphorus and potassium by crop type. For soyabean, the application rates data were only available for 27 of the 236 production countries included in the model, and for varying years

[23] http://www.fao.org/ag/agp/fertistat/index_en.htm (accessed 25/03/13)

(the latest year available is 2003). The application rates (kg/ha) per fertilizer type were multiplied by the soyabean land (hectares) required for UK demand to give an indication fertilizer consumption and associated impacts that this could have on biodiversity (see Section 1.2.1 in the full report and the soyabean case study for more details on links between fertilizer use and biodiversity). The top ten countries with the largest nitrogen fertilizer consumption rates are shown in Table ii.8 (data for phosphorus and potassium are available in the full report). Brazil has a low rate of application, but harvests a large land area for UK demand so total consumption is estimated as almost as high as the USA, where application rates are higher, but land area harvested is lower.

Country name	Soyabean land area harvested to satisfy UK demand for all goods and services (ha), 2007 *	Data year	Rate of Nitrogen application, FertiStat (kg/ha)	Consumption of Nitrogen for soyabean for UK demand (tonnes) *
USA	195,831	1998	30	5,875
Brazil	503,767	2002	8	4,030
China	60,574	1997	60	3,634
Argentina	369,341	2002/2003	2	739
Canada	22,916	2000	25	573
Paraguay	35,719	1997	10	357
Viet Nam	1,056	1999	45	48
Uruguay	3,555	1998	10	36
Hungary	401	1999/2000	52	21
Thailand	1,293	2001	12	16

Table ii.8. Soyabean nitrogen application rates and total consumption for UK demand. Asterisk (*) represents data from model output.

The datasets produced by the MRIO-physical use model can also be disaggregated by the specific products that UK consumers demand. This can be useful for exploration of which commodity groups purchased by the final consumer contain embedded products of interest somewhere in their supply chain and the origin of the production or land impact.

These data are organised in two ways:

1) By the last country where the product is imported from to the UK (for example, this may be the Netherlands); and then the total global production or land requirements anywhere in the world needed in order to satisfy UK demand for that product.

2) By the location of the original production of the products that have the raw material (crop) embedded within them – i.e. where the production and land impact is actually occurring in order to satisfy UK demand for the product.

Table ii.9 shows data organised according to description (1) above; the top ten products purchased by UK consumers and where they purchased those products from (for example retail trade[24] in the

[24] All of these source sectors relate to descriptions used in the GTAP database which can be viewed here: https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector.asp (accessed 25/03/13). These codes can be matched to the ISIC3 classification and details are provided in the following document: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3777 (accessed 25/03/13). Retail trade in particular is a broad sector category, including sales of motor vehicles and fuel, retail trade of goods in stores, retail sale of food, repair of goods and hotels and restaurants. Retail sale of food is of particular interest for commodities and this is

UK), along with the global land area required (anywhere in the world) to produce the required amount of that product for UK demand. For example, 'Vegetable oils and fats' purchased in the UK by UK consumers require 23,620 hectares of soyabean land somewhere in the world. Similarly, 'Wearing apparel' purchased from China (imported) by UK consumers requires 31,546 hectares of land.

Table ii.10 shows results organised according to description (2) and provides the origin of production for UK demand for particular product groups.

These tables demonstrate that there are a number of products purchased for final consumption that may have high embedded quantities (and associated land use) of soyabean, but that may not be typically associated with that product, for example soyabean embedded in wearing apparel. Product groups can contain high embedded soyabean land area for one (or both) of two reasons – the sector includes many products with high amounts of soyabean used within their supply chains (e.g. for 'food products nec' or for 'vegetable oils and fats'); or there is high level of UK final demand expenditure on a variety of individual products within that sector that may each have small amounts of soyabean embedded within them (e.g. 'Public Administration Defence Education Health').

Country where final product is purchased	Source sector of final product purchased by UK consumers	Global soyabean land area requirement (ha) *
United Kingdom	Food products nec[25]	378,906
United Kingdom	Retail trade	79,628
United Kingdom	Public Administration Defence Education Health	74,777
United Kingdom	Beverages and tobacco products	62,864
China	Wearing apparel	31,546
Argentina	Vegetable oils and fats	29,924
United Kingdom	Vegetable oils and fats	23,620
United Kingdom	Construction	21,133
Denmark	Food products nec	19,802
Netherlands	Food products nec	19,562

Table ii.9. Products purchased by UK consumers and associated soyabean land requirements embedded within those products, with country of purchase. Asterisk (*) represents data from model output.

matched to ISIC3 code 522 in the GTAP database. ISIC3 includes purchases from stores specialized in the sale of any the following merchandise lines: fresh or preserved fruit and vegetables; dairy products and eggs; meat and meat products (including poultry); fish, other seafood and products thereof; bakery products; sugar confectionery; beverages (not for consumption on the premises); tobacco products; other food products. The sector 'Public Administration, Defence, Education, Health' includes all expenditures on the following ISIC3 groups: Public administration and defence; compulsory social security; Education; Health and social work; Sewage and refuse disposal, sanitation and similar activities; Activities of membership; organizations n.e.c.; Extra-territorial organizations and bodies.

[25] Food products not elsewhere classified (nec). For all GTAP product descriptions see: https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector.asp (accessed 25/03/13). Food products nec include: prepared and preserved fish or vegetables, fruit juices and vegetable juices, prepared and preserved fruit and nuts, all cereal flours, groats, meal and pellets of wheat, cereal groats, meal and pellets n.e.c., other cereal grain products (including corn flakes), other vegetable flours and meals, mixes and doughs for the preparation of bakers' wares, starches and starch products; sugars and sugar syrups n.e.c., preparations used in animal feeding, bakery products, cocoa, chocolate and sugar confectionery, macaroni, noodles, couscous and similar farinaceous products, food products n.e.c.

Country of soyabean production/ impact origin	Source sector of final product purchased by UK consumers	Soyabean land area required in each country to satisfy UK demand for each product (ha) *
Brazil	Food products nec	250,025
Argentina	Food products nec	174,345
United States of America	Food products nec	64,970
Brazil	Vegetable oils and fats	40,986
Brazil	Beverages and tobacco products	38,324
Brazil	Retail trade	37,784
Argentina	Vegetable oils and fats	29,917
Brazil	Public Administration Defence Education Health	29,852
Argentina	Trade	27,433
Argentina	Beverages and tobacco products	26,214

Table ii.10. Products purchased by UK consumers and associated soyabean land requirements embedded within those products, with country of original production. Asterisk (*) represents data from model output.

The significance this land area impact has in the country of production, however, depends on the nature of the land use/land cover in which it is taking place, and/or what it may be displacing, and therefore the sensitivity of that receiving environment. To address this requires a more detailed examination at the case study level.

ii.3.3. Stage 3: Case study of selected commodity and location of production

The final part of the assessment framework involves a case study approach, considering the potential biodiversity impacts that production may generate in a particular region. Brazil was selected for the case study for soyabean production impacts. This decision was largely due to Brazil's position at the top of the production output and land use rankings. Details presented in Box ii.1 represent a summary of the Brazil soyabean case study results; full details can be found in the main report. It should be noted that these case studies are based on information drawn from the literature and any views expressed represent those of the cited sources rather than the authors or Defra.

Box ii.1. Summary of Brazil soyabean case study (Reference list in main report).

The majority of soyabean (75%) is grown in the cerrado region of Brazil. This is one of the largest savannah-forest complexes in the world and contains a diverse mosaic of habitat types and natural communities. Agricultural development has been described as one of the largest threats to biodiversity in the region, with potential loss of natural habitats to crop production and associated infrastructure (Fearnside 2001). To date, it has been estimated that two-thirds of the Brazilian cerrado and cerradao have already been converted to agriculture (Galford 2010). In 2005, it was estimated that there were 137 animal species threatened with extinction in the cerrado (Klink and Machado 2005) and the IUCN Red List indicates that, in Brazil, crop farming is currently threatening 34 critically endangered species and a further 65 endangered species (IUCN 2012).

Within the Mato Grosso state, where production of soyabean is highest, the rate of deforestation and land-clearing for crop and cattle production has slowed considerably since a peak in 2003/2004 (Macedo et al. 2012). Macedo et al. (2012) highlight that during recent expansion in production, a historical oversupply of land meant that there was plenty available without the need for accelerated new deforestation. However, Galford (2010) has undertaken analysis that suggests that once this existing land is used up any increased demand may cause a fresh wave of deforestation in the region.

Recently, soyabean farming, particularly in the northern regions of the country, has become increasingly concentrated and mechanised, with cultivated areas ranging from between 500 and 5000 hectares (Fundação Agrisus 2006). Developments in crop breeding and crop engineering in response to global product demand and national development activities have also resulted in large-scale conversions of natural ecosystems or lower production agricultural lands (e.g. pasture) to row-crop agriculture (Galford 2010). Soyabean production also generates significant soil erosion, especially in areas where long cycles of crop rotation are not implemented (Clay 2004).

Some studies are available (e.g. Donald 2004, Cerdeira et al. 2007) on the impacts of chemical pesticides and fertilizers and increased used of genetically modified soyabean on biodiversity in specific areas in Brazil, with initial indications of damaging effects from intensive use and build-up of chemicals in the environment. However, many of these studies highlight the need for further research in this area, along with better monitoring and regulation of the chemicals in use.

There is movement in Brazil to guarantee that soyabean expansion takes place in a responsible manner and according to national laws. European consumers have increasingly required that the product they buy must be produced according to environmental and social standards, and be certified by specific programs, such as the Roundtable on Responsible Soy (Institute for International Trade Negotiations 2011).

Overall, the case study demonstrates that there a numerous complex issues surrounding crop production, land use change, pollution and potential biodiversity impacts in Brazil. Whilst importing and investing countries may have the potential to shape production in exporting countries, further research would therefore be needed to draw firm policy conclusions for the UK. In the future, growing global demand for food is likely to put increased pressure on resources, and the historical and current impacts identified in the case study are also likely to be important in areas of future expansion.

ii.4. Discussion

The approach developed presents a new perspective on the global impacts of UK consumption, which is potentially highly powerful for undertaking a wide analysis of potential drivers of biodiversity loss in producing regions, and simultaneously assessing a variety of different commodities in a consistent, comparable and repeatable manner. The inclusion of supply chain impacts and retention of the origin of production within the international database is a fundamental step forward in understanding the potential holistic impacts in one country associated with consumption in another. Once areas of particular importance have been identified, and potentially monitored over time, completing the assessment with more detailed locally-specific datasets (as demonstrated within the case studies) represents a valid and powerful mechanism for analysing the potential impact that UK consumption is having on overseas biodiversity.

High-level comparisons between the impact of UK demand and the availability of goods produced or land area required on an international per capita basis demonstrate that the UK places a larger pressure compared to that available per person globally for some products, and smaller for others. If the global population each had an equal share of the world's rice production for example, there would be approximately 99 tonnes per thousand people, but for UK demand for all goods and services only 54 tonnes of rice per thousand people are required. On the other hand, demand for all goods and services in the UK requires far more cocoa than a world per capita production, with only 0.6 tonnes per thousand people produced globally and 2.2 tonnes per thousand people (3.8 times more) required for UK demand, which is similar for wheat where UK demand requires 2.8 times the global per capita amount. Possible explanations for this include geographic- or culture-led consumption patterns in the UK, for example preferences for wheat over rice as a staple cereal, or fashion-led purchasing of clothing leading to higher than average cotton demand. As a relatively affluent nation there is also likely to be greater demand in the UK for high value, non-essential items such as coffee and cocoa, or high-technology products with embedded bauxite. This information, including the use of the environmental extensions highlighted, may be useful for communication of the issue of consumption, and the targeting of particular products for future exploration.

Of the products analysed so far, we can begin to get an impression of where in the world consumption in the UK may place greatest pressure on resources, land use, water and biodiversity. Evidence from the focus on soyabean in Brazil demonstrates the links between UK consumption and soyabean production and land use in South America, particularly Argentina and Brazil. Evaluation at the product level indicates that soyabean is not only consumed in the UK through food products and vegetable oils and fats, but also through the purchasing of products such as clothes from China. Retaining the location of the origin of production within the international database, rather than aggregating into a total footprint figure or just showing the country of last import, provides a first step towards linking UK consumption to regional and locally specific impacts overseas. This is particularly important for the environmental extensions such as water and fertilizer use, where specific local circumstances can alter the significance that use of this resource may have on local biodiversity. It also serves as a guide for possible countries and commodities to focus on in case studies for future policy recommendations.

ii.4.1. Limitations and assumptions of the framework

A key strength of the methodology is that it draws directly from authoritative sources of data on trade and production and internationally recognised biodiversity information. However, the use of such empirical statistics which often contain data inadequacies means that certain assumptions have to be made when compiling the data for use within the methodology, and certain limitations result which should be taken into account when interpreting the results. The full limitations and assumptions are listed in the report and they are summarised here:

Data quality:

- Any datasets are subject to possible errors and inaccuracies. GTAP and FAO are the main sources of data for this analysis and although these datasets are deemed to be some of the highest quality available, they are based on survey or submitted statistics, harmonised and aggregated data, and in some cases have missing data which could influence modelling outputs.
- GTAP data are published regularly and provide good global coverage for world-wide assessment, but the nature of the data collection and harmonisation requirements mean that they are often produced with a considerable time lag; the most recent database is for 2007. International support and funding for this type of database provision may reduce this time lag, but it is therefore important to supplement this with trend data (where available) or more recent data at the local level.

Model composition:

- Due to data limitations, the development of a global financial input-output model requires assumptions about the distribution of imports across sectors. Similarly, limited data are available to describe which sectors require which products at the individual product level in physical terms. Whilst this doesn't affect the ability of the model to complete the reallocation from production to consumption, it does mean that during the construction of the model imports of a product from different countries have to be treated as a homogenous group when being distributed for use within industrial sectors of that country.
- Physical data on re-exports, which is important for building the physical use table from trade data, is unavailable. To overcome this problem we have developed an algorithmic approach to ensure that re-exports are accounted for.

Data availability:

- There is limited availability of trade data for fisheries and minerals/metals in comparison to agricultural products. In addition, marine fisheries statistics are commonly reported according to the vessel sovereignty and/or landing site and therefore contain limited information regarding catch location. Assigning impact to a 'producing' country may therefore be erroneous if fishing occurred in the open seas or other territorial waters.
- Coverage of the environmental extensions used in this report is not always complete. In some cases (e.g. fertiliser statistics, grey water) there are significant data gaps, which mean that true impacts may be overlooked where data are not available.
- The biodiversity data used in this report are based on international datasets that are readily available. However, there are biases in both species and geographic coverage of these datasets that have not been collated specifically to assess links to threats from production activities. As such, rather than attempting to link data on biodiversity quantitatively to units

of production associated with final demand, biodiversity data is only qualitatively linked to model outputs.

Proper consideration of the above assumptions and limitations should not lead to the inference that the methodology has fatal flaws, or that these flaws will be irrevocable in the future (the research field and quality and availability of data is improving rapidly). Instead, this understanding should be used to ensure that the methodology, which represents a potentially powerful tool and resource for analysis, is not misapplied.

ii.4.2. Recommendations

The main report contains a full discussion of recommendations for applications of the framework and methodological developments that could be explored in the future. A summary of these is presented here:

Data improvements:

- To assess the sensitivity of the methodological results, sensitivity analyses could be conducted on some of the model assumptions (for example the re-export algorithm) or through the use of alternative trade, production and environmental extension data sources.
- Physical production and trade data for additional product groups should be incorporated into the datasets. The major focus here has been on products of agriculture, but additional forestry, mining and energy, and fisheries production could be incorporated in the future to broaden the application of the framework to other sectors.
- Exploration of additional environmental extensions (and additional investment to improve the coverage of the internationally-available environmental extension data used in this project) is warranted to improve the modelled links to potential environmental and biodiversity impact. Additionally, extensions which encompass attempts to mitigate biodiversity loss (e.g. protected areas, certification schemes) have not been included in this study, but may be useful for policy analysis and could be incorporated.
- Development of aggregated indicators for potential biodiversity impact has not been attempted in this project, but could potentially be developed and may be useful when disseminating outcomes from the model.
- The preliminary case studies presented in this project rely on project-team expertise, and information from academic and grey literature and the internet. Future, more extensive, case-studies are recommended in conjunction with governments and experts of the countries or regions under study.

Policy application and further analysis:

- The product-specific and consumption-category-specific detail that is accessible with the model lends itself to analysis from the perspective of specific industrial sectors. The addition of a more comprehensive set of products would also allow an assessment of aggregated, in addition to these product-specific, impacts.
- Although only applied to UK consumption within this project, the model can be applied from the perspective of any country. It would be beneficial to conduct future analysis which includes consideration of consumption of other countries as impacts in a country are likely to be associated with demands from many countries acting concurrently.

- Downscaling the methodology to assess individual, local, or business consumption-based impacts could be useful for policy making at sub-national scales. Extension of the methodology to non-biodiversity-related indicators should be possible and would allow analysis of potential biodiversity impacts within a wider socio-economic and environmental setting.
- Development of timeseries data would be useful to monitor potential changes in trade and associated impacts over time. Several approaches could be adopted to develop timeseries information.
- Simple scenario analysis can be conducted within the existing methodological framework to explore potential future changes in consumption and production. Development of alternative methodologies (such as general equilibrium modelling) using the same or similar data could also be developed to complement future scenario work.
- Development of further case studies should form an integral component of future applications of the assessment framework developed here.

Using the methodology as a formal indicator of biodiversity impact:

The methodology developed in this project has the potential to be used as the foundation of a 'Global Impacts' indicator for use to measure progress towards Convention on Biological Diversity targets. Key features of the methodology which make it suitable include: an ability to use readily available, regularly updated, datasets; flexibility to incorporate alternative and/or additional data; retention of product detail than can be extended to a variety of potential information sources linked to biodiversity impact; incorporation of complete global trade interactions via the use of an MRIO model. In order to formalise the methodology as an indicator, the following developments should be considered:

- Inclusion of a greater number of products (including non-agricultural products) and potential aggregation of products to analyse the combined impacts of product groups.
- Further data comparison and verification of results against alternative datasets and methodologies to ensure broad consistency of outcomes.
- A method for generating timeseries data that would allow measurement of potential changes in impacts over time.
- Formalisation of environmental extension priorities and presentation of outputs to ensure consistent reporting and efficient communication of information.
- Incorporation of methodological improvements (such as those presented above) to improve model outputs.

Measuring the impacts on global biodiversity of goods and services imported into the UK

Methodology Report

February 2013

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Contents

1. Introduction

Continued growth in global demand for goods and services is a major contributor to on-going environmental degradation. However, increasing trade liberalization and the resulting increased complexity of supply chains has led to the geographic separation of production-driven environmental impacts from the point of consumption. Although able to acknowledge their potential importance as drivers of environmental and societal impact, consumers and policy makers therefore find it increasingly difficult to understand the real-world consequences of their consumption.

This study focuses on one potential impact of the pressure that growing demand and resource extraction and use place on the environment – the loss of biodiversity. The main drivers of biodiversity loss globally are: habitat change (including land use change and modification of rivers and water withdrawal); over-exploitation; invasive alien species; pollution; and anthropogenic climate change. As the project focus is UK consumption, we concentrate on identifying production activities overseas that generate export goods for the UK that could also lead to local biodiversity loss. The most likely direct and pertinent drivers in this case will be habitat change, overexploitation and pollution.

We will address this challenge by linking two distinct research streams: the analysis of trade pathways and supply chains (both direct and indirect) for both goods and services to identify important sources of production; and identification and analysis of production systems and products and their impacts based on geographically specific biodiversity-relevant information. Combining these research streams involves overcoming issues with data-availability (for trade, production, and biodiversity) and assessment of complex resource pathways and environmental interactions.

This document focuses on the methodology used to link financial trade data with physical production and environmental data. The result of the methodology is an allocation of production, in terms of tonnes of a good produced, to UK consumption. This production information can then in turn be linked to biodiversity drivers and impacts.

2. Background to the method development and project

The UK Department for Environment, Food and Rural Affairs (Defra) have commissioned this study to investigate the impacts that consumption in the UK has on biodiversity overseas. The main objective of this work is to provide a database-driven methodology for linking UK imports to geographically-defined impacts on biodiversity. Researchers at the Stockholm Environment Institute (SEI), University of York, with support from Collingwood Environmental Planning (CEP) have proposed a method to answer this question which utilises and applies recent developments in multi-regional input-output (MRIO) modelling. The method is outlined in this paper. The research project started in November 2011, with a final report to be published and database provided by March 2013.

An interim report was provided to Defra in March 2012 and included a review of existing methodologies, trade and consumption data availability and biodiversity indicators. Following this process the project team recommended that a multi-regional input-output approach is applied to ensure that all indirect impacts of UK consumption are captured (a key requirement of the project brief). From knowledge of MRIO approaches, and previous work conducted in conjunction with partners on the OPEN:EU project (http://www.oneplaneteconomynetwork.org/), we then recommended the development of a methodology, based on the latest footprinting analysis (as presented by Ewing et al. (2012)), to link financial multi-regional input-output (MRIO) tables with physical production and trade information. The main advantage of this approach, as highlighted by Ewing et al. (2012), is the maintenance of product-level detail traditionally found in physical flow accounting, combined with the full supply-chain detail that MRIO analysis provides. This approach has previously been used to create the 'Footprint Family' of indicators for tracking human pressure on the planet, as described in Galli et al. (2012).

Due to its capacity to retain product-level detail and full supply chain impacts, this MRIO-F approach is an appropriate technique to begin to link UK imports to geographically-defined impacts on biodiversity. However, whilst the MRIO-F method is particularly useful for tracking the impacts associated with consumption for any pollutant or resource use that has the same effect regardless of the origin of production (such as greenhouse gases), impacts that vary depending on the local conditions (such as water use or biodiversity) require more information to attempt to link consumption to the actual impacts on the ground. The methodology described in this paper will therefore be used to extend these latest footprint family developments and MRIO-F modelling advances to capture both a broad set of indicators of the drivers of biodiversity loss, along with possible methods to link these to data on local impacts and localised effects.

We start with an overview of the methodological approach proposed for this study which in theory can be applied to any production system given sufficient production and trade information. Details are given of the assumptions taken to link the physical and financial data sets. We explain how a GTAP8 (Global Trade Analysis Project: https://www.gtap.agecon.purdue.edu) MRIO table linked to physical agricultural production data from FAO is implemented based on the work of Ewing et al. (2012) and Peters, Andrew, and Lennox (2011). In the case where extensive trade information is not readily available we detail an alternative technique for linking the physical data to the MRIO table. This is briefly summarised following the explanation of the physical use table extension. We finish with an overview of how production data may be linked to drivers of biodiversity loss. We hope that this will contribute to the further development and progress of these types of indicators and further raise the profile of monitoring both direct and indirect impacts of activities through consumption and trade-based methods.

3. Methodology and model development

The following section describes the method used to link physical data to a financial MRIO table.

3.1. The model structure overview

The basic data structure of the model is based on environmentally-extended input-output analysis, with the inclusion of the latest developments for incorporating physical data described by Ewing et al. (2012) and is shown in Figure 1.

Ewing et al. (2012) describe various different options for linking the monetary and physical datasets; the simplest approach for integrating physical data with a financial MRIO is a direct allocation of all primary products to their producing MRIO sectors, and the most complex would be to use physical data directly within the MRIO table. The second option, whilst theoretically more powerful, would require disaggregation of the MRIO sectors which is a resource intensive task and requires data that is not consistently available across all products. The first option is useful and applicable when physical data are limited and is described in more detail in Section 4.2.

As a compromise between the most simple option and a full sectoral disaggregation, Ewing et al. (2012) describe a method which involves the construction of a 'physical use' matrix. This has the advantage of maintaining product level detail in physical units, and can be linked to the MRIO table using datasets that contain highly aggregated information about product supply and use. In this case rows in the physical use table represent physical products by country, columns represent sectors of the MRIO model and the country where they are located. The advantage of this method is that detailed mass flow accounts (and therefore product-level information) can be maintained alongside the original monetary structure.

Constructing matrices of the use of physical commodities ('physical use tables') and linking these to the financial MRIO table is the most complex part of the model development and requires a number of assumptions that are detailed below. The research team have also developed a number of algorithms for overcoming some of the data restrictions. Whilst the methods used to develop this model have followed the mathematical descriptions outlined in Ewing et al. (2012), some assumptions and development approaches may differ in order to utilise the implemented datasets, chosen for their ability to accommodate potential biodiversity-specific impacts.

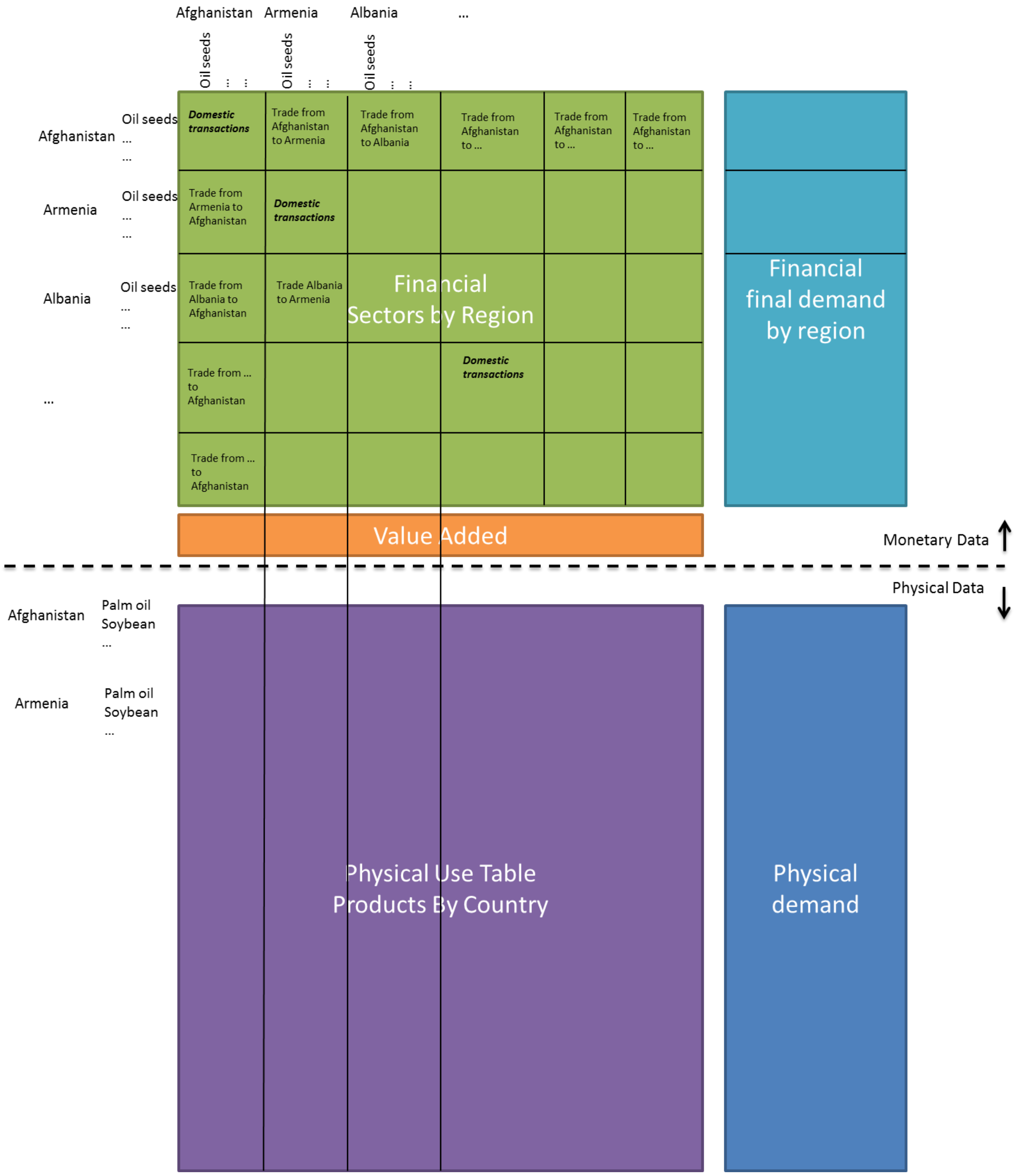

Figure 1: Diagram of MRIO physical model adapted from: Brad R. Ewing, Troy R. Hawkins, Thomas O. Wiedmann, Alessandro Galli, A. Ertug Ercin, Jan Weinzettel, Kjartan Steen-Olsen, Integrating ecological and water footprint accounting in a multi-regional input–output framework, Ecological Indicators, Volume 23, December 2012, http://www.sciencedirect.com/science/article/pii/S1470160X12000714

3.2. Data preparation for linking physical and MRIO tables

3.2.1. MRIO table

In order to track both direct and indirect flows of goods and services through the world economy (and therefore also for UK consumption) it is first necessary to construct a multi-regional input-output (MRIO) table, which represents the supply and use of goods and services, in monetary values, between numerous world regions and their industrial sectors. We have chosen to use GTAP data to construct our MRIO, following the method of Peters, Andrew, and Lennox (2011). Further details of the construction of the GTAP data are given in Sections 4.1.1. and 4.1.2.

3.2.2. Physical data collection

To create a product-level physical use table, a dataset that provides production and trade data for many products across multiple countries (in physical units) is required. If this trade information extends to physical trade between sectors then allocation based on the detailed physical data can be completed, however, in the majority of cases trade information is limited to inter-region trade, in which case other data must be used to inform use across sectors.

3.2.3. Concordances between datasets

In order to link the two datasets, products, sectors, regions and countries must be matched so that the physical data can be allocated to the most appropriate monetary sector in the MRIO table. As there is no international harmonised system for physical and monetary accounting, the MRIO and physical product data sources are likely to contain different region and industry categorisations. Therefore a concordance table to link the datasets must be developed. This is often based on manual matching between classification systems and various assumptions taken according to product descriptions and any existing published concordances.

3.3. Creating and applying the MRIO-physical use model

3.3.1 Creating the physical use table

Assume physical production data covers R countries and S products, and the MRIO table provides information for R* regions and S* sectors:

Physical production data is in form of an R x S matrix, with each element a quantity of production for one product in one country.

The physical trade data is represented by an R x R x S three-dimensional matrix, with each “layer” detailing the trade for a specific product, with each value in that layer a quantity exported from one region to another. Diagonal entries within a layer incorporate the production information and trade information to represent domestic use of domestic production. For a chosen product within the physical dataset, it follows that production/trade is therefore represented by an R x R matrix.

Applying the concordance relationship between the physical production/trade data and the financial MRIO table, each country in R is related to its respective region classifications within R*. The data can then be transformed into an R x R* matrix, with all exports (and domestic use) from regions in R allocated to regions in R*.

This newly allocated trade is then distributed amongst all sectors (S*) and final demand (y within MRIO framework) within each region in R*, weighted according to industry and final demand for imported sectors from the MRIO data. The data is therefore in the form of an R x (R* x S*) two-dimensional matrix, with the exports from each region in R (rows) distributed and assigned to each sector in S* within each region in R* (columns).

Each row in this matrix is then divided element-wise by the x vector (total output) calculated from the MRIO dataset to ascertain the physical quantity demand per monetary unit of output for each of the regions and sectors within the MRIO dataset.

3.4.3 Applying Leontief

Once the physical use and MRIO table have been constructed the model must be run to calculate the use of physical products associated with a given demand.

The Leontief inverse is calculated from the MRIO data and multiplied by the physical quantity demanded per unit financial output. Multiplying this by the final demand data (y) from the MRIO model produces an (R* x S*) x (R x R*) matrix, with a row for each GTAP sector within each GTAP region, and a column for production in each country in R due to demand in each region in R*.

Production due to final demand from a specific region therefore forms a subset of this result. To obtain production due to demand in a single region, in the above step it is only required to multiply by the final demand vector for the desired region.

4. Implementation of the method with real data

The preceding section includes an overview of the methods. This section explains how we have used available trade and production data to construct the MRIO and physical use matrices, along with the assumptions required to do this.

4.1. Data acquisition and preparation

4.1.1. GTAP8 (2007) Data

GTAP8 is the latest dataset to be released by GTAP, and includes both 2004 and 2007 datasets for 57 sectors within 129 global regions. To work with the GTAP8 database, it is necessary to download the relevant dataset and accompanying programs from the GTAP website and then extract the required information. This data extraction was done by first outputting a disaggregated set of the most recent (2007) data (any desired aggregation can later be performed) in the GTAPAgg program which comes with the download. The outputted ZIP file contains a file 'basedata.har' which includes all of the required data. An SEI-created '.bat' file then uses the 'har2csv' executable (obtained by downloading the GEMPACK software suite) to extract a number of different arrays of data in nine separate '.txt' files.

4.1.2. Creation of an MRIO table from GTAP8 database

We followed the method for constructing a MRIO table (of 57 sectors and 129 world regions) from the GTAP database given in Peters, Andrew, and Lennox (2011). A custom Matlab script, created by SEI, was used to read and import the data from the GTAP '.txt' files and generate Z, y, X and L matrices (for the MRIO analysis), which are output and saved in both .csv and .mat formats. These are then in a usable form for direct examination or use in Matlab for further calculations, respectively.

For each region within the GTAP database the geographic origin of commodities is known, however information about the distribution of these commodities across sectors is resolved only in terms of ‘domestic’ or ‘imported’ commodity use. An implicit assumption in the MRIO table, therefore, is that imports of a given commodity to a specific region are treated identically in terms of their distribution across different sectors, regardless of their country of origin. Similarly, due to the concordances between the two datasets, different commodities end up being treated in the same way. For example, “Asparagus” and “Strawberries” will both come under the “Vegetables, fruits, nuts” sector in the GTAP dataset and consequently be distributed across sectors according to the same weighting.

4.1.3. Physical production: FAO (2007) data

We have chosen to focus primarily on products of primary agricultural production (but see Section 4.2) as FAO statistics on these products are detailed in comparison with other physical commodity datasets. FAO datasets can be downloaded directly from the faostat.fao.org website. Choosing 2007 data to match the latest available GTAP data, different datasets need to be downloaded for different commodity types, and for each commodity type there are datasets for production and trade (as well as additional information). The data is downloaded in ‘.csv’ format which can then be imported into Matlab where SEI’s custom scripts reorganise the data into a usable ‘physical use’ format. This reorganisation consists of a number of methodological steps and involves tackling a number of data issues:

4.1.3.1. Region irregularities

There are some issues/irregularities within the FAO data. For example, Chinese production and trade data within the FAO dataset is described under a number of different country names and codes. There are four sub-regions ([41] `China: Mainland’; [96] `China: Hong Kong SAR’; [128] `China: Macau SAR’ and [214] `China: Taiwan province of’), and two listings simply under the name `China’ (country codes [351] and [357]).

All production data is assigned to country listing [351] `China’, with no listings reported for the other entries. However, the trade data is much less consistent; exports from Chinese regions are reported by entries [96], [128], [351] and [357], and entries [41], [96], [128], [351] and [357] are also reported as exporting partners by non-Chinese trade partners.

After consulting with FAO on the subject, clarification was received that the four sub-regions should sum to the value of the [351] `China’ listing, and that [357] `China’ is an aggregation of [41] `China: Mainland’ and [214] `China: Taiwan province of’. It was further clarified that whilst production was originally reported in disaggregated form for the four sub-regions, production is now only reported in aggregated form for all of China (i.e. entry [351]) due to changes in data acquisition in recent years.

Given the importance of production data (and specifically production origin) in the methodology for assigning impacts, it is necessary to consider Chinese trade in the same aggregated form for consistency. It would therefore be preferable to just take the aggregated values for trade to and from entry [351] `China’ as an overall value for China’s trade. Unfortunately, not all regions report this value, and so in these cases an aggregation has to be made manually from the data. The easiest and most efficient way to do this is to either sum the values for the four sub-regions or, equivalently, sum the reported value for the semi-aggregated [357] `China’ region and the remaining two sub-regions. However, the inconsistent data reporting does not make such an approach viable. Some countries only report an aggregated trade value, some report for the four sub-regions and others report a combination of semi-aggregated and sub-region. To complicate things further, some report a mixture of the above methods, often with "duplicated" entries.

As such, a careful and methodical approach is taken to construct the data for China. As stated above, production data is simply extracted for the [351] `China' entry. For trade, the processing of the data is split into two parts to handle exports to and exports from China, though the methodology is effectively identical.

For reported exports from China, reported trade from any of the six Chinese regional entries is isolated for each product and to each of the other FAO countries. If it exists, trade reported from the four sub-regions is summed, as is trade reported from [357] `China' and the [96] and [128] sub-regions. These two summed values are then compared to any reported values for [351] `China', and the largest of these three values is assigned as the total Chinese export of the given commodity to the given region. Exports to China are handled in the much the same way. For a given product and exporting country, all reported exports to any of the six Chinese regional listings are isolated, and the same aggregations as above are performed. As with outgoing trade, the largest of the three attained values is chosen as the export value from the specified region to China.

The choice of the largest of these values is an attempt to account for gaps in the data. When a value is reported for [351] `China', as an aggregation of the four sub-regions, it should theoretically be larger than or equal to (depending on data reporting) any of the summed values. Checking the data reveals that this holds for all reported trade data. In effect, the algorithm takes the value for trade to/from [351] `China' where it exists, and when it doesn't takes the largest value from the sum of the four sub-regions or the sum of the semi-aggregated [357] `China' and the [96] and [128] sub-regions.

4.1.3.2. Incomplete data

The FAO data is downloaded in the form of '.csv' files containing matrices comprised of columns denoting codes for the reporting country, partner country (where applicable), and commodity, and a column for the relevant data value (e.g. quantity). The data consists only of reported values for production and trade, and so needs to be expanded into a sparser dataset (i.e. have gaps in the data filled with zero-valued entries where no production or trade occurs) in order to create a full trade list which can be formed into a complete inter-regional trade matrix.

4.1.3.3. Data irregularities

The FAO export data includes an "unspecified" region entry for exports reported with no detail of the recipient country. There are different options available for dealing with this data. One option is to make assumptions based on the trade patterns of the countries that have listed exports to an unspecified region, and extrapolate this pattern to redistribute the unspecified exports to other countries. Such assumptions would be difficult to justify, however. An alternative option is to remove the unspecified region from the data. This will affect the total exports, and in turn the net balances, of all countries reporting exports to an unspecified region since they will no longer register in the data. A third approach, that is currently being adopted, is to treat the "unspecified" regions as a country in itself. Since there are no reported imports from unspecified regions (and obviously no reported production data), this new "country" exists within the data purely as an importer (and in our model has no concordant region within the GTAP MRIO and is therefore excluded from the MRIO analysis). Whilst this approach does not in any way attempt to reallocate the exports to their true recipients, as mentioned above the assumptions necessary to do so are problematic to defend. Unlike the second option mentioned above, this approach does leave the total export quantities intact. As a result, whilst the data is not precise in terms of destination for these exports, it is as complete as possible in terms of accounting for absolute export quantities (which is important for calculating re-exports; see Section 4.1.5 and Annex 2) without the need for contentious assumptions.

4.1.3.4. Import/Export mismatches and data reporting errors

Available crop data from FAO consists of production, export and import quantities. Export data and import data often do not match up (i.e. what Region *i* says it exports to Region *j* does not match what Region *j* says it imports from Region *i*), and net balances for regions (i.e. production + imports - exports) can also be negative.

The mismatch of import and export data can be caused by a number of factors, such as time lag due to transport (e.g. product leaves exporter in December and arrives with importer in January), differing reporting periods (e.g. one region reports annually over the period January-December, another region reports annually over the period April-March) and misclassification of products (e.g. exporting region classifies product as 'Wheat', importing region reports same product as 'Miscellaneous grains') to name a few. Human error and mistakes may occur in addition.

A negative net balance for a region can occur as a result of the above discrepancies in the reporting of production, import and export data, but can additionally also occur when all reporting is theoretically correct. For example, a commodity such as wheat grain can be stored for significant periods of time and in significant quantities. Consequently, if one year the wheat grain harvest is particularly poor in a given region, production quantities will be lower than usual yet export quantities may remain unaffected due to the use of stored wheat grain to meet demand. As such, a negative net balance should not be assumed to be incorrect.

As the import and export datasets do not match up, it is necessary to pick one or the other (or some combination of the two) to describe trade. It has been decided within this project to utilise the export dataset to construct the trade tables since exploration of the data reveals it to contain more information than the import dataset.

4.1.4. GTAP-FAO concordance

The FAO and GTAP datasets differ significantly in their country/region and commodity/sector categorisations, with many regions and sectors within the GTAP dataset being aggregations of the countries and commodities appearing within the FAO data. Consequently, it is necessary to construct concordance matrices to link countries and commodities within the FAO dataset to the regions and sectors within the GTAP dataset, respectively (see Equation 1 and Equation 2). For example, the FAO dataset contains production and trade information for "Asparagus", whilst in the wider GTAP sectors this would be aggregated with other items under the much broader "Vegetables, fruits, nuts" sector. Similarly, the FAO dataset contains explicit data for "Papua New Guinea", but within the GTAP dataset this is grouped within the "Rest of Oceania" region. The Country-Region concordance between the FAO and GTAP datasets is relatively simple to construct since a large number of countries in the FAO dataset have direct counterparts in the GTAP listings and the database documentation on the GTAP website is comprehensive in its description and breakdown of the regional aggregations. Comparatively, composing the Product-Sector concordance table is a much larger undertaking; very few products have direct equivalents, and whilst documentation also exists regarding the GTAP sectoral groupings it is less comprehensive. Although some products are very easy to assign to the relevant sector, others require more consideration and we have used our judgement when assigning concordance.

$$R(r_1\ r_2\ \ldots\ r_{236}) \quad \rightarrow \quad R^*(r_1^*\ r_2^*\ \ldots\ r_{129}^*\ )$$

Equation 1: Regional concordances from the FAO to the GTAP datasets with 236 counties reassigned to 129 regions. Set *R* denotes the set of countries in the FAO dataset, and set $R^*$the set of regions in the GTAP dataset.

$$S(s_1\ s_2\ \vdots\ s_{183}\ ) \quad \rightarrow \quad S^*(s_1^*\ s_2^*\ \vdots\ s_{57}^*\ )$$

Equation 2: Commodity/sector concordances from FAO to GTAP datasets see an even greater degree of aggregation. When considering FAO data for primary agriculture products, 183 commodities have been assigned to the 57 sectors within the GTAP dataset. Set *S* denotes the set of commodities in the FAO dataset, and set $S^*$the set of sectors in the GTAP dataset.

4.1.5. Calculating re-exports

The reported import and export data provided by FAO does not necessarily provide information regarding the true origin of the imported/exported product; i.e. no distinction is made between the export of a domestically produced product and the re-export of a previously imported product. In order to correctly assign the impact of production to the final consumer, re-exports need to be considered.

Whilst the data in FAOStat for crop products contains no explicit information regarding re-exports, by making certain assumptions and developing and applying an algorithm it is possible to use implicit information within the data to form an approximation of re-exports. At the broad scale, three possible options are:

- (a) Available natively produced products are assumed to be exported before any imported goods are re-exported.
- (b) Available imported goods are assumed to be re-exported before any natively produced products are exported.
- (c) Exported products consist of both natively produced and imported products, which are exported in proportion to available quantity (or some weighted variation thereof).

A simple example of these options is provided in Annex A. In each case the region exports the same quantity of goods and is left with the same net quantity. What changes is the composition of the export and, consequently, the remaining products which the region retains.

In general, in Case (a), if production is greater than total exports, then no re-exporting will occur. Conversely, in Case (b), if total imports are greater than total exports, then no exporting of the domestically produced commodity will occur, and all outgoing trade will be in the form of re-exports. Case (c) ensures a combination of exports of natively produced products and re-exports (wherever production and trade of the same commodity occurs within a given region), but requires rules to be specified to govern this.

As well as these differences, each of these options depends on common broad assumptions about trade behaviour, as well as production, in order to be implemented. The FAO trade data account for production and trade information aggregated over an annual period, and therefore provide no detail regarding when a given commodity was produced or exported/imported within this period. Certain commodities will see higher levels of temporally correlated production (for example seasonal products) and this will possibly manifest itself as periodic patterns in trade. This is a common issue when trying to assign re-exports to periodically reported trade data.

Another issue arising when addressing re-exports is the previously mentioned negative net balances of production, imports and exports. If one is assuming that exports consist of a combination of natively produced products and re-exported imports, when a negative net balance occurs (that is, production + imports – exports < 0) it must be decided from where the commodity to meet this extra demand is originating.

We have selected case (c), weighted according to available quantities of domestic and imported commodities, for use within this project. Full details of the algorithms developed to account for these re-exports are presented in Annex B.

4.1.6. Creating the physical use table

This step is achieved by using the FAO physical dataset to define production and inter-country trade quantities, and the GTAP MRIO monetary table to disaggregate the inter-region trading down to the inter-sector trading level.

Combining the two datasets in this way creates a new dataset which is a combination of both the FAO countries and commodities and the GTAP regions and sectors. For a given country and commodity within the FAO dataset, the final use and demand is presented in the form of a list of the GTAP regions and sectors.

4.2 Dealing with other physical datasets

When dealing with other production datasets, the information present is often not as complete as that which can be derived from the FAO datasets for agriculture. In these instances, the methods described in Section 3.3.1 for implementing the data and creating the physical use table needs to be suitably adjusted.

The FAO datasets for fisheries production and trade provide a good example. Whereas the agriculture data provides detailed accounts of production and inter-country trade for each product (where applicable), the fisheries data provides values for total production, import, export and re-export quantities. Whilst the addition of re-export data is useful as it avoids the need for estimation (see Section 4.1.5), for each product in each region only four values are available: production, total imports, total exports and total re-exports, with no information as to the origin or destination of imports, exports and re-exports.

In such cases it is not possible to make a full physical use table from the available data and the simplest alternative workaround, as highlighted in Ewing et al. (2012), is to simply allocate the production information to the concordant producing region and sector within the GTAP data. Whilst this method is not as powerful as the physical use table approach, as the use of products is governed by the monetary sector-aggregated information within the MRIO, it allows retention of product-level production information. In cases where data is not sufficient to construct a full physical use table, we will adopt this alternative methodology.

5. Environmental extension overview

The hybrid MRIO system translates units of monetary final demand into the corresponding units of physical production (in tonnes for agricultural products) occurring in different countries that are required to fulfill demand. An environmental extension can be linked to this data if further information is known about the environmental impact associated with a unit of production. For the purposes of assessing potential impact to biodiversity, where impacts are generally locally specific, it is important that this impact data is resolved to country level (i.e. assuming adequate data, regional or world-average impacts should be avoided). Additionally, where possible, given the retention of product-level production detail it is also preferable to have product-level impact data.

Along with the production and trade values mentioned above, FAOStat also contains relatively detailed information about impacts associated with primary production. For example, yield and land use data for most crop types in most regions is available, which when scaled to the production figures coming from the model can estimate the land required for production. FAO also collates information on fertiliser application per unit production, although this dataset is relatively incomplete.

For the impacts of water use, the Water Footprint Network (WFN) (http://www.waterfootprint.org) provide information per unit of production for different crops in different countries for green, blue and grey water. Green water measures water stored naturally in the soil, blue water measures fresh surface and groundwater (i.e. that used for irrigation), and grey water measures water pollution. The WFN and FAO also provide information on water scarcity for different catchments/regions that can be used in conjunction with the water footprint data to assess the likely impact of water extraction vs. availability (see Lenzen et al (2012a) for an example).

The extensions above attempt to quantify potential country-level drivers of biodiversity loss. Biodiversity datasets are also available that can inform us of the likely biodiversity impacts associated with production. For example, WWF have compiled a list of Ecoregions which may be overlaid with country-level production. The IUCN prepare a global Red List of threatened species and BirdLife International identify Important Bird Areas. These datasets include details of the anthropogenic drivers of potential loss which can be linked to the associated production information from the model. A similar approach has been adopted in a recent study by Lenzen et al. (2012b).

When linking data quantitatively (for example assigning land use to production quantities), the data must be constructed to form a matrix with dimensions R x S (where R and S are the number of countries and products in the physical dataset, respectively), with each element in the matrix providing a unit impact per unit mass (e.g. for land use, ha/tonne) value for production of the corresponding product in the corresponding country.

Current output from the hybrid MRIO system is typically in the form of data for a single product (detailing the physical production in each country due to demand from each of the sectors in each region of the MRIO dataset). To convert this production information into environmental impact data, it is necessary to isolate the relevant data from the environmental extension matrix (the column corresponding to the product of interest), and multiply each element of the hybrid MRIO output by the appropriate entry (i.e. the corresponding country of production).

This environmentally-extended data will thus have the same dimensions as the hybrid MRIO output, but instead of describing the production in different countries due to demand across different regions and sectors, the data will now provide information as to the impact (e.g. ha of land used) associated with final demand.

6. References

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Annex A. Re-export options

As an example, assume a region has 1500 units of a domestically produced commodity, 1000 units of the commodity imported from other regions, and exports 2000 units.

In Case (a), as much of the demand as possible is met with domestically produced goods, with the remainder made up by re-exporting previously imported goods:

$$\begin{array}{ccc} Initial & Export & Remaining \\ \begin{pmatrix}1500\\1000\end{pmatrix}, & \begin{pmatrix}1500\\500\end{pmatrix}, & \begin{pmatrix}0\\500\end{pmatrix}. \end{array}$$

In Case (b), as much of the demand is met by re-exporting previously imported goods as possible, with domestically produced goods only exported as necessary to meet the demand:

$$\begin{array}{ccc} Initial & Export & Remaining \\ \begin{pmatrix}1500\\1000\end{pmatrix}, & \begin{pmatrix}1000\\1000\end{pmatrix}, & \begin{pmatrix}500\\0\end{pmatrix}. \end{array}$$

Finally, in Case (c), the trade is made up as a weighted proportion of exports of domestically produced goods (1500/(1500+1000) = 0.6) and re-exports of previously imported goods (1000/(1500+1000) = 0.4):

$$\begin{array}{ccc} Initial & Export & Remaining \\ \begin{pmatrix}1500\\1000\end{pmatrix}, & \begin{pmatrix}1200\\800\end{pmatrix}, & \begin{pmatrix}300\\200\end{pmatrix}. \end{array}$$

In each case the region exports the same quantity of goods (2000 units) and is left with the same net quantity (500 units). What changes is the composition of the export and, consequently, the remaining products which the region retains.

Annex B. Calculating re-exports

One algorithmic approach to calculating re-exports is outlined here with the example of a three-region model with one commodity. The three regions each produce a given quantity, x_i (i=1:3), annually. It follows that

$$Production = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix}.$$

The trade of the commodity between the regions can be expressed by a number of trade terms, x_{ij} (i,j=1:3), where i denotes the exporting region and j the trade partner (importing country). It follows that in terms of a trade matrix, production can be considered as a region effectively trading with itself:

$$Production = \begin{pmatrix} x_{11} & 0 & 0 \\ 0 & x_{22} & 0 \\ 0 & 0 & x_{33} \end{pmatrix}.$$

Similarly, a number of trade terms x_{ij} (i≠j, i,j=1:3), express the inter-region trading

$$Exports = \begin{pmatrix} 0 & x_{12} & x_{13} \\ x_{21} & 0 & x_{23} \\ x_{31} & x_{32} & 0 \end{pmatrix},$$

where the jth entry in the ith row is the export from Region i to Region j. Similarly, there is a corresponding trade matrix for imports (which if all data matched up, would be the transpose of the exports matrix). Ignoring re-exports, it follows that all exports of the commodity from a given region come from that region's production, and so it follows that the final distribution of production (*DOP*) of the commodity is described by

$$DOP = \begin{pmatrix} x_{11} - (x_{12} + x_{12}) & x_{13} & x_{13} \\ x_{21} & x_{22} - (x_{21} + x_{23}) & x_{23} \\ x_{31} & x_{32} & x_{33} - (x_{31} + x_{32}) \end{pmatrix}.$$

The ith row sums to the total production quantity of the commodity by Region i, and the different values denote its final distribution among all three regions. The sum of the jth column equals the total commodity possessed by Region j, and the different values their origin.

Any of the production or trade variables can be 0 without loss of generality, however if

$$x_{ii} < \sum_{j \neq i} x_{ij}$$

for any i=1:3, then a negative value will appear in the ith diagonal entry (i.e. exports are greater than production).

To account for re-exports, it is necessary to consider what has come into the region before deciding what goes out. Different methods for addressing this bring with them different sets of assumptions and effects.

One approach is to break the annual trade process down into a number of smaller time steps, and to calculate the traded commodities in the next time step by considering the commodity distribution at the current time. Within this framework, there are a number of different assumptions and choices that can be imposed regarding initial conditions and trade.

For example, each region can initially be considered to be in possession of its total annual production of the commodity, such that the initial conditions are

$$DOP(0) = \begin{pmatrix} x_{11} & 0 & 0 \\ 0 & x_{22} & 0 \\ 0 & 0 & x_{33} \end{pmatrix}.$$

Initial trade can then only be of the domestically grown commodity (i.e. no re-exports). If the year is broken down into *n* segments of duration δt, after one time step the distribution will look like

$$DOP(\delta t) = \begin{pmatrix} x_{11} - \frac{1}{n}(x_{12} + x_{13}) & \frac{1}{n}x_{12} & \frac{1}{n}x_{13} \\ \frac{1}{n}x_{21} & x_{22} - \frac{1}{n}(x_{21} + x_{23}) & \frac{1}{n}x_{23} \\ \frac{1}{n}x_{31} & \frac{1}{n}x_{32} & x_{33} - \frac{1}{n}(x_{31} + x_{32}) \end{pmatrix}.$$

Now that initial trade has occurred, subsequent trade can include the re-exporting of the commodities along with exports. The composition of the subsequent trade then needs to be defined; one option is to have subsequent exports/re-exports in proportion to the quantity of the imported and domestic commodities possessed by each region.

For example, continuing the above example to time $2\delta t$, if we consider trade from Region 1 to Region 2, there will be the export of Region 1's domestically produced commodity as well as the re-export of Region 2 and Region 3's commodities previously imported into Region 1.

The first column shows the commodities possessed by Region 1. In the time δt to $2\delta t$, Region 1 needs to export a quantity of commodity to Region 2 equal to $\frac{1}{n}x_{12}$. To calculate the composition of this trade, it is simply required to normalise the total resource possessed by Region 1. It can be seen that

$$Region\ 1_{total} = x_{11} - \frac{1}{n}(x_{12} + x_{13}) + \frac{1}{n}x_{21} + \frac{1}{n}x_{31}$$

And so the export/re-export composition will be

$$\frac{\frac{1}{n}x_{12}}{x_{11} - \frac{1}{n}(x_{12} + x_{13}) + \frac{1}{n}x_{21} + \frac{1}{n}x_{31}} \begin{pmatrix} x_{11} - \frac{1}{n}(x_{12} + x_{13}) \\ \frac{1}{n}x_{21} \\ \frac{1}{n}x_{31} \end{pmatrix},$$

where the *i*th element of the resulting vector is the quantity of commodity produced in Region *i* exported/re-exported by Region 1 to Region 2.

In general, if at time *t* the *DOP* is

$$DOP(t) = \begin{pmatrix} x_{11}(t) & x_{12}(t) & x_{13}(t) \\ x_{21}(t) & x_{22}(t) & x_{23}(t) \\ x_{31}(t) & x_{32}(t) & x_{33}(t) \end{pmatrix},$$

trade from region *i* to region *j* in time *t* to time *t*+ δt is given by

$$\frac{\frac{1}{n}x_{ij}}{x_{1i}(t)+x_{2i}(t)+x_{3i}(t)} \begin{pmatrix} x_{1i}(t) \\ x_{2i}(t) \\ x_{3i}(t) \end{pmatrix}.$$

Running this process iteratively for all n time steps (i.e. to time $t = n\delta t = 1\,year$) yields a final distribution of production matrix. In the case of calculating re-exports for the FAO agriculture data, *n* is taken to be 10,000 which provides sufficient levels of accuracy whilst keeping computational time manageable (this requires about 24 hours for the full dataset, but only needs to be calculated once).

The assumption that each region begins the annual period with its full annual production quantity of the commodity biases trade towards export rather than re-export. An alternative approach is to break the production up over the year across the different time steps. In this way, the system ceases to be closed (that is all commodities are placed in the system initially and simply redistributed over time), but rather a constant input is being made into the system in the form of production (production in region *i* acts like an import from a region external to the system).

If this approach is adopted, then initially all regions possess zero commodity. In each time step, the same behaviour occurs as above, but first an input is made due to the production. The process of the first time step looks like as follows:

$$DOP(\delta t)_1 = \begin{pmatrix} \frac{1}{n}x_{11} & 0 & 0 \\ 0 & \frac{1}{n}x_{22} & 0 \\ 0 & 0 & \frac{1}{n}x_{33} \end{pmatrix},$$

$$DOP(\delta t)_2 = \begin{pmatrix} \frac{1}{n}x_{11} - \frac{1}{n}(x_{21}+x_{13}) & \frac{1}{n}x_{12} & \frac{1}{n}x_{13} \\ \frac{1}{n}x_{21} & \frac{1}{n}x_{22} - \frac{1}{n}(x_{21}+x_{23}) & \frac{1}{n}x_{23} \\ \frac{1}{n}x_{31} & \frac{1}{n}x_{32} & \frac{1}{n}x_{33} - \frac{1}{n}(x_{31}+x_{32}) \end{pmatrix}$$

$$= \frac{1}{n}\begin{pmatrix} x_{11}-(x_{12}+x_{13}) & x_{12} & x_{13} \\ x_{21} & x_{22}-(x_{21}+x_{23}) & x_{23} \\ x_{31} & x_{32} & x_{33}-(x_{31}+x_{32}) \end{pmatrix}.$$

To expand to the general case like above, if at time *t* the distribution of production is

$$DOP(t) = \begin{pmatrix} x_{11}(t) & x_{12}(t) & x_{13}(t) \\ x_{21}(t) & x_{22}(t) & x_{23}(t) \\ x_{31}(t) & x_{32}(t) & x_{33}(t) \end{pmatrix},$$

It follows that trade from Region *i* to Region *j* in time *t* to time *t*+ δt is given by

$$\frac{\frac{1}{n}x_{ij}}{x_{1i}(t) + x_{2i}(t) + x_{3i}(t) + \frac{1}{n}x_{ii}} \begin{pmatrix} x_{1i}(t) \\ x_{2i}(t) + \frac{1}{n}x_{ii} \\ x_{3i}(t) \end{pmatrix},$$

where the "$\frac{1}{n}x_{ii}$" term in the vector is added to the *i*th row.

As mentioned above, setting the system up with each region initially possessing their entire production of the commodity biases trade in favour of export over re-export. To demonstrate this, a simple two region system with one commodity can be used. If each region produces 1 unit of the commodity per year, and trades 0.5 units of the commodity per year, we have that

$$Production = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix},$$

and

$$Exports = \begin{pmatrix} 0 & 0.5 \\ 0.5 & 0 \end{pmatrix}.$$

If re-exporting is ignored, this leaves all commodities equally distributed between the two regions, with

$$DOP = \begin{pmatrix} 0.5 & 0.5 \\ 0.5 & 0.5 \end{pmatrix}.$$

If the first method for re-exporting is adopted with each region initially being allocated its entire annual production, the final production distribution matrix ends up as

$$DOP = \begin{pmatrix} 0.568 & 0.432 \\ 0.432 & 0.568 \end{pmatrix}.$$

With the second method, where production is introduced gradually with each time step, the final trade matrix generated is

$$DOP = \begin{pmatrix} 0.667 & 0.333 \\ 0.333 & 0.667 \end{pmatrix}.$$

Comparing results from the two re-export methods, it can be seen that the first method results in more of the domestically produced commodity being exported than the second method. The distribution of production from the second methods differs from when no re-exports are calculated by over 33%, and from the first method for re-exports by over 17%.

These methods provide simple and understandable means of generating re-exports from the available trade data. Implicit in the algorithm is the effect that the same item could be traded back and forth between two or more regions a large number of times (up to *n* times), which would economically make very little sense in reality and thus not occur. However, since the data does not explicitly deal with individual items/groups of items, but rather just a measure of mass or units produced and traded (i.e. there is no way to identify/track one tonne of wheat separately from another produced in the same region, for example), this real-world phenomenon does not manifest itself in the numerical results. It is the final answer provided for the distribution of production that is of interest, and not the intermediate steps.

Another effect of these algorithms is that they don't allow for the net balance of a commodity to be negative; the sums of the rows will always be equal to the production quantity of the respective regions. What this means in real terms is that if a country is reported as producing quantity *P,* importing quantity *I* and exporting *E* of a given commodity, if the exports exceed the sum of total production and imports (i.e. $E>P+I$), then the exports are implicitly scaled to $E=P+I$. Consequently, all domestically produced and imported quantity of the commodity will be exported, and no quantity will be left for domestic use. This can be changed to allow for negative net balance (i.e. allow a country to export a commodity it has not produced/imported in the current trade period), but as mentioned before, this requires further assumption about the origin of the commodity being traded.

Below is a real world example using the FAO data for Wheat production and trade. The data covers the top 5 producing regions by quantity (China, India, United States of America, Russian Federation and France), the UK, and all other regions aggregated into a "Rest of World" region.

The final distribution of production (*DOP*) of the commodity is calculated and shown for three methods of dealing with re-exports:

- (1) Re-exports are ignored and trade assumed to be as described by the export dataset.
- (2) Re-exports calculated assuming that all regions possess full production quantities at the beginning of the trade period.
- (3) Re-exports calculated assuming that all regions produce their commodities at a constant rate throughout the trade period (default method chosen for the project).

Production and export data for the top 5 Wheat producing countries, the UK and the Rest of the World from the FAO datasets are given as:

$$Production\ \text{(raw FAO data)} = \begin{matrix} \text{CHN} & 109298296 \\ \text{IND} & 75806700 \\ \text{USA} & 55820400 \\ \text{RUS} & 49368000 \\ \text{FRA} & 32763500 \\ \text{GBR} & 13221000 \\ \text{ROW} & 276333496 \end{matrix}$$

and

$Exports$ (raw FAO data) =

	CHN	IND	USA	RUS	FRA	GBR	ROW
CHN	0	0	3150	0	0	0	2333470
IND	12	0	40	0	0	2	195
USA	1312050	0	0	0	16461	107749	032822700
RUS	0	1242270	0	0	0	2566	013199300
FRA	50	0	112	142	0	167411	142188000
GBR	10	0	0	0	46485	0	1865020
ROW	63301	1078020	2386440	477123	495014	1261510	0

If Method 1 is applied and re-exports are ignored, all trade is comprised of exports from the producing region. The final distribution of production is given by

DOP=

	CHN	IND	USA	RUS	FRA	GBR	ROW
CHN	106962000	0	3150	0	0	0	23334700
IND	12	75806500	40	0	0	2	195
USA	1312050	0	21561400	0	16461	107749	32822700
RUS	0	1242270	0	34923900	0	2566	13199300
FRA	50	0	112	142	18377000	167411	142188000
GBR	10	0	0	0	46485	11309500	18650200
ROW	63301	1078020	2386440	477123	495014	1261510	270572000

Calculating re-exports according to Method 2 by initially assigning all produced commodities to the respective regions before implementing trade, the resulting distribution of production is calculated as:

DOP=

	CHN	IND	USA	RUS	FRA	GBR	ROW
CHN	106977000	3975.48	8069.92	1546.1	1473.77	4419.85	2302080
IND	12.2993	75806500	24.7579	0.13468	0.137229	2.26106	205.329
USA	1267740	55238.5	22564000	21473.1	32463.2	158827	31720600
RUS	1870.13	1258120	34763.7	35009900	8340.79	27363.8	13027700
FRA	2060.72	24179.80	37421.2	9519.98	18529800	180922	13979600
GBR	266.038	3082.68	4751.95	1197.85	33524.8	11421100	1757090
ROW	88411.5	975688	1302130	357533	329311	1056110	272224000

In contrast, when Method 3 is utilised and production is implemented as a progressive process with new production injected into the system as each time step, the resulting distribution of production is:

DOP=

	CHN	IND	USA	RUS	FRA	GBR	ROW
CHN	106992000	7416.23	7961.57	2305.81	1932.63	7518.49	2279600
IND	12.3257	75806500	16.5829	0.211581	0.18713	2.44134	209.176
USA	1242280	101366	23059200	31516	35563.4	192710	31157700
RUS	4421.38	1272410	37875.9	35075200	10957.1	44803.8	12922300
FRA	4785.87	45029.7	40611.2	14098.5	18629900	188910	13840200
GBR	579.803	5429.25	4891.46	1688.15	25075.4	11514500	1668830
ROW	93453.3	888629	800591	276284	231508	900275	273143000