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Assessing physical trade flows of materials of biological origin to and from Scotland

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Summary

Introduction

Many countries are heavily dependent on products of biological origin produced domestically and sourced from abroad. Consumption of biomass is not necessarily only ‘direct’ (i.e. utilised directly in the production and final use of products) because it can also occur indirectly through complex supply-chains. Accounting for ‘indirect’ biomass use (i.e. that occurring across the whole manufacturing chain of products) is essential if total biomass consumption is to be assessed. This report presents the results of an extended model analysis to tackle this issue.

In 2012/13, JNCC and SNH commissioned work to quantify the consumption of biomass (food, feed, fibre) within the Scottish economy and assess potential impacts that may be associated with this consumption. The resulting report[1] provides the first biomass Material Flow Account (MFA) for Scottish biomass production, imports and exports. However, there are important components of traded biomass that an MFA (using standard trade data) is unable to capture, including intra-UK trade, the raw materials embedded in more complex products and services, and the original country of production of the biomass.

Holistic assessment of consumption is particularly important when considering the environmental pressures in one country due to demand for goods and services by another. Biomass production is a major driver of biodiversity loss due to the necessary conversion of natural habitats to, for example, agricultural and planted forest land. There is increasing pressure from EU and national-level resource efficiency strategies to decouple consumption from negative environmental impacts, and biodiversity targets under the Convention on Biological Diversity[2] and the EU2020 Biodiversity Strategy[3] require monitoring systems and evidence to assess the global impacts associated with consumption at national levels.

Approach

A multi-regional input-output (MRIO) model was the chosen approach to complete this analysis; mapping global supply chains and estimating localised environmental pressures associated with Scottish biomass consumption. The MRIO framework is a well-established method for what is often termed “footprint” or “consumption-based” analysis, and this same technique was applied for the UK in a study conducted by The Stockholm Environment Institute (SEI) for the Department of Environment Food and Rural Affairs (Defra) to assess the impacts of UK consumption on biodiversity abroad (West *et al* 2013).

The MRIO approach captures inputs required by different economies and the outputs that they produce, detailing all financial transactions within an economy, and between different regions’ economies, at an aggregate level (i.e. inputs and outputs between different industrial sectors). MRIO analysis is therefore particularly suited to capturing embedded biomass along supply/production chains, as well as linking production and associated impacts to the region of origin.

SEI has developed an extended MRIO model (the Input-Output Trade Analysis (IOTA) model). This model links commodity production and trade data, in physical units, with a global financial trade flow model to form what is termed a ‘hybridised physical-financial

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[1] Available on request from the JNCC.
[2] Aichi Target 4: *‘By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits’*
[3] Target 6: *‘Help Avert Global Biodiversity Loss by 2020’*

MRIO model'. This technique can be used to estimate the flows of physical resources along international supply chains, identify the point of production, and estimate the resource and environmental impacts associated with that production.

In this report, the UK version of the IOTA model was 'downscaled' to estimate the commodity requirements for Scottish consumption only. This downscaling process required estimates of the consumption profile of Scottish consumers (which is available from sources such as the Office for National Statistics (ONS)) rather than information on intra-UK trade flows. This downscaling approach overcomes the limitation of the lack of intra-UK trade data present in the MFA, providing a more accurate estimate of total consumption.

Commodities included in this assessment

The IOTA model can be run for some 200 different commodities contained within the FAOSTAT database[4], although the scope of this project limits the number of commodities that can be compiled and analysed. An initial assessment of Scottish final consumption patterns and standard UK trade statistics revealed a number of food products that dominate consumption and imports. Based on consideration of these data for 'primary commodities', the following commodities were short-listed for inclusion: soya bean, oil palm fruit, sunflower seed, wheat, maize, paddy rice, sugar cane, bananas, potatoes, and tomatoes. These commodities represent an important component of international agricultural production for Scottish consumption.

Results

Comparing the commodities embedded in Scottish consumption from IOTA with standard trade data collected in the MFA highlights a number of differences. The discrepancy between these two datasets clearly demonstrates the added value and importance of capturing not only the direct trade in commodities, but also those embedded in longer and more complex supply chains. FAO domestic supply[5] information can show very low utilisation, with total UK imports of derived products (based on HMRC data) appearing lower than Scottish consumption (as estimated by IOTA). Because IOTA captures the primary products embedded along complete supply chains, it provides additional information on the likely quantity of production required that is not supplied by the other data sources. Large differences between data sources can be seen within sugarcane, paddy rice and maize, for example, which may imply more complex/indirect supply chains for these commodities.

At the individual commodity level, Scottish consumers require more than world-average production of certain commodities, and lower than average production of others, i.e. if the total supply of commodities was distributed across the total global population, Scottish consumers would be consuming more than their 'equal share' of some products and less than their 'equal share' of others.

For example, according to the IOTA results, per capita Scotland is responsible for almost three times as much wheat production as the global per capita average, but only approximately 1.5 times the world average agricultural land area associated with wheat production (Figure S1). Given that, according to the IOTA model, much of the wheat that is consumed in Scotland is also produced within the UK where intensive agriculture is prevalent, this finding is logical. Commodities destined for Scottish consumption where efficiency of production is close to the world average (i.e. both the production and land-use ratios are similar) include sugarcane and paddy rice.

[4] FAOSTAT database: http://faostat3.fao.org/faostat-gateway/go/to/home/E
[5] Domestic supply: domestic production of a commodity plus imports, minus exports, plus adjustments for changes in stock.

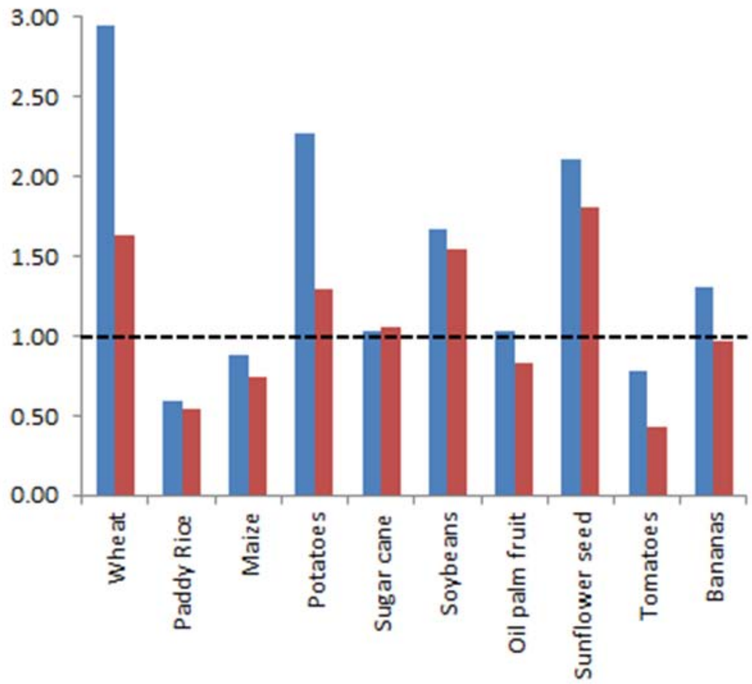

Figure S1. Relative per capita production (blue bars) and the associated land use (red bars) for ten different commodities due to Scottish demand compared to the global average (black dotted line).

The IOTA model can also identify the top countries of production/impacts associated with Scottish demand, or highlight sectors that drive such production and impacts. In doing so, the key localised production and potential environmental impacts associated with different commodities that are driven by Scottish demand, and individual components of this demand, can be isolated. Figure S2 visualises the location and quantity of production of sunflower seeds for Scottish final demand, representing how much of the production of sunflower seeds in different countries is embedded in Scottish consumption.

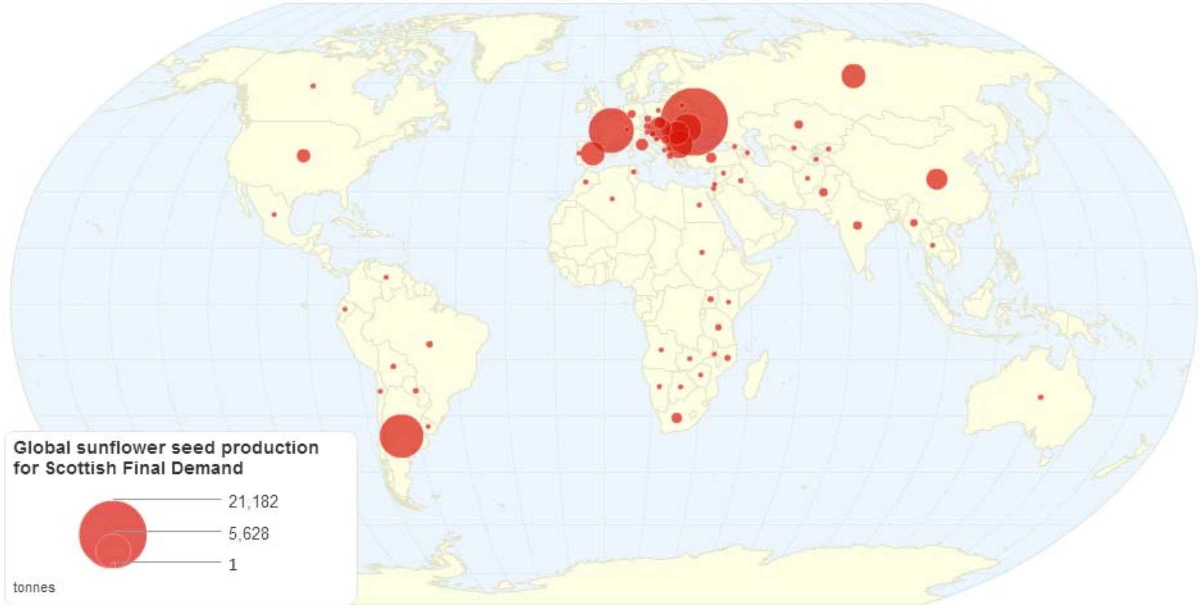

Figure S2. Visual representation of relative quantities of sunflower seed production occurring in different countries due to total Scottish demand (direct and embedded consumption). Source of mapping software: Chartsbin.com.

Discussion

The IOTA approach represents the complete economic and trade system. Whilst HMRC and FAO statistics include some derived products, as seen from the IOTA results, Scottish reliance on commodities such as maize, sugarcane and oil palm fruit is much higher than these alternative statistics would suggest. Furthermore, with its inclusion of physical production information in each country, the IOTA approach ensures that production locations are identified. HMRC data, for example, reveals certain countries as major exporters of given commodity-based products, whereas IOTA reveals that none of the production of this commodity (and associated impacts) occurs in these countries.

The ability to pinpoint the country of production also allows extension of the data to include factors associated with environmental impacts in a way that is not possible with the alternative data sources/methods. This report demonstrates that land use information, water use, and fertiliser information can readily be connected to the model. Theoretically, any information (environmental or socio-economic) that can be associated with production of the commodities under study can be integrated into the model to assess potential impacts associated with production. This might also form the basis for exploring biodiversity impacts associated with consumption of biomass, though further work is required to develop a workable method for linking production and biodiversity impacts in the region of origin.

MFA and IOTA-based approaches may be seen as complementary to an extent. The MFA for Scotland, whilst lacking intra-UK trade information (a key limitation of this approach when applied in Scotland), contains readily-updateable detailed Scottish production information and some relatively aggregated non-UK trade information within a yearly time-series from the HMRC, whilst IOTA provides detail on the potential location of production destined for Scottish consumption, and ensures that all embedded supply chains are considered.

Recommendations for future model developments

Future work and developments roughly fall under two categories: addressing data uncertainties, and extending the model's application and scope.

Complementarity with the MFA approach

A key limitation of the Regional Trade Statistics data used within the MFA approach is its high level of aggregation relative to UK Overseas Trade Statistics. Theoretically, UK import data (from HMRC Overseas Trade Statistics) could be downscaled to estimate imports due to Scottish demand at a higher product resolution. This more highly resolved data would potentially allow for a more direct comparison of import data to commodity results from IOTA. However, such an approach would still not account for intra-UK trade and so would not capture Scottish imports of goods produced within the rest of the UK.

Addressing data uncertainties

The hybridisation of physical and financial data currently relies on relative levels of sector expenditure to distribute traded raw commodities within the domestic economies. Additional information such as data on the use of commodities for seed, feed, food supply and processing, could be utilised to better proportion domestic supply of commodities across the appropriate sectors to a higher level of accuracy.

Sensitivity analysis on underlying datasets (for example, by repeated manual or stochastic perturbation of data used within the model) and model assumptions could help determine relative sensitivity of model results on its component data sources. Correspondingly the potential repercussions of different assumptions within the underlying datasets and model implementation could guide best practice and highlight the relative importance of areas of future development.

Extending the model's applications and scope

Expansion of the commodities considered (e.g. across all cereal, oil-seed, vegetable commodities) would facilitate comparison between the datasets of total reliance on agricultural biomass (and crop groups) from agriculture rather than individual commodities. Inclusion of products from forestry and fisheries could also be investigated.

The IOTA approach could be used to compile time-series information. Currently, 2004 and 2007 economic data are available within GTAP8 and the forthcoming GTAP9 dataset will add another timestamp for comparison. This economic data could be supplemented by yearly physical production and trade data which is already available from FAOStat.

The development of techniques to analyse supply chain pathways in more would potentially be helpful to determine key intermediate stages and locations of processing, allowing a more detailed and pinpointed assessment of 'responsibility' for impact.

Additional work on the environmental extensions currently analysed would improve accuracy, and the extension of the scope (by assessing other environmental and socio-economic impacts), relevance of data (e.g. water scarcity implications as well as water use) and accuracy (e.g. by investigating the inclusion of better fertiliser data) would improve the ability of the IOTA model to identify potential positive and negative impacts associated with production.

Contents

1 Background

The UK, and Scotland, is heavily dependent on products of biological origin - both produced domestically and sourced from overseas. This dependence on 'biomass' includes the consumption of products derived from timber and plant fibres (e.g. clothing, energy) but also foodstuffs used both for direct human consumption and in animal feed. Importantly, consumption of biomass is not necessarily 'direct' (i.e. utilised directly in the production and final use of products) but can occur further upstream within the supply chain. Accounting for 'indirect' biomass use (i.e. that occurring across the whole manufacturing chain of a specific product) is very important if the total impacts associated with consumption are to be properly assessed.

Holistic assessment of consumption is particularly important when considering the environmental impacts that may originate in one country due to demand for goods and services in another. Biomass production is a major driver of biodiversity loss due to the necessary conversion of natural habitats to, for example, agricultural and planted forest land. Biodiversity targets under the Convention on Biological Diversity (Aichi Target 4: "*By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits"*) and the EU2020 Biodiversity Strategy (Target 6: *"Help Avert Global Biodiversity Loss by 2020"*) require monitoring systems and evidence to assess the global impacts associated with consumption at national levels. Furthermore, decoupling economic growth from resource use and associated environmental impacts is a key priority within the EU's 2020 Strategy and Roadmap to a Resource Efficient Europe, with the EU calling for *"indicators to measure progress relating to the use of land, material, water and greenhouse gas emissions, as well as biodiversity"* (EC 2012). Scotland's 2020 Challenge for Scotland's Biodiversity also recognises the need to consider trade and global supply chains in analysis of progress towards the more efficient use of natural resources[6].

Following recent work by the JNCC and Defra to investigate UK-level reliance on products of biomass (Weighell 2009, 2011; NEA 2011; West *et al* 2013), in 2013 JNCC and SNH commissioned 'Phase 1' of work to quantify the consumption of biomass within the Scottish economy and assess potential impacts that may be associated with this consumption. The resulting report, by the Stockholm Environment Institute (SEI), is entitled 'Scottish Biomass Account: Investigating the Global Footprint caused by Scottish Consumption, Production and Trade Flows of Materials of Biological Origin' and details the construction of a Material Flow Account (MFA)[7] for Scottish biomass production, imports and exports. Whilst providing a useful dataset for the assessment of material consumption (covered further in the Section 5 (Discussion)), the MFA suffers from a number of restrictions that limit its suitability in assessing overseas impacts associated with biomass imports specifically related to Scotland. The limitations identified were:

- Import and export data for Scotland are available from HMRC Regional Trade Statistics, but this excludes detail on intra-UK trade (i.e. the movement of goods between the UK and Scotland) and therefore real imports and exports to/from Scotland are underestimated;
- imports and exports are measured in terms of the mass of the goods, rather than the mass of the total materials used in the creation of those goods, which means that the

[6] See: http://www.scotland.gov.uk/Publications/2013/06/5538/5
[7] A Material Flow Account contains results of Material Flow Analysis, which is an analytical method of quantifying flows and stocks of materials within an economic system. An MFA is reliant on information about production of these materials within the system and the imports and exports to and from this system.

amount of raw materials actually consumed in the production process is also not accounted for;
- the trade statistics from the HMRC, on which the MFA was based, contain import information only on the point of last consignment which may or may not be the country of production, and therefore may not accurately represent the likely source of potential production impacts.

The second phase of the project (which this report details) aims to therefore complement the Scottish biomass MFA, and address these key limitations, i.e. the objectives of the project are to:

- Provide an approach to assess Scotland's consumption and imports which does not rely on the availability of intra-UK trade;
- assess 'upstream'[8] material requirements for biomass products imported and consumed in Scotland; and,
- identify the countries of origin of production for biomass products imported in Scotland.

Within Phase 1 of the project, a multi-regional input-output (MRIO) approach was recommended to overcome the limitations associated with the MFA. In 2013, Defra published a study - conducted by SEI - that detailed the development of such an approach at UK level (West *et al* 2013). The 'inputs' and 'outputs' of an MRIO approach refer to the inputs required by different economies and the outputs that they produce. Input-output approaches capture all transactions within an economy at an aggregate level (i.e. by detailing the inputs and outputs between different industrial sectors). The 'multi-regional' aspect refers to the fact that a number of countries or regions are represented within the model, allowing analysis of trade interactions between countries. These characteristics mean that an MRIO approach is suited to overcoming two of the key limitations outlined above, specifically:

- The input-output model ensures that the model captures the flows of goods and services throughout the entire economy so that even those commodities that are 'embedded' during the course of intermediate manufacturing, or those that undergo many levels of processing, can still be linked to final consumption[9];
- the multi-regional structure (which in this case contains 129 distinct regions) allows identification of the region responsible for the production of the commodity that is embedded in final consumption.

However, MRIO data is commonly only available in financial (i.e. monetary) terms at the scale of relatively aggregated industrial sectors. This financial data is generally available at a courser level of aggregation than the physical information (i.e. mass) available detailing agricultural production[10] and trade in products of agriculture that can be obtained from international sources such as the Food and Agriculture Organization of the United Nations (FAO)[11]. This physical information, which is available at the individual crop-level, is invaluable in assessing potential impacts associated with agricultural production as different crop types have different requirements (e.g. in terms of land use, water, pesticide and fertiliser use). Within the Defra study, this physical information was hybridised with the financial MRIO to form a physical-financial MRIO model (and named the Input-Output Trade

[8] i.e. material requirements that occur in the manufacture of goods and the provision of services within the supply chains of products eventually consumed within Scotland.
[9] Because the full supply chain system is included, the model therefore also implicitly captures any wastage of materials along the supply chain, ensuring that a complete estimate of the material requirements of the production associated with final consumption is obtained.
[10] Physical data for other, non-agricultural, commodities (e.g. metals from mining) is also available, but is not considered in this project.
[11] E.g. from FAO's FAOStat database: http://faostat3.fao.org/faostat-gateway/go/to/home/E

Analysis (IOTA) model[12]), allowing an estimate of the flows of physical resources at crop level along international supply chains and the identification of the point of production of primary commodities (which, for agricultural data sourced from FAO is at the resolution of 236 individual countries). Additionally, the assessment in physical units of production allows an 'extension' of the model to estimate the resource and environmental impacts associated with this production.

The IOTA model developed in the Defra study presents results for consumption at the UK level. In order to present results for Scotland only, the model must therefore be 'downscaled' to estimate the economic transactions needed for Scottish consumption only. This downscaling process requires estimates of the consumption profile of Scottish consumers (which is available from sources such as the Office for National Statistics (ONS)) rather than information on intra-UK trade flows. Hence, it overcomes the first limitation of the MFA by providing an estimate of total consumption of imports. The downscaling approach is described in Section 3 (Method) of this report (and assumptions and limitations are described in Section 5 (Discussion)).

Section 2 (Commodity choices) of this report details the selection process[13] of ten commodities used to demonstrate the application of the IOTA model for exploring the impacts of Scottish consumption. Additional commodities for future analysis could be prioritised with reference to the same data sources. This section also serves to introduce some of the key datasets that are used to downscale the UK-level IOTA model for Scottish consumption (as covered in Section 3 (Method)) and which are used as comparisons against the model results. The methods used to downscale the IOTA model to Scotland are then presented, followed by results for the chosen commodities. Thereafter, results are discussed in the context of the previous MFA study, highlighting key aspects, differences, and limitations of the two approaches. Finally, further recommendations are made for model and data improvements.

[12] Details of the methods and assumptions used to conduct this hybridisation are available in the associated methodology report for the Defra study (Croft *et al* 2013).
[13] By conducting a similar analysis using the data sources highlighted within this section, additional commodities for future analysis could also be prioritised.

2 Commodity choices

Commodities are defined as products which are consumed, either directly or indirectly (i.e. ‘embedded’ within other products during the course of intermediate manufacture or processing), by consumers. Within IOTA, these commodities are represented physically in terms of mass, and must be ‘concorded’ with the financial information contained within the input-output model (i.e. physical and financial information must be aligned). The process of incorporating a single commodity (e.g. a single crop type) requires collation of data from external datasets into a format that the IOTA model can use, and for the purposes of this project (designed to demonstrate the IOTA model application for Scottish consumption) a selection of ten commodities have been chosen from the many hundreds available for analysis[14]. In future, following this initial process of model development for Scottish consumption, it will be relatively straightforward to integrate additional agricultural commodities into the model to produce a more complete picture of consumption.

Due to their extensive coverage within UN FAOStat – and their historical role as a focal point for a variety of potential environmental extensions[15] - products of agriculture generally allow the full demonstration of the current functionality of the IOTA model (although it is possible to include other commodities such as forestry-products, fisheries-products or minerals). All of the commodities selected in this project are therefore agricultural. Though it is possible to include other products of biomass (and non-biomass) within IOTA, this has not been done here because: a) they lack detailed readily accessible trade information in physical units (e.g. FAO fisheries and forestry data has limited information on trade compared to agricultural data) and therefore require additional manipulation to implement within IOTA; b) they may not contain adequate information on the location of production (e.g. within FAO data, products of marine fisheries are often only resolvable to large oceanic areas rather than countries); and c) without additional research into the availability of adequate data, they are not easily associated with product-level environmental extension information.

Although the IOTA model takes a holistic (i.e. a total supply chain) approach to assessing impacts associated with imported goods, an initial assessment of Scottish final consumption patterns, Regional Trade Statistics and imports into the UK[16] is useful to identify commodity candidates for inclusion in the model. Although in many cases imported commodities from such datasets (which may ultimately be consumed by domestic householders, industry, or exported[17]) are only *derived* from the primary commodities considered in the ‘physical’ component of the IOTA model, in most cases it is possible to determine the primary commodity to which the derived product relates; and thus information about derived products can help determine which primary commodities are key candidates for consideration[18].

[14] Thus, in contrast with an MFA approach, this study does not try to account for all biomass consumption, but instead focuses on the embedded supply chains and source regions of specific biomass commodities.
[15] Environmental extensions are datasets containing environmental information that are explicitly linked to the data on industrial outputs required to fulfil demand, and that result from input-output models. These environmental extensions are implemented to gain insight into the environmental impacts associated with production and supply systems.
[16] Each of these data sources are addressed in turn as they represent a transition from Scotland-specific consumption data (which defines likely overall consumption patterns within Scotland) through to UK import data (which contains specific product-level detail).
[17] Data from the IOTA model will ultimately only consider impacts associated with final consumption within Scotland which overcomes problems associated with defining the final destination for imports.
[18] As previously discussed, whilst this information is potentially useful as a guide to selection of commodities, it is restricted in its ability to distinguish the origin or impact of these commodities due to the limited information on the true source of products within direct trade statistics, and the fact that the mass of derived products is not necessarily directly related to environmental impacts. The IOTA methodology is employed to overcome these limitations.

Data for Scottish Household Expenditure (from the Office for National Statistics), HMRC Regional Trade Statistics, and HMRC UK Overseas Trade Statistics, which were used to guide the selection of the ten commodities, are presented in Appendix 1. The data reveal a number of food products that dominate consumption and imports. Some key consumption categories are meat-based, which are not considered as primary products in the IOTA model (due to their significant primary-commodity-based feed inputs) and are therefore not candidates for inclusion within the model. Additionally, many of the key products imported are derived (or secondary) products or by-products which fall at intermediate stages along the supply chain (i.e. are not primary agricultural commodities), e.g. oil-cake of soya beans is a processed form of soya bean production. In the following shortlist, only the 'primary commodities' are considered from which these secondary products may be derived.

Based on consideration of the data contained in Appendix 1 (i.e. the relative mass of imported and consumed products) the commodities shown in Table 2.1 were shortlisted for inclusion. Additional reasons for shortlisting (based, for example, on knowledge of the extent to which commodities may be 'embedded' along the supply chain[19]) are also given.

Table 2.1. Ten commodities shortlisted for inclusion within the downscaled IOTA model. Includes a brief description of motive for inclusion, and also states whether or not the commodity was assessed within the UK version of the model produced for Defra in 2013.

Commodity	Compiled in Defra Project	Reason for shortlisting
Soya beans	Yes	Highly important component of animal feed – and therefore a likely key component in the top commodity group of imports into Scotland.
Oil Palm Fruit[20]	Yes	Mostly used for food. A component of animal feed (as a by-product of palm oil extraction), many processed foods for human consumption, personal care products. With topical environmental impact concerns.
Sunflower seed	No	Another component of animal feed (as a by-product of oil extraction) and processed food for human consumption.
Wheat	Yes	The UK's most important imported cereal crop; key component of bread and baked goods (which are 2nd and 3rd in Scottish expenditure on food); widely grown in the UK. Also used for the production of bioethanol.
Maize	No	High levels of UK imports; likely to also be embedded in many products for human consumption , also used in animal feed and as a bioenergy feedstock; grown in the UK.
Paddy rice	Yes	Rice-based commodities appear three times in top-ten cereals list. Also very important as a foodstuff in overseas countries and therefore likely to be key crop embedded in supply chains.
Sugar cane[21]	Yes	High levels of imports (used in cane sugar and cane molasses which are the top two imports in the 'sugar category'). Key component of many processed products. Used for the production of bioethanol.
Bananas	Yes	High UK imports in comparison with other fruits.

[19] The impacts of which are hidden in direct trade statistics, but will emerge within the IOTA model results.
[20] No physical trade data in FAO, i.e. no recorded trade of 'raw' commodity occurs.
[21] No physical trade data in FAO, i.e. no recorded trade of 'raw' commodity occurs. See Section 3 – (Method) for an explanation of how commodities with no physical trade information are incorporated.

Potatoes	**No**	**Highest vegetable imports. A key staple food also grown commonly in the UK.**
Tomatoes	**No**	**Relatively high imports. Key staple fruit also grown in the UK.**

3 Method

A diagrammatic overview of the steps required to downscale the IOTA model to Scotland is provided in Figure 3.1, and explained fully within this Method section.

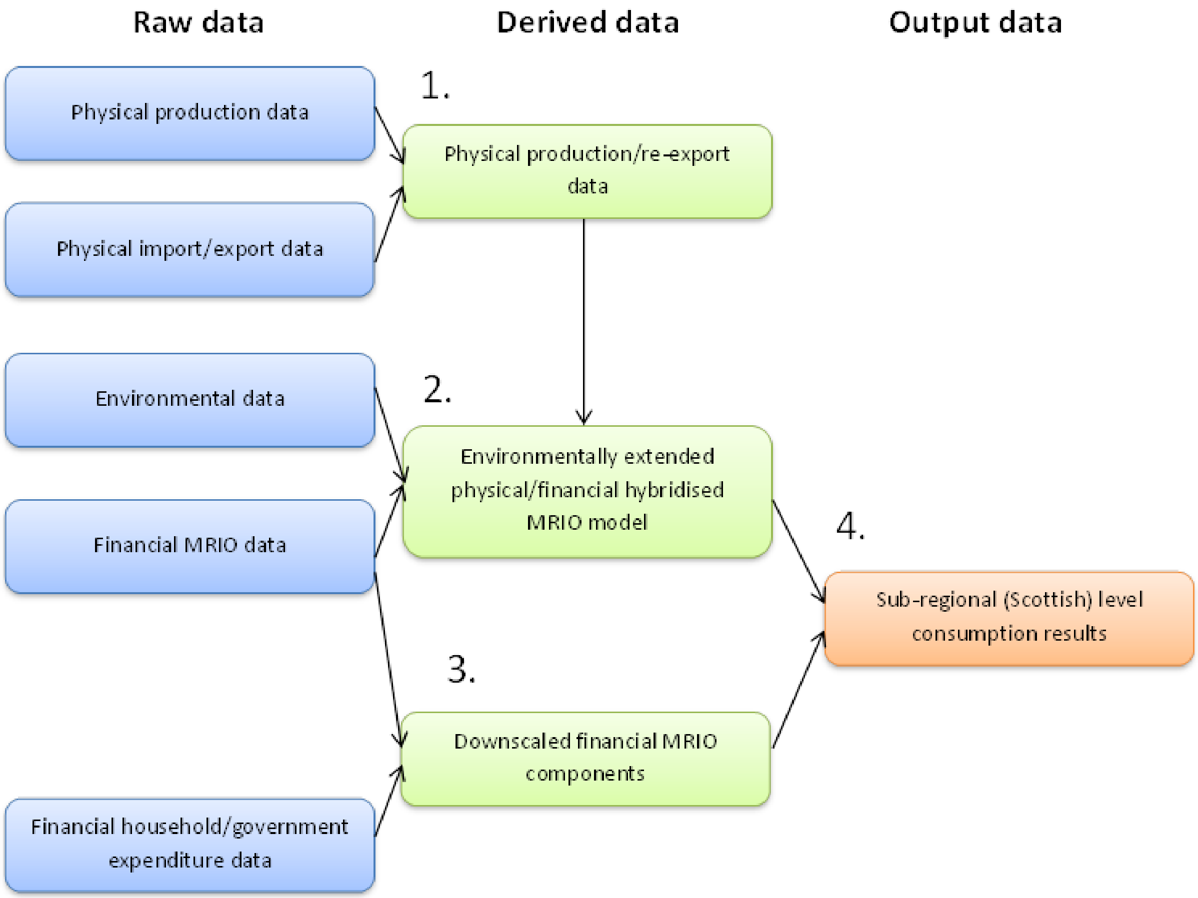

Figure 3.1. Diagrammatic overview of the steps and data sources required to create the downscaled version of the IOTA model: Step 1. Physical production and trade data are algorithmically combined to produce a fully consistent dataset describing imports, exports and domestic supply[22], and accounting for re-exports. Step 2. Financial MRIO data and physical production/re-export data (from Step 1) are combined to produce a hybridised physical flow dataset. Environmental data then extends the data from production quantities to incorporate production-related environmental impacts. Step 3. Expenditure data for Scotland and the UK are used to downscale UK final demand expenditure within the MRIO to the Scottish level. Step 4. Scottish level final demand (from Step 3) is applied to the hybridised MRIO (from Step 2) to obtain production and impact data associated with Scottish consumption.

3.1 Input-output overview

The IOTA (Input-Output & Trade Analysis) model is a hybrid input-output model that works by combining global financial data - in the form of input-output tables - with physical production and trade data, and environmental extension information. The model allows estimation of embedded environmental impacts of a region's consumption[23], regardless of

[22] Domestic supply: domestic production of a commodity plus imports, minus exports, plus adjustments for changes in stock.
[23] A 'region' is defined within the IOTA MRIO as a country, or group of countries, for which discrete inter-industry and final demand information is available.

where in the world production occurs. Using this model, it is possible to estimate the flows of a large number of commodities between industrial sectors and countries, and link consumption in one location to the production, land area and other inputs (e.g. water and fertiliser) required in another.

Within IOTA, the Global Trade Analysis Project (GTAP[24]) financial database is used to compile a global multi-regional input-output (MRIO) model comprising 129 regions (the final region being "Rest of World"; thus capturing the entire global economy) and 57 industrial sectors encompassing all global market transactions[25]. The GTAP8 database describes detailed financial flow data for the year 2007, with the derived MRIO tables detailing the intermediate requirements across all sectors and regions (i.e. transactions between industrial sectors), as well as final demand (e.g. household and government purchases) for each region. Although the underlying financial structure within the GTAP8-derived MRIO is for 2007, hybridisation (see Section 3.2) with more up-to-date physical data for production and trade allows an initial distribution of more modern physical commodity information across supply chains, and ensures that total production, consumption and associated impacts are updated. The use of older financial data relies on the assumption[26] that intermediate demand between sectors and final demand for sectors retains the same structure, i.e. that supply chains linkages and manufacturing efficiencies remain the same. This assumption is described in more detail in Section 5 (Discussion).

3.2 Model hybridisation and implementation

The input-output tables contained within IOTA include financial data for international industrial transactions and final consumption by end users (i.e. household, government, *etc*.). When the model is run, a 'Leontief inverse' matrix[27] is derived from the input-output tables, which represents inputs required (direct and embedded) per unit expenditure of final demand. That is, for each unit expenditure of final demand in a given sector (within a given region), the Leontief inverse matrix returns all inputs from all sectors (across all regions) required to produce the corresponding output.

For a given commodity, physical data on production and trade are concorded with, and then fed into, the financial model, with financial flows being replaced with estimates of physical flows of the chosen commodity. In order to overcome the phenomenon that previously imported goods may also be exported without processing by countries, available trade data[28] is used to estimate re-exports (i.e. exports consisting of previous imported goods as opposed to those domestically produced) which ensures that the IOTA model is able to fully map the raw primary commodities from country of production to true destination (i.e. where processing or final consumption occurs)[29]. The production data and these derived re-export data are then used to provide physical inputs and an initial redistribution of these inputs respectively, with the MRIO financial data then being used to fully distribute the physical products throughout the system. In cases where physical data is limited to production information and no physical trade data exists[30] (such as for sugarcane and oil palm fruit where trade of the raw commodity does not occur), domestic supply is simply equal to

[24] See: https://www.gtap.agecon.purdue.edu/default.asp
[25] There is usually a trade-off in internationally compiled multi-regional input-output databases between the number of industrial sectors and the number of geographic regions represented. The GTAP database represents a good balance between these constraining factors.
[26] This is a constraint of the availability of financial data as opposed to a methodological/model limitation.
[27] For more details on the Leontief inverse, a technique developed by Wassily Leontief in the 1930's, see Miller & Blair 2009.
[28] For agricultural commodities this is sourced from FAOStat.
[29] For full details of the need for, and form of, this re-export methodology, refer to West *et al* 2013.
[30] This is typically due to a commodity which is not traded in a raw, unprocessed form, as opposed to data gaps in reported trade statistics.

domestic production and so the methodology allocates production quantities to the concordant sector and region of production.

Following this hybridisation process, rather than describing financial inputs from different sectors necessary for a unit output from a given sector, the Leontief inverse matrix (described above) instead represents physical inputs (in terms of the chosen commodity) required to produce output, providing a picture of direct and embedded quantities of the chosen commodity required to meet final demand across all different regions and sectors. For any environmental extensions applied within the model (see Appendix 2 for details of those applied in this study), the physical commodity data is converted into the relevant physical quantities and units for the extension. For example, for land use, production of a given commodity in tonnes is converted into the land area in hectares required to produce this commodity. This is done at the country level, i.e. the land area requirements – obtained from FAO's country-level statistics on agricultural commodity yields - are specific to the country of production as well as the commodity choice. As before, this converts the model output from a picture of financial inputs required to meet final demand into the relevant direct and embedded requirements, in this example land area, necessary to meet the production required to satisfy demand.

Thus with knowledge of final demand for Scotland, it is possible to calculate financial inputs (direct and embedded) across all sectors and regions required to satisfy Scottish final demand. The environmentally extended Leontief inverse matrix in conjunction with physical production and trade data can therefore be used to estimate localised environmental requirements per unit expenditure of Scottish final demand. However, the GTAP database describes trade and consumption at the UK national level only. Therefore, the main model enhancement that will be implemented in this project is the process of downscaling this information to the Scottish consumption level; this requires a disaggregation of final demand data to the Scottish level which requires additional data sources.

3.3 Downscaling final consumption for Scotland

Final demand within the IOTA model is divided into household, government and capital investment expenditure[31], as well as international transport margins[32]. To give an accurate estimation of Scottish final demand expenditure, these different components of final demand need to be downscaled from a UK to Scottish level. For household expenditure, this is achieved by using Office for National Statistics (ONS) Living Costs and Food (LCF) spending data which allows household final demand in Scotland to be determined as a proportion of total UK expenditure[33]. This data is then used to split the GTAP UK household final demand information into Scottish/rest of UK demand.

To adjust government expenditure to a Scottish level, the most recent ONS Country and Regional Analysis data[34] are used as a guide for Scottish government spending in different economic sectors, and are used to split the UK level final demand data for government spending into Scottish/rest of UK final demand.

[31] For more information on the structure of the GTAP database on which the economic data within IOTA is based see: https://www.gtap.agecon.purdue.edu/AgEc618/modules/readings/Structure_GTAP.pdf
[32] Payments made to international transport sectors involved in the movement of goods between regions. For more information on international transport see: https://www.gtap.agecon.purdue.edu/resources/download/2431.pdf
[33] See Family Spending, 2013 Edition: http://www.ons.gov.uk/ons/rel/family-spending/family-spending/2013-edition/index.html. Table a35 presents three-year average (2009 to 2011) household expenditure data by region.
[34] See ONS Country & Regional Analysis: https://www.gov.uk/government/publications/country-and-regional-analysis-2013. Data for 2011-12 within Tables B1-4 used in calculations.

Within the ONS household expenditure data and regional government expenditure data, expenditure categories are different to those provided in the GTAP database. As a consequence, customised concordance mappings between the two expenditure datasets and the GTAP final demand categories have been created in order to align the different datasets and make them compatible.

The other areas of final demand within GTAP (i.e. capital investment[35] and international transport) form a smaller proportion of total final demand. In the absence of readily accessible Scotland-specific expenditure data to allow for the downscaling to the Scottish level, it is assumed that capital investment and international transport expenditure in Scotland is the same per capita as for the rest of the UK, and is therefore scaled according to relative population size[36].

3.4 Model output

When running the model, output is generated for a chosen country or region of final demand and a chosen commodity of interest. In this study, the region is a downscaled representation of UK final demand used as an estimate of Scottish demand, which is run for ten individual commodities.

Raw output from the model when run for a given commodity is a set of matrices, one for production and one for each of the environmental extensions (land use and Green, Blue and Grey Water use). Each of these matrices is 7,353x236 elements in size, with columns representing the 236 countries of production/impact from the FAO data, and the rows representing the 57 GTAP sectors of demand in each of the 129 GTAP regions. Each cell within these matrices denotes the production/impact associated with the commodity occurring in the respective FAO country (column) due to Scottish final demand for products from a given GTAP sector within a given GTAP region (row).

This raw output therefore contains a rich level of sectoral and geographic detail about Scottish consumption impacts. However, at this resolution, the data is somewhat intractable to work with and difficult to communicate. Furthermore, previous studies using MRIO approaches have shown that aggregation of results increases data reliability (Lenzen *et al* 2010). As a result, the raw output data are aggregated in a number of different ways before analysis takes place:

- **Country-level data** - Summing all rows, the data is reduced to a 236 element vector specifying the production/impact associated with the chosen commodity occurring in each of the FAO countries due to Scottish demand across all sectors from all regions (i.e. total Scottish final demand for all goods and services). This provides the link between Scottish demand and localised production and impacts for each commodity.
- **Sector level by country of production** - By reorganising the data and aggregating, the output can be transformed into 57 by 236 element matrices, with rows denoting the 57 GTAP sectors, and columns the 236 FAO countries. In this form, each element denotes commodity production/associated impact occurring in a specified country (column) due to Scottish demand for a specified sector (row) across all regions.

[35] For example, investment for the generation of fixed assets (property, plant and equipment) by business, government and households.
[36] Obtained from the ONS LCF Surveys 2013 (See: http://www.ons.gov.uk/ons/rel/family-spending/family-spending/2013-edition/index.html). An alternative would have been to use relative GDP ratios between Scotland and the rest-of-UK, but this is, in practice, similar to population ratios.

- **Sector level by region of purchase**[37] - Summing all columns provides a 7,353 element vector, with each element denoting total global commodity production/impact occurring due to Scottish demand for (i.e. purchases within) a given sector within a given region. This can be further aggregated to provide global production/impact occurring due to Scottish demand for a specified sector from all regions, or due to Scottish demand across all sectors within a specified region.

Table 3.1 summarises the aspects of the raw data which these three different data formats preserve. By reorganising and aggregating the raw output data in these ways, it becomes possible to order the data and identify the top countries of production/impacts associated with Scottish demand, or highlight sectors that drive such production and impacts[38]. In doing so, the key localised production and potential environmental impacts associated with different commodities that are driven by Scottish demand, and individual components of this demand, can be isolated.

Table 3.1. Summary of components of information preserved from the raw model output data when processed into the three different forms assessed within this report. In each instance, certain dimensions of information are aggregated in order to condense the data into a tractable and interpretable format.

	Country detail of location of production/impact	Regional detail as to location of purchase	Sectoral detail as to sector of purchase
Raw data output	✓	✓	✓
Country level data	✓		
Sector level by country of production/impact	✓		✓
Sector level by region of purchase		✓	✓

[37] 'Region of purchase' refers to the region (within IOTA) within which the sector purchased from (via Scottish final demand) resides. For example, if there is Scottish final demand for sunflower oil produced by the 'Vegetable oils and fats' sector in Ukraine, then Ukraine is the 'region of purchase'.
[38] Other aggregations and manipulations of the data are possible, but these are deemed the most relevant in this work.

4 Results

The following section first presents, for the ten chosen commodities, total production associated with Scottish final demand, with comparative statistics from alternative (HMRC and FAO) sources. This production, and associated agricultural land use, is then compared against global production and land use values. For selected commodities, information is also presented on the location of production associated with Scottish demand, and environmental extension data linked to this production. Finally, analysis is presented which allows identification of the sectoral nature of the demand that is responsible for production.

4.1 Total global production due to Scottish demand

Table 4.1 shows, for the ten commodities, the total production due to Scottish demand, total production due to UK demand, imports into the UK (data from HMRC), and 'Domestic Supply'[39] to the UK (data only available up to 2009 from FAO). Additional details related to the compilation of data from HMRC and FAO sources are provided in Appendix 3 as HMRC and FAO values provided in Table 4.1 may constitute both raw and derived products.

MFA datasets comprise data about domestic production, plus imports and exports to/from a country. Within the MFA for Scotland prepared in Phase 1, Scottish-specific production information and Regional Trade Statistics were utilised. Three of the ten chosen commodities are produced in Scotland[40]. Regional Trade Statistics for Scotland from HMRC are not, however, at a high enough resolution to enable comparison at the individual commodity level, so data for imports into the United Kingdom are instead shown in Table 4.1. FAO domestic supply data gives an estimate of utilisation of commodities within the UK economy (data is not available for Scotland).

It is interesting to compare these data to outputs from the IOTA model. For example, in contrast to all other commodities analysed, domestic production of potatoes within Scotland exceeds global potato production necessary to satisfy Scottish final demand. Therefore, from a consumption perspective, this information suggests that Scottish consumers are 'responsible' for the production of a lower quantity of potatoes than are actually produced in Scotland (but see below for further discussion). For sugarcane[41] total UK imports of derived sugar products known to be sourced from sugarcane (HMRC) appear lower than Scottish consumption (as estimated by IOTA). Because IOTA captures the sugarcane embedded along complete supply chains, it provides additional information on the likely quantity of production required that is not supplied by the other data sources. For example, if a commodity is used in many stages of production, and/or across many countries, this will not necessarily be reflected in import data used in HMRC or FAO statistics, but *will* be captured with the IOTA approach. Large differences in quantity estimates between data sources – which can also be seen within paddy rice and maize, for example – may therefore imply more complex/indirect supply chains for these commodities.

[39] Domestic supply equates to production plus imports, minus exports, plus changes in stock. This information is sourced from FAOStat 'Commodity Balances', which show balances of food and agricultural commodities and include the equivalents of their derived products falling within the same commodity group.

[40] Data displayed for Scottish production here is obtained from background data used to prepare the EW-MFA in Phase 1 of this project.

[41] Note: FAO domestic supply information for sugarcane shows very low utilisation. This is due to the fact that FAO data does not distinguish between sugar refined from sugarcane or sugarbeet and therefore data on these derived products is not included in Table 4.1, whereas HMRC data does partially disaggregate this information.

Table 4.1. Collation of commodity production statistics, processed IOTA model output data, import and domestic supply data. For each commodity, domestic production (from economy wide (EW) MFA) and total global production due to domestic consumption (IOTA output) are listed for Scotland, with production for Scottish consumption also shown as a percentage of that for the UK. At the UK level, imports (HMRC) and domestic supply (FAO) are also presented for comparison purposes.

	Data	Production in Scotland	Total production due to Scottish demand	Production for Scottish demand as % of production for UK demand	Total production due to UK demand	Imports into the UK	Domestic Supply in the UK (2009)
	Source	EW-MFA	IOTA		IOTA	HMRC	FAO
	Units	tonnes	tonnes		tonnes	tonnes	tonnes
	Date	2011	2011		2011	2011	2009
IOTA Commodity	Wheat	933,340	1,525,211	8.90%	17,141,210	1,069,124	14,193,134
	Paddy Rice	0	320,347	8.82%	3,633,484	642,848	1,139,668
	Maize	<10,000[42]	580,605	8.79%	6,605,112	1,058,914	1,121,970
	Potatoes	1,390,000	628,750	8.17%	7,692,025	836,698	7,468,132
	Sugarcane	0	1,390,123	8.76%	15,868,933	1,343,122	51
	Soya beans	0	322,893	8.68%	3,718,958	2,835,318	3,471,811
	Oil Palm Fruit	0	184,750	8.62%	2,142,949	910,778	1,345,306
	Sunflower Seed	0	63,414	8.69%	729,602	646,020	896,243
	Tomatoes	700	90,759	8.43%	1,076,881	1,072,032	1,245,280
	Bananas	0	101,994	8.18%	1,246,327	1,054,414	888,368

Table 4.2 shows, for the ten commodities, the total production and agricultural land use[43] due to Scottish demand compared to, and as a percentage of, total global production and agricultural land use. Where the percentage of land required is less than the percentage of production required, this implies greater-than-average resource efficiency (i.e. the production requires less land than would be expected with world-average yields). For potatoes, wheat and tomatoes, the land use due to Scottish demand will include land *within* Scotland (as these commodities are grown in Scotland). According to Scottish government statistics[44], in 2011 wheat production occupied 115,412 hectares, potatoes occupied 31,073 hectares, and tomatoes occupied 3.7 hectares of Scottish land. For these commodities (and ignoring the fact that a portion of the commodities grown on Scottish land will be consumed outside Scotland via export of raw or processed commodities) the 'reliance' on non-Scottish land is 150,187 hectares for wheat, and 1,511.3 hectares for tomatoes. Land used to produce potatoes in Scotland exceeds that required for consumption by 12,713 hectares.

[42] Maize is recorded alongside other feed crops in Scotland's Agricultural Statistics http://www.scotland.gov.uk/Topics/Statistics/Browse/Agriculture-Fisheries/PubFinalResultsJuneCensus

[43] Land use data sourced from FAOStat (see Appendix 3 for more details).

[44] See: Abstract of Scottish Agricultural Statistics: http://www.scotland.gov.uk/Topics/Statistics/Browse/Agriculture-Fisheries/PubAbstract/Abstract2013

Table 4.2. Collation of commodity production statistics and processed IOTA model output data for 2011 production and land use. For each commodity, global production due to Scottish demand (IOTA output) and total global production (FAO) are listed, with the former also presented as a percentage of the latter. The same information is also shown for land use, with land use due to Scottish consumption (IOTA output), total global land use for production (FAO), and land use due to Scottish consumption as a percentage of total global land use for production presented for each commodity.

	Data	Production due to Scottish Demand	Total global production	Percentage of global production required to meet Scottish demand	Land use due to Scottish demand	Total global land area used	Percentage of global land use required to meet Scottish demand
	Source	IOTA	FAO		IOTA	FAO	
	Units	tonnes	tonnes		hectares	hectares	
	Date	2011	2011		2011	2011	
IOTA Commodity	Wheat	1,525,211	699,490,446	0.22%	265,599	220,312,194	0.12%
	Paddy Rice	320,347	724,959,981	0.04%	65,075	163,626,363	0.04%
	Maize	580,605	888,008,422	0.07%	94,566	172,048,410	0.05%
	Potatoes	628,750	374,198,535	0.17%	18,360	19,215,249	0.10%
	Sugarcane	1,390,123	1,819,419,962	0.08%	20,060	25,581,153	0.08%
	Soya beans	322,983	262,352,402	0.12%	118,121	103,598,727	0.11%
	Oil Palm Fruit	184,750	241,226,904	0.08%	10,218	16,619,004	0.06%
	Sunflower Seed	63,414	40,713,562	0.16%	34,540	25,867,213	0.13%
	Tomatoes	90,759	158,019,581	0.06%	1,515	4,723,067	0.03%
	Bananas	101,997	106,058,471	0.10%	3,780	5,255,172	0.07%

Figure 4.1 shows the ratio between production and land use for Scottish consumption per capita and a theoretical average per-capita global consumption[45], obtained by scaling data from Table 4.2 to Scottish and global 2011 populations.

[45] i.e. assuming that global production of a commodity is divided equally between the global population.

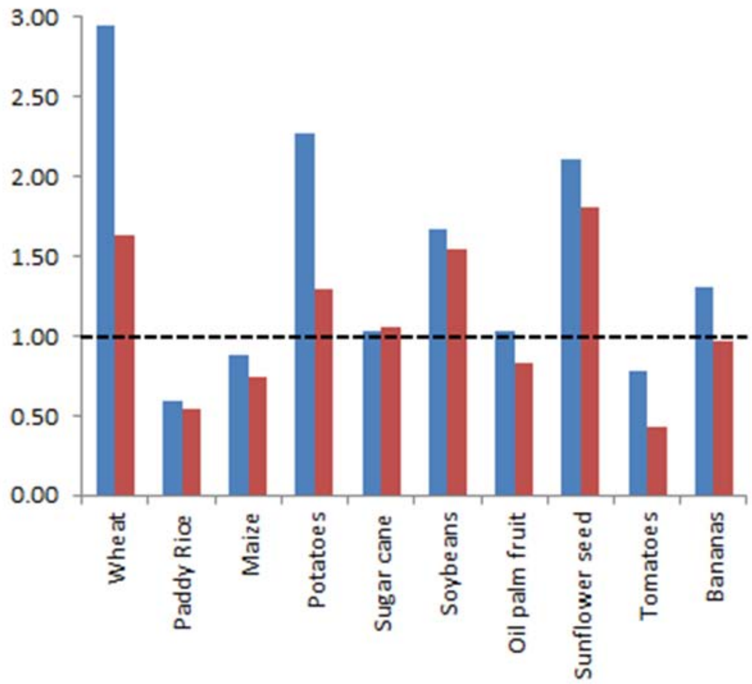

Figure 4.1. Relative production (and associated land use) per capita for different commodities due to Scottish demand compared to global average. Red and blue bars show the ratio between Scottish per capita consumption and theoretical average global consumption per capita, for production and land use respectively.

This data reveals that Scottish consumers are responsible for higher than world-average production of wheat, potatoes, soya beans and sunflower seeds, and lower than average production of rice, maize and tomatoes, i.e. if the total supply of commodities was distributed across the total global population, Scottish consumers would be consuming more than their 'fair share' of wheat *etc*., and less than their 'fair share' of rice etc. In Figure 4.1, where the agricultural land area bars are lower than the production bars, this implies greater-than-average production efficiency[46]. For example, according to the results, Scottish consumers are responsible for almost three times the world per capita production of wheat, but only approximately 1.5 times the world average agricultural land area. Given that much of the wheat consumed in Scotland is also produced within the UK, where intensive agriculture is prevalent, this finding is logical. Commodities destined for Scottish consumption where efficiency of production is close to the world average (i.e. both the production and land-use ratios are close to equal in height) include sugarcane and paddy rice.

4.2 Location of production and further environmental extension analysis

Unlike data derived from other sources (e.g. HMRC) which detail the point of last dispatch (rather than the point of production; although these *may* be the same) of imported commodities, the IOTA outputs are able to define and estimate production within source regions. Data for sunflower seed, tomatoes and potatoes is provided here, and data for other analysed commodities can be found in the supplementary MS Excel spreadsheets. Where 'United Kingdom' is listed as a source region, this includes Scotland and the rest of the UK.

[46] Greater efficiency in land use does not necessarily imply lower overall environmental impact, as this may be facilitated by an increase in the use of other inputs e.g. water, pesticides and fertilisers.

4.2.1 Sunflower seed

Figure 4.2 and Table 4.3 show the location and quantity of production of sunflower seeds for Scottish final demand. The table also includes information on how much of the production of sunflower seeds in the specified country is embedded in Scottish consumption, and HMRC data on the quantity (and relative country rank by quantity (high to low) of related imported product(s)) of sunflower seeds and derived products imported into the UK.

Figure 4.2. Visual representation of relative quantities of sunflower seed production occurring in different countries due to total Scottish demand (direct and embedded consumption). Source of mapping software: Chartsbin.com.

Production of sunflower seeds in Ukraine, France and Argentina contribute over 60% of total production necessary to fulfil Scottish final demand. These countries are also represented within the top four locations of import from HMRC statistics, but in a different order (e.g. Ukraine appears as the largest producer within IOTA, but third within HMRC). Moldova is the 4th largest supplier according to IOTA, but no imports of sunflower seeds or derived products from Moldova were recorded by the HMRC in 2011. As a major point of final dispatch, the Netherlands is ranked second in HMRC data (not shown) but does not feature in IOTA outputs as, according to FAO, no production of sunflower seeds occurs in this country.

Table 4.3. Top ten countries by total sunflower seed production (tonnes) due to Scottish consumption in 2011.For each country, the following information is shown: total in-country production due to Scottish demand (IOTA output); the percentage of total global production for Scottish consumption which this accounts for; the total production taking place in the country (FAO); the percentage of total in-country production which goes to meet Scottish demand; the total quantity of related products imported into the UK from the country (derived from HMRC); and the relative rank of this country in HMRC import data, when compared against quantities imported from other countries. The final row in the table provides the same information for production occurring across all countries of the world.

	Data	Production to meet Scottish demand	% of total production that takes place to meet Scottish demand	Total production in country	% of country production used to satisfy Scottish demand	Total imported from country into the UK	Rank in HMRC import data
	Source	**IOTA**		**FAO**		**HMRC**	
	Units	**tonnes**		**tonnes**		**tonnes**	
Country of production	**Ukraine**	21,182	33.40%	8,670,500	0.24%	100,319	3
	France	9,285	14.64%	1,880,705	0.49%	187,115	1
	Argentina	8,708	13.73%	3,671,748	0.24%	76,427	4
	Republic of Moldova	3,817	6.02%	427,353	0.89%	-	-
	Bulgaria	3,407	5.37%	1,439,700	0.24%	6,779	10
	Russian Federation	2,649	4.18%	9,697,450	0.03%	43,682	5
	Romania	2,527	3.99%	1,789,326	0.14%	346	25
	Spain	2,505	3.95%	1,090,171	0.23%	6,421	11
	Hungary	2,251	3.55%	1,374,784	0.16%	4,820	15
	China	2,021	3.19%	2,313,000	0.09%	10,945	9
	TOTAL (all countries)	63,414	100%	40,713,562	0.16%	646,020	

4.2.1.1. Agricultural Land Use

Table 4.4 shows the agricultural land required, in rank order for the top ten producer countries, for sunflower seed production to fulfil Scottish final demand. Changes in rank order in comparison with Table 4.3 imply differences in relative land use efficiency. For example, Argentina has replaced France at rank 2, due to the fact that more land is used per tonne of sunflower seed produced.

Table 4.4. Top ten countries by total land requirements (hectares) for sunflower seed production due to Scottish consumption in 2011. For each country, the following information is shown: total land use for production due to Scottish demand (IOTA output); the percentage of total global land use for production for Scottish consumption which this accounts for; the total land use for production taking place in the country (FAO); and the percentage of total in-country land use which use is required to meet Scottish demand. The final row in the table provides the same information for production occurring across all countries of the world.

	Data	Land use to meet Scottish demand	% of total land use that takes place to meet Scottish demand	Total land use in country for commodity	% of country land use for commodity used to satisfy Scottish demand
	Source	**IOTA**		**FAO**	
	Units	**hectares**		**hectares**	
Country of production/ Location of impact	**Ukraine**	11,523	33.36%	4,716,600	0.24%
	Argentina	4,134	11.97%	1,743,040	0.24%
	France	3,657	10.59%	740,722	0.49%
	Republic of Moldova	2,450	7.09%	274,237	0.89%
	Spain	1,983	5.74%	862,869	0.23%
	Russian Federation	1,972	5.71%	7,221,000	0.03%
	Bulgaria	1,768	5.12%	747,131	0.24%
	Romania	1,403	4.06%	993,258	0.14%
	Hungary	949	2.75%	579,548	0.16%
	China	821	2.38%	940,200	0.09%
	TOTAL (all countries)	34,540	100%	25,867,213	0.13%

4.2.1.2. Green, Blue and Grey Water use

Table 4.5 shows Green, Blue and Grey Water use[47], in rank order for the top ten, for sunflower production. Note that, in the source data, Grey Water use is not available for Moldova (which is in the top-ten by production quantity). Equivalent tables for estimated

[47] Blue Water refers to surface and groundwater use, Green Water refers to rainwater use and Grey Water refers to the volume of freshwater required to assimilate pollutant loads (nitrogen only) –see Appendix 2

fertiliser inputs used for production are presented in the supplementary MS Excel spreadsheets[48].

Table 4.5. Water use (m^3) for sunflower seed production due to Scottish consumption in 2011. For Blue, Green and Grey water use, the top-ten countries by water use required for production due to Scottish demand are listed along with the associated water requirements.

	Data	Blue Water use		Green Water use		Grey Water Use
	Source	IOTA		IOTA		IOTA
	Units	m^3		m^3		m^3
Country of production/ Location of impact	Spain	2,261,853	Ukraine	65,999,993	France	4,848,685
	China	689,338	Argentina	23,264,099	Ukraine	1,552,742
	Ukraine	501,142	France	11,439,488	Hungary	1,324,012
	Romania	292,960	Republic of Moldova	10,872,061	China	938,858
	Iraq	158,064	Bulgaria	10,472,435	Romania	312,534
	India	148,803	Russian Federation	9,237,587	United States of America	291,964
	Sudan	104,564	Romania	7,598,576	Spain	284,445
	France	101,171	Spain	6,241,387	Germany	265,195
	Turkey	100,846	China	4,553,476	Slovakia	245,045
	Argentina	99,796	Hungary	4,248,356	Argentina	226,093
	TOTAL (all countries)	5,071,224	TOTAL (all countries)	170,708,339	TOTAL (all countries)	11,360,687

Despite relative low levels of production for Scottish demand (see Table 4.3), Spain appears highest in Blue Water use, and other relatively arid areas appear in this list such as Iraq, Sudan and Turkey, reflecting the reliance on irrigation to ‘top-up’ natural rainfall. France appears to produce a relatively high amount of Grey Water for its sunflower production, which is also reflected in FAO Fertistat data for N application rates (see supplementary MS Excel spreadsheets).

4.2.2 Tomatoes

Figure 4.3 and Table 4.6 show the location and quantity of production of tomatoes for Scottish final demand. The table also includes information on how much of the production of tomatoes in the specified country is embedded in Scottish consumption, and HMRC data on the quantity (and relative rank) of tomatoes and derived products imported into the UK.

[48] In comparison with other environmental extension datasets utilised, fertiliser data is patchy and relatively outdated. It is therefore included in the supplementary MS Excel spreadsheets for information, and to demonstrate the potential to attach this type of extension to the IOTA model, but is not discussed further.

Production of tomatoes in China, Spain and the Netherlands contribute almost 60% of total production necessary to fulfil Scottish final demand. These latter two countries are also represented within the top three locations of import from HMRC (in reverse order). Although China is top of the IOTA ranking (with double the production of Spain), it is only 11th in HMRC data. Brazil is estimated by IOTA to be the 6th largest producer, but is not present as an importer within HMRC data.

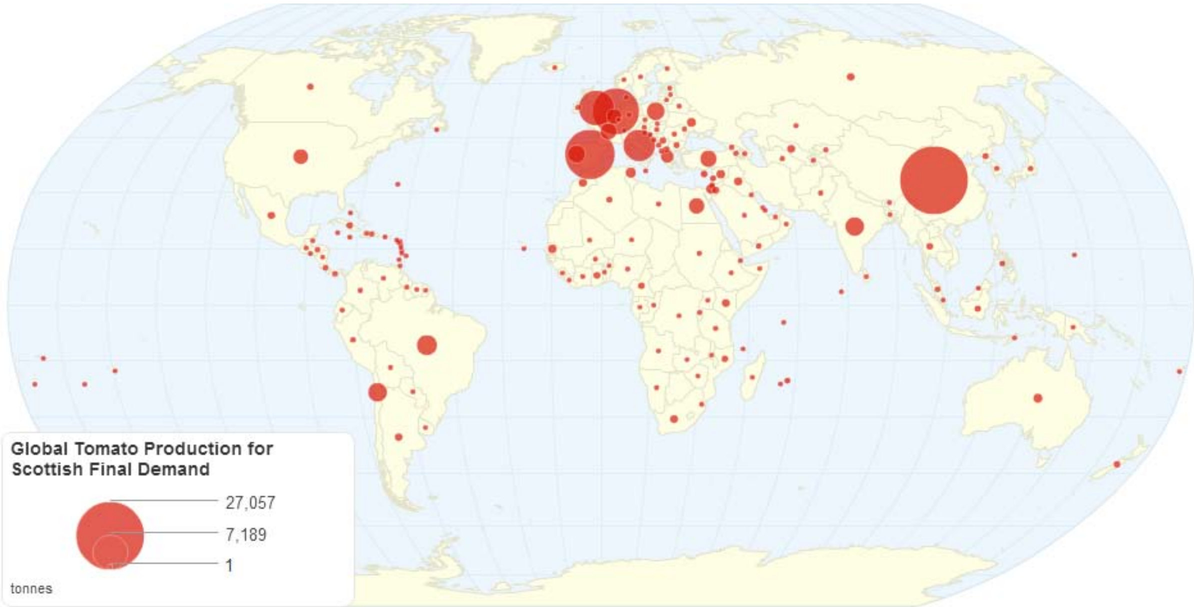

Figure 4.3. Visual representation of relative quantities of tomato production occurring in different countries due to total Scottish demand (direct and embedded consumption). Source of mapping software: Chartsbin.com.

Table 4.6. Top ten countries by total tomato production (tonnes) due to Scottish consumption in 2011. For each country, the following information is shown: total in-country production due to Scottish demand (IOTA output); the percentage of total global production for Scottish consumption which this accounts for; the total production taking place in the country (FAO); the percentage of total in-country production which goes to meet Scottish demand; the total quantity of related products imported into the UK from the country (derived from HMRC); and the relative rank of this country in HMRC import data, when compared against quantities imported from other countries. The final row in the table provides the same information for production occurring across all countries of the world.

	Data	Production to meet Scottish demand	% of total production that takes place to meet Scottish demand	Total production in country	% of country production used to satisfy Scottish demand	Total imported from country into the UK	Rank in HMRC import data
	Source	**IOTA**		**FAO**		**HMRC**	
	Units	**tonnes**		**tonnes**		**tonnes**	
Country of production	**China**	27,057	29.81%	48,572,921	0.06%	10,773	11
	Spain	14,322	15.78%	3,864,120	0.37%	221,904	3
	Netherlands	12,434	13.70%	815,000	1.53%	312,028	2
	United Kingdom	7,091	7.81%	89,800	7.90%	-	-
	Italy	5,779	6.37%	5,950,215	0.10%	319,066	1
	Brazil	2,239	2.47%	4,416,652	0.05%	-	-
	Chile	1,935	2.13%	726,000	0.27%	1,642	17
	India	1,924	2.12%	16,826,000	0.01%	41	32
	Poland	1,722	1.90%	712,295	0.24%	17,493	8
	Portugal	1,623	1.79%	1,245,364	0.13%	52,238	4
	TOTAL (all countries)	90,759	100%	158,019,581	0.06%	1,072,032	

4.2.2.1. Agricultural land use

Table 4.7 shows the agricultural land required, in rank order for the top ten, for tomato production to fulfil Scottish final demand. The Netherlands has moved from 3rd (in production quantity to meet Scottish demand) to 10th (in land use to meet Scottish demand) in this ranking (and the UK from 4th to 13th - not shown), implying that land use efficiency is very high (e.g. via high-intensity production in greenhouses).

Table 4.7. Top ten countries by total land requirements (hectares) for tomato production due to Scottish consumption in 2011. For each country, the following information is shown: total land use for production due to Scottish demand (IOTA output); the percentage of total global land use for production for Scottish consumption which this accounts for; the total land use for production taking place in the country (FAO); and the percentage of total in-country land use which use is required to meet Scottish demand. The final row in the table provides the same information for production occurring across all countries of the world.

	Data	Land use to meet Scottish demand	% of total land use that takes place to meet Scottish demand	Total land use in country for commodity	% of country land use for commodity used to satisfy Scottish demand
	Source	**IOTA**		**FAO**	
	Units	**hectares**		**hectares**	
Country of production/ Location of impact	**China**	549	36.25%	985,817	0.06%
	Spain	190	12.53%	51,204	0.37%
	Italy	101	6.66%	103,858	0.10%
	India	99	6.53%	865,000	0.01%
	Turkey	42	2.80%	328,000	0.01%
	Brazil	36	2.39%	71,473	0.05%
	Egypt	34	2.27%	212,446	0.02%
	Poland	32	2.15%	13,441	0.24%
	Chile	30	1.98%	11,227	0.27%
	Netherlands	26	1.71%	1,702	1.53%
	TOTAL (all countries)	1,515	100%	4,723,067	0.03%

4.2.2.2. Green, Blue and Grey Water use

Table 4.8 shows Green, Blue and Grey Water use, in rank order for the top ten, for tomato production. Equivalent tables for estimated fertiliser inputs used for production are presented in the supplementary MS Excel spreadsheets.

Table 4.8. Water use (m^3) for sunflower seed production due to Scottish consumption in 2011. For Blue, Green and Grey water use, the top-ten countries by water use required for production due to Scottish demand are listed along with the associated water requirements.

	Data	Blue Water use		Green Water use		Grey Water Use
	Source	IOTA		IOTA		IOTA
	Units	m^3		m^3		m^3
Country of production/ Location of impact	Spain	325,955	China	4,931,054	China	2,668,151
	Egypt	194,952	Spain	495,573	Spain	363,918
	Italy	177,534	Italy	373,195	India	83,036
	India	110,698	Poland	293,033	Egypt	82,042
	United States of America	85,223	India	241,950	Italy	76,396
	Turkey	80,125	Brazil	152,396	Chile	31,931
	China	77,177	Ukraine	108,817	Turkey	29,404
	Iraq	76,375	Netherlands	89,473	Cuba	27,367
	Uzbekistan	64,521	Turkey	85,268	United States of America	24,919
	Senegal	45,141	Ghana	79,242	Netherlands	24,900
	TOTAL (all countries)	1,715,072	TOTAL (all countries)	8,107,299	TOTAL (all countries)	3,667,638

Egypt appears second in the rank of Blue Water use, despite not featuring in the top ten by production for Scottish demand (Table 4.6), reflecting relatively arid growing conditions. China's production dominance is matched by high Green and Grey Water use. India has relatively high Blue, Green and Grey Water use in comparison to production.

4.2.3 Potatoes

Figure 4.4 and Table 4.9 show the location and quantity of production of potatoes for Scottish final demand. The table also includes information on how much of the production of potatoes in the specified country is embedded in Scottish consumption, and HMRC data on the quantity (and relative rank) of potatoes and derived products imported into the UK.

Figure 4.4. Visual representation of relative quantities of potato production occurring in different countries due to total Scottish demand (direct and embedded consumption). Source of mapping software: Chartsbin.com.

Production of potatoes in the UK (which will itself include Scotland; production data for Scotland (Table 4.1) suggests 1,390,000 tonnes of potatoes were produced in total in Scotland in 2011) contributes almost three-quarters of the production necessary to fulfil Scottish final demand. Other countries contribute to the remaining quarter, demonstrating that - with reference to the earlier discussion (Section 4.1) - despite the fact that Scotland may be seen as a net ‘exporter’ of potatoes, production impacts will still occur overseas driven by Scottish consumption. Excluding UK production, China is the biggest producer for Scottish demand but only appears 23rd in the rank of HMRC import data implying that potatoes from China are embedded in other products and/or reach the UK via intermediate trade pathways.

Table 4.9. Top ten countries by total potato production (tonnes) due to Scottish consumption in 2011. For each country, the following information is shown: total in-country production due to Scottish demand (IOTA output); the percentage of total global production for Scottish consumption which this accounts for; the total production taking place in the country (FAO); the percentage of total in-country production which goes to meet Scottish demand; the total quantity of related products imported into the UK from the country (derived from HMRC); and the relative rank of this country in HMRC import data, when compared against quantities imported from other countries. The final row in the table provides the same information for production occurring across all countries of the world.

	Data	Production to meet Scottish demand	% of total production that takes place to meet Scottish demand	Total production in country	% of country production used to satisfy Scottish demand	Total imported from country into the UK	Rank in HMRC import data
	Source	IOTA		FAO		HMRC	
	Units	tonnes		tonnes		tonnes	
Country of production	United Kingdom	459,561	73.09%	6,115,000	7.52%	-	-
	China	49,207	7.83%	88,353,845	0.06%	145	23
	Netherlands	19,690	3.13%	7,333,472	0.27%	359,796	1
	Poland	15,133	2.41%	8,196,700	0.18%	807	13
	Belgium	11,162	1.78%	4,128,669	0.27%	203,619	2
	France	11,048	1.76%	7,440,219	0.15%	53,914	4
	Germany	6,729	1.07%	11,800,000	0.06%	33,844	6
	India	4,885	0.78%	42,339,400	0.01%	174	20
	Israel	4,562	0.73%	621,106	0.73%	62,345	3
	Chile	4,465	0.71%	1,676,444	0.27%	-	-
	TOTAL (all countries)	628,750	100%	374,198,535	0.17%	836,697	

4.2.3.1. Agricultural land use

Table 4.10 shows the agricultural land required, in rank order for the top ten, for potato production to fulfil Scottish final demand. The Ukraine, Russia and DPR Korea (North Korea) all now appear in this top ten, indicating that land use efficiency is relatively low in these countries.

Table 4.10. Top ten countries by total land requirements (hectares) for potato production due to Scottish consumption in 2011. For each country, the following information is shown: total land use for production due to Scottish demand (IOTA output); the percentage of total global land use for production for Scottish consumption which this accounts for; the total land use for production taking place in the country (FAO); and the percentage of total in-country land use which use is required to meet Scottish demand. The final row in the table provides the same information for production occurring across all countries of the world.

	Data	Land use to meet Scottish demand	% of total land use that takes place to meet Scottish demand	Total land use in country for commodity	% of country land use for commodity used to satisfy Scottish demand
	Source	**IOTA**		**FAO**	
	Units	**hectares**		**hectares**	
Country of production/ Location of impact	**United Kingdom**	10,972	59.76%	146,000	7.52%
	China	3,022	16.46%	5,426,433	0.06%
	Poland	739	4.03%	400,500	0.18%
	Netherlands	428	2.33%	159,233	0.27%
	Ukraine	237	1.29%	1,443,000	0.02%
	France	236	1.28%	158,643	0.15%
	Belgium	223	1.21%	82,341	0.27%
	India	215	1.17%	1,863,200	0.01%
	Russian Federation	214	1.16%	2,202,600	0.01%
	Democratic People's Republic of Korea	169	0.92%	139,000	0.12%
	TOTAL (all countries)	18,360	100%	19,215,249	0.10%

4.2.3.2. Green, Blue and Grey Water use

Table 4.11 shows Green, Blue and Grey Water use, in rank order for the top ten, for potato production. Equivalent tables for estimated fertiliser inputs used for production are presented in the supplementary MS Excel spreadsheets.

Table 4.11. Water use (m^3) for potato production due to Scottish consumption in 2011. For Blue, Green and Grey water use, the top-ten countries by water use required for production due to Scottish demand are listed along with the associated water requirements.

	Data	Blue Water use		Green Water use		Grey Water Use
	Source	IOTA		IOTA		IOTA
	Units	m3		m3		m3
Country of production/ Location of impact	United Kingdom	5,844,676	United Kingdom	30,237,273	United Kingdom	10,845,301
	Egypt	714,426	China	10,574,140	China	3,926,160
	Israel	471,184	Poland	2,913,041	Chile	1,537,208
	Chile	466,759	Netherlands	1,505,171	Poland	1,201,405
	China	360,414	Ukraine	1,329,343	Netherlands	578,926
	Peru	200,256	India	1,080,559	France	519,644
	India	177,642	Russian Federation	946,465	United States of America	472,798
	France	176,622	Belgium	899,022	Belgium	318,495
	United States of America	161,492	France	873,454	Egypt	291,646
	Australia	123,965	Democratic People's Republic of Korea	759,166	Israel	253,545
	TOTAL (all countries)	10,058,783	TOTAL (all countries)	57,068,146	TOTAL (all countries)	21,611,767

Countries such as Egypt, Israel, Chile and Peru feature towards the top of the Blue Water table despite relatively low levels of production for Scottish demand. The UK's position as top producer for Scottish demand is matched by large amounts of Grey Water use, but this is only roughly three times higher that estimates for Grey Water use in China, despite production being more than nine times higher in the UK. Relative Grey Water use in Chile appears to be very high in comparison with production for Scottish demand.

4.2.4 Other commodities

Table 4.1. shows that UK reliance on overseas agricultural commodities is higher than HMRC import data would suggest, e.g. for sugarcane, rice, maize and palm oil fruit. More detailed data for all ten commodities is available in the supplementary MS Excel spreadsheets. Here we present an overview of results from IOTA for the commodities not covered in more detail above.

Maize: The estimate for China, the largest producer (192,318 tonnes) for Scottish demand, is more than double the next highest country (the United States; 80,042 tonnes) and accounts for 33% of total production needed to satisfy Scottish demand. This is also reflected in a high level of land use, with Brazilian land use appearing as second highest (8,920ha) despite only ranking 4th in production (37,557 tonnes). China is highest for Blue, Green and Grey water use. China's production to meet Scottish demand is largely superior to the total maize imported into the UK (184 tonnes); China only appears 20th in the rank of HMRC import data. This implies that maize from China is embedded in other products and/or reaches Scotland via intermediate trade pathways.

Soya bean: Brazil (134,705 tonnes) and Argentina (99,120 tonnes) dominate production, together accounting for over 72% of production for Scottish demand, with the United States contributing another 51,648 tonnes (16%). These also appear as the main exporting countries in HMRC data. Production is also matched by similar proportional land use for these countries. To fulfil this production, the United States requires almost 43 times the amount of Blue Water of Brazil, despite producing only just over a third of the amount of soya bean. Compared to relative production, China appears relatively high in the ranking for Grey Water use.

Paddy rice: Three countries are responsible for almost 75% of paddy rice production for Scottish demand; China (167,865 tonnes; 52%), India (39,531 tonnes; 12%), and Thailand (32,485 tonnes; 10%). Land use in Thailand (11,218 ha) is estimated to be slightly higher than in India (11,008ha) despite lower production. China's production to meet Scottish demand is largely superior to the total rice imported into the UK from China (330 tonnes); China only appears 30th in the rank of HMRC import data. The main sectors of purchase in China associated with Scottish demand produce non-food goods e.g. textile/wearing apparel.

Sugarcane: Brazil leads sugarcane production for Scottish demand (310,195 tonnes; 22%), but several other African countries also make a relatively large contribution; particularly Mauritius (246,189 tonnes; 18%), Swaziland (104,056 tonnes; 7.5%) and Mozambique (97,440 tonnes; 7%). Sugarcane production in these countries (to meet Scottish demand) is superior to the total sugarcane imported into the UK (317,025 tonnes) suggesting again that some of the sugarcane is embedded in other products (e.g. processed foods) or reaches the UK via intermediate trade pathways. A relatively large proportion of total in-country production from these African nations is driven by Scottish demand (Mauritius 5.8%; Swaziland 2.1%; Mozambique 2.9%) reflecting direct trade of sugar between these countries and the UK. In comparison with other countries, Mozambique's production appears to be relatively highly reliant on Blue Water use. Sudan also has very high Blue Water use in comparison to production levels. Compared to levels of production, land use in Cuba appears high.

Oil palm fruit: Four South-East Asian countries are responsible for over 90% of the production of oil palm fruit for Scottish demand; Malaysia (97,191 tonnes; 53%), Indonesia (45,848 tonnes; 25%), Papua New Guinea (15,592 tonnes; 8%) and Thailand (9,601 tonnes; 5%). Indonesia, Malaysia and Papua New Guinea also appear in HMRC data as the main three exporters of oil palm fruit to the UK. Land use proportions for these countries are similar. Blue Water use is not typical for palm oil production (with data only present for Guinea as a result).

Wheat: The UK produces almost two-thirds of production for Scottish demand (1,007,676 tonnes; 66%), with China the next highest producer (93,684 tonnes; 6%). Proportional land use for the UK, however, is lower (130,046ha; 49%) reflecting a relatively intensive UK production system. Total Blue Water use is highest in India (and Grey Water use in India is also high), despite providing under 3% of production for Scottish demand. Pakistan also has very high relative Blue Water use.

Bananas: Three Latin-American countries produce 55% of banana production for Scottish demand; Colombia (22,060 tonnes; 22%); Costa Rica (21,979 tonnes; 22%) and Ecuador (12,743 tonnes; 12.5%). These also appear as the top exporters to the UK in HMRC data.

The main sectors of purchase are food-based and bananas seem less embedded in other non-food products than some of the other commodities considered such as rice. Belize is also a notable producer as, although it provides just under 6% (5,818 tonnes) of the banana production for Scottish demand, almost 8% of total in-country production from Belize is driven by Scottish consumers. Relative land use for banana production in Brazil is relatively high compared to production. Of the three top producers, Costa Rica is most heavily reliant on Blue Water, using four times as much as Colombia for a similar level of production. China has a high level of Grey Water use relative to production.

4.3 Sectoral demand

The following tables contain, for sunflower seeds[49], more detailed information on the sectors and regions associated with Scottish final demand that are responsible (top ten) for commodity production. Table 4.12 shows sector level results according to country of impact[50], i.e. sectors for which Scottish final demand from a specific sector (aggregated across all regions) causes production in a specific region. For example, Scottish final consumption of ‘Food products nec’ (a sector including a variety of processed foods) from any region leads to an estimated 11,481 tonnes of sunflower seed production in Ukraine, 4,767 tonnes in France, 4,477 tonnes in Argentina, 2,105 tonnes in Moldova, 1,666 tonnes in Bulgaria and 1,228 tonnes in Romania (plus other contributions not presented in Table 4.12). Where there is a high contribution associated with a specific sector there are two, interacting, explanations: a) a high overall expenditure on this sector by Scottish consumers; and/or b) a high relative reliance on the commodity of interest (somewhere along the supply chain) in the manufacture of products (and/or delivery of services) in this sector.

[49] Equivalent tomato and potato data is available in the supplementary MS Excel spreadsheets.
[50] See ‘Sector level by country of production/impact’ in Table 3.1.

Table 4.12. Top-ten countries by sunflower seed production (tonnes) due to Scottish final demand for global sectors in 2011. Scottish final demand across the different global sectors (i.e. sectors across all regions) can be linked to the country level production required to meet this demand. For each of the top-ten countries of production associated with Scottish final demand for the different global sectors, the following are listed: the associated global sector of final demand; production quantity (IOTA output); and the percentage of total production for Scottish demand that this country and sector combination accounts for.

	Data	Sector of purchase by Scotland consumer	Production quantity to fulfil Scottish demand	% of total production that takes place to meet Scottish demand
	Source		**IOTA**	
	Units		**tonnes**	
Country of production	**Ukraine**	**Food products nec**[51]	11,481	18.11%
	France	**Food products nec**	4,767	7.52%
	Argentina	**Food products nec**	4,477	7.06%
	Ukraine	**Beverages and tobacco products**	2,442	3.85%
	Ukraine	**Vegetable oils and fats**	2,228	3.51%
	Republic of Moldova	**Food products nec**	2,105	3.32%
	Bulgaria	**Food products nec**	1,666	2.63%
	Ukraine	**Trade**	1,586	2.50%
	France	**Beverages and tobacco products**	1,373	2.17%
	Romania	**Food products nec**	1,228	1.94%

Table 4.13 shows sector-level results according to region of purchase[52], i.e. purchases by Scottish consumers from sectors within specific regions and resulting global production (i.e. no information on where this production occurs). For example, Scottish final consumption purchases from sectors located within the UK are associated with the majority of global

[51] 'nec' stands for 'not elsewhere classified', i.e. a group of commodities not classified elsewhere in the data. In this case, 'Food products nec' is a GTAP industrial sector described as: 'Other Food: 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.'

[52] See 'Sector level by region of purchase' in Table 3.1.

production due to Scottish demand. This is unsurprising given that many of the purchases made of processed products within Scotland (e.g. of ‘Food products nec’) are likely to be of final products manufactured within the UK rather than overseas. Scottish purchases within the ‘Vegetable oils and fats’ sector from the Ukraine are likely to be associated with a large amount of Ukrainian sunflower production relative to global production.

Table 4.13. Top-ten regionally-defined sectors of Scottish final demand by required global sunflower seed production (tonnes) in 2011. Scottish final demand for regional sectors (i.e. sectors within a specific region of the IOTA model) can be linked to the global production required to meet this demand. For each of the top-ten regionally-specific sectors driving global production associated with Scottish final demand, the following is listed: associated global production quantity (IOTA output); and the percentage of total production for Scottish demand that demand from this region and sector accounts for.

	Data	Sector of purchase by Scotland consumer[53]	Production quantity to fulfil Scottish demand	% of total production that takes place to meet Scottish demand
	Source		IOTA	
	Units		tonnes	
Region of purchase by Scotland consumer	United Kingdom	Food products nec	23,460	36.99%
	United Kingdom	Beverages and tobacco products	4,783	7.54%
	United Kingdom	Trade	4,179	5.59%
	United Kingdom	Public Administration Defense Education Health	3,699	5.83%
	Ukraine	Vegetable oils and fats	2,168	3.42%
	France	Food products nec	1,375	2.17%
	France	Beverages and tobacco products	1,056	1.67%
	United Kingdom	Construction	806	1.27%
	Spain	Food products nec	731	1.15%
	United Kingdom	Vegetable oils and fats	726	1.14%

[53] High production of commodities may be driven by demand for non-food-related sectors in cases where there is high overall expenditure on these sectors, and/or where there is a relatively high level of *embedded* commodity along the sector’s supply chain. The appearance of ‘Construction’ in this list, for example, is likely particularly indicative of the former, i.e. high overall expenditure.

5 Discussion

The MFA for Scotland compiled in Phase 1 of this project presented a time-series based 'mass-balance' overview of biomass production, imports and exports. However, reliance on Regional Trade Statistics to estimate trade flows into Scotland resulted in a lack of *intra-UK* trade data which therefore underestimated import and export movements within this MFA dataset. Although country-level information is present in the trade statistics on which MFA approaches rely, this data only includes point of dispatch information for products rather than point of origin. Furthermore, the MFA contains trade information based usually on the mass of the imported – often derived – product which is not representative of the mass of the primary biomass commodities used in the manufacturing process.

The methods and results presented above demonstrate the potential of the IOTA modelling approach to overcome these limitations. HMRC import data (on which the Scottish MFA is based) contain information sufficient to allow *some* (but not all) of the derived products that may be associated with raw commodities to be identified. However, information is only provided on a discrete stage in the supply chain (i.e. the trade of a product between one country and another, with no information or prior processing or subsequent use of the product), whereas the IOTA approach represents the complete economic and trade system. Consequently, the IOTA model ensures that all raw commodity production that is associated with upstream components of a product's supply chain is included. As a result, according to the IOTA results (see Table 4.1), UK (and by inference, Scottish) reliance on commodities such as maize, sugarcane and oil palm fruit is much higher than associated HMRC and FAO statistics would suggest. Furthermore, with its inclusion of physical production information, the IOTA approach ensures that production locations are identified. HMRC data, for example, only reveals that the Netherlands is a major exporter of sunflower seed-based products, whereas IOTA reveals that none of the production of the sunflower seeds (and associated impacts) actually occurs in this country[54].

The ability to pinpoint the country of production also allows extension of the data to include factors associated with localised environmental impacts in a way that is not possible with alternative data sources/methods. Here, it has been demonstrated that land, water and fertiliser use information (as described in Appendix 3) can readily be connected to the model. Theoretically, any information (environmental or socio-economic) that can be associated with the production of the commodities under investigation can be integrated into the model to assess potential impacts associated with production.

As discussed in the report from Phase 1, HMRC trade statistics do not provide estimates of *raw material equivalents* i.e. the mass of raw materials that are embedded in processed and derived products. As an example, whilst HMRC data contains detailed information at a product level which allows identification of the mass of 'tomato sauce' traded, this does not provide information on the mass of *tomatoes* (either embedded upstream in the supply chain, or physically contained) in this sauce. Because IOTA contains information on the mass of commodities produced, and represents the complete international supply chain system, it is able to identify the raw materials embedded within Scottish consumption. However, as a trade-off, the resolution of final demand categories is low (e.g. 'Tomato sauce' would be contained within the broader 'Food products nec' classification) in comparison with the more detailed product classifications available in, for example, HMRC statistics.

Whilst, as demonstrated in comparison with MFAs, there are several key advantages of adopting an IOTA-based approach to assess Scottish consumption impacts, there are also

[54] Instead, flows that occur via the Netherlands are pinpointed to the associated country of production.

limitations. Firstly, the data used to produce the MFA is based largely on official government statistics which are regularly updated, allowing time-series information to be compiled relatively quickly in comparison with IOTA (although see recommendations in Section 6.2). Furthermore, whereas data across all types of biomass consumption is readily available for compilation into MFA frameworks, within IOTA– to date – focus has been on the analysis of a limited number of commodities. Whilst these tend to be key commodities in terms of importance to UK and world economies and global agricultural production, they are not representative of all biomass consumed in Scotland. Inclusion of additional commodities, although perfectly possible, is a more time consuming process in comparison to MFA compilation due to the relative complexity of the IOTA model. Additionally, there are assumptions that must be understood when applying and interpreting an IOTA approach which are described in more detail below.

Aspects of MFA and IOTA-based approaches therefore may be seen as complementary to some extent. The MFA provided in Phase 1 contains readily-updateable detailed Scotland-specific production information[55] and some relatively aggregated trade information within a consistent annual time-series (although the lack of intra-UK trade data is a major limitation to the value of this trade data within the Scottish MFA), whilst IOTA provides detail on the potential location of production destined for Scottish consumption, and ensures that all *embedded* supply chains are considered.

5.1 Model assumptions and updatability

5.1.1 Model and data assumptions

Because the methods described in this work are based on GTAP-derived IO tables which include the entire UK as a regional unit, it was necessary to ‘downscale' the final demand components of the MRIO data from the UK to the Scottish level in order to capture production and impacts associated with Scottish demand. This was done by concording data on the relative levels of Scottish and UK expenditure to the relevant GTAP sectors of final demand, providing an estimate of Scottish final demand expenditure. This approach does not make any estimations of, or assumption about, Scottish domestic production (and associated impacts). Instead, whilst consumption and demand is downscaled from the UK to Scottish levels, production and associated impacts are an aggregated component of those for the UK as a whole, i.e. UK based impacts due to Scottish demand are not disaggregated. This approach, and the resultant lack of Scottish specific production and impact information within the model results, are a consequence of a lack of appropriate data at the Scottish level (i.e. currently, Scottish specific trade information is not sufficient to use within an MRIO framework such as IOTA).

An implicit assumption within the IOTA model is that Scottish imports (and exports) of different final and intermediate goods follow the same supply and trade patterns as those for the rest of the UK. Whilst this is perhaps not likely to hold for all products, it is an unavoidable assumption in the absence of further data on trade explicitly to Scotland. If more detailed Scottish-specific data is produced in the future, then the general methodological approach adopted here may be adapted to incorporate this data (i.e. adoption of the IOTA methodology does not preclude integration of enhanced datasets in the future).

Another implicit assumption due to the use of the GTAP8 database (the most recent GTAP release available) stems from the fact that the underlying financial data within the IOTA model is from 2007. This means that the relative transactions between different sectors (within and between different regions) within the economy remain the same, i.e. the supply

[55] Domestic production is UK-based in IOTA and reliance on Scottish production cannot currently be estimated within this framework.

chains and trade patterns occur as for 2007. As discussed in the Section 3 (Method), this is partly remedied by hybridisation of financial data with more recent[56] physical commodity production and trade data associated with producing countries. Whilst this does update physical quantities of production (and associated impacts) and initial trade of raw commodities to 2011 levels, it does still leave financial supply chain elements of the model structure based on the 2007 data. Attempts to scale the financial data to account for inflation and economic growth/contraction would not actually alter the *model structure* (i.e. supply chains linkages and manufacturing efficiencies remain the same) nor, therefore, the resultant model outputs (i.e. the quantity of production associated with Scottish final demand). Therefore financial scaling has not been undertaken for this study[57]. Any attempts to alter the financial model structure would essentially require the construction of a new MRIO dataset which is a non-trivial and time consuming process (as reflected by the release of GTAP data only approximately every four years).

MRIO datasets in general have a reliance on empirical statistics from a variety of sources. The datasets are typically compiled from national statistics and survey data, with estimates across countries and sectors often extrapolated from available information. Consequently, core data used in the construction of the IO tables have an inherent level of uncertainty (which will vary depending on the quality of the source statistics). Different countries and sectors will be more or less reliable than others (depending on, for example, the resources available for reporting, data sensitivity *etc*.), and provide different quantities and classifications/aggregations of data within their reports. There is, however, a general trend towards better data collation and dissemination in both developed and developing countries, and the compilation of data for use in IO tables within National Accounts is becoming increasingly common. As a result, data quality and availability should continue to improve for the foreseeable future.

Other assumptions and limitations associated with the compilation and application of MRIO datasets and models are documented and discussed within West *et al* 2013. Whilst these limitations are important to understand when implementing MRIO tables and interpreting results, MRIO tables and models provide information which cannot be replicated as efficiently by other methods and are therefore an incredibly useful tool in the analysis of international supply chains.

The hybridisation of the physical and financial data requires the distribution of physical production and trade data across sectors within the MRIO model. The derived physical data used within the model provides the domestic supply of a commodity within each country (i.e. production plus imports, minus exports) along with information on the country of origin. However, due to the nature of the available trade data, it only contains information at the country level and not at an industrial sector level. Consequently, once the countries within the physical data have been concorded to the regions within the MRIO, assumptions are necessary to further distribute the raw commodity across the sectors within each region. Within this application of the model, this is achieved by using the relative levels of expenditure by sectors on products of the producing sector. For example, United States imports of Brazilian soya bean are distributed across US sectors according to their relative levels of expenditure on the Brazilian 'Oilseed' sector (the producing sector of soya bean). Whilst this is a logical approach, it means that commodities are distributed into the initial stages of supply chains according to the (relatively) highly aggregated financial data. This can be partially remedied by the use of further data to control the initial distribution of commodities within economies (see section 5.2 for more details).

[56] Total per-country production levels for each of the studied commodities therefore use 2011 values, and so local and global quantities of production are accurate for 2011.
[57] If production per monetary unit of final demand was required as an output, scaling of financial data would be required.

5.1.2 Updatability of model and data

Physical data for production and trade of commodities is regularly updated and released by FAO. For each year for which data is available (both historically, and into the future), the model can use this data as the input for physical production and the initial physical trade distribution of the chosen commodity. Similarly, land use data from FAO is available on an annual basis. Water and fertiliser use data are less frequently updated due to the greater complexity involved with their collection and estimation. The Water Footprint Network data used within this work for water use associated with crop production is based on a ten year average calculated from 1996-2005[58]. Similarly, the FAO Fertistat database used to provide the fertiliser use statistics (see supplementary MS Excel spreadsheets) draw data from 1989-2005 to provide as much coverage (geographically and across commodities) as possible. In each case, whenever more up to date data becomes available, it can be relatively easily incorporated into the model (assuming the same or similar data formats are retained) to update results.

The GTAP database used to derive the underlying financial model is updated approximately every three to four years, with the latest data representing the economy three to four years prior to release (i.e. the next update due in 2014 or 2015 will include data for 2010 or 2011). In this respect, the GTAP data is never fully “up to date”, and the assumptions pertaining to a reliance on an older economic structure will always exist when trying to capture impacts relating to more recent consumption and production. However, future utilisation of the upcoming 2010/11 dataset would not only provide a more recent snapshot of the world economy and its structure than the older 2007 dataset, but also would likely be more relevant and reliable for estimations of recent economic activity as it should reflect the economy post-2008 global financial crisis.

In previous successive GTAP releases, classifications and region listings have been adjusted and updated, meaning that different releases are not directly comparable, and any attempt at comparison requires efforts to concord differences between datasets. However, GTAP8 included an updated version of the previous data release (for 2004) along with the most recent data (2007). The GTAP9 release is expected to include data for 2004 and 2007, as well as the new data for 2010/11. Now that the Scottish IOTA model has been developed, the inclusion within GTAP of multiple datasets, updated for corrections and amendments (as well as with aligned formatting), will allow for time series data to be generated with relatively little effort, with intermediate years estimated in a similar way to what has been done here (i.e. using physical production and trade data for these intermediate years, whilst accepting assumptions about the underlying economic structure).

5.2 Recommendations for future model developments

Additional work on the IOTA model and analysis of trade statistics could be undertaken to increase the comparability of data between the alternative approaches, and the depth of analysis possible. Future work and developments roughly fall under two categories: addressing data uncertainties, and extending the model’s applications and scope.

5.2.1 Addressing data uncertainties

A key limitation of the Regional Trade Statistics data used within the MFA approach is its high level of aggregation relative to UK Overseas Trade Statistics. Within the IOTA approach applied here, UK final demand data was downscaled using data from the ONS Living Costs

[58] It is not clear if, or when, this data will be revised, although various alternative approaches and methods to estimate water use and availability could theoretically be investigated.

and Food Survey. Theoretically, UK import data (from HMRC Overseas Trade Statistics) could be downscaled in a similar manner to estimate imports due to Scottish demand at a higher product resolution. This more highly resolved data would potentially allow for a more direct comparison of import data to commodity results from IOTA. However, such an approach would still not account for intra-UK trade and so would not capture Scottish imports of goods produced within the rest of the UK.

The hybridisation of physical and financial data currently relies on relative levels of sector expenditure to distribute traded raw commodities within the domestic economies. Whilst this is a logical approach in the absence of further data, it does bring with it issues of accuracy due to the levels of sectoral aggregation within MRIO datasets. However, such data is available for certain commodities, allowing for more accurate dissemination of physical data within the financial model of the economy. For example, FAO datasets for commodity balances contain data on the use of commodities for seed, feed, food supply and processing. This information can be utilised to better proportion domestic supply of commodities across the appropriate sectors, meaning the distribution of physical goods data within the financial model can be executed to a higher level of accuracy.

Sensitivity analysis on underlying datasets (for example, by repeated manual or stochastic perturbation of data used within the model) and model assumptions could help determine relative sensitivity of model results on component data sources and methods. Comparisons of results for different methodological approaches would help to isolate the effects of certain aspects of model implementation on output, either to guide best practice or to highlight the relative importance of areas of future development. In terms of time-series implementation (see below), sensitivity analysis could be critical for understanding the effects of different financial data, and thus making the best choices for interpolating between available reference years within the MRIO datasets.

5.2.2 Extending model applications and scope

Ignoring the absence of intra-UK data, the MFA contains an overview of biomass flows for Scotland for which the commodities analysed within IOTA represent a sub-set. Expansion of commodities considered (e.g. across all cereal, oil-seed, vegetable commodities) would facilitate comparison between the datasets of aggregated reliance on total biomass from agriculture. Inclusion of products from forestry and fisheries could also be investigated for comparison against these categories within the MFA.

The IOTA approach could be used to compile time-series information to overcome limitations within the time series data available with the MFA. Whilst the MFA time series data for Scotland does not cover intra-UK trade, an IOTA time series would account for the complete supply chain. Currently, 2004 and 2007 economic data is available within GTAP8 and the forthcoming GTAP9 dataset will add another timestamp for comparison. This economic data could be supplemented by yearly physical production and trade data which is already available from FAOStat. This would require a choice of financial data to use for intermediate years (for example, 2006 could be based on the 2004 or 2007 GTAP database), which could be guided by analysis of alternative existing MRIO datasets which, although not suitable for direct application within the IOTA model, do contain annual time-series data. Such choices could be particularly important for periods surrounding significant economic events such as the 2008 financial crisis.

Although the IOTA model captures the extent of Scottish reliance on embedded agricultural commodities, currently the results give limited information on supply chain pathways. The development of techniques to analyse these pathways would potentially be helpful to determine key intermediate stages and locations of processing, allowing a more detailed and pinpointed assessment of ‘responsibility’ for impact. For example, if analysis highlighted the importance of intermediate demand for paddy rice within the textile industry of China, subsequent case study analysis could help determine the nature of this rice consumption (e.g. for use in worker meals – which may be thought of as 'incidental' demand).

Additional work is required on the environmental extensions currently analysed, and these could also be extended. Work to improve the scope (e.g. by assessing other environmental and socio-economic impacts), relevance of data (e.g. by assessing water scarcity implications as well as water use) and accuracy (e.g. by investigating the availability and inclusion of better fertiliser data) would improve the ability of the IOTA model to identify potential positive and negative impacts associated with production.

The analysis of environmental extensions might also form the basis for exploring biodiversity impacts associated with consumption of biomass, though further work is required to develop a workable method for linking production and biodiversity impacts in the region of origin.

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http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=17829

Appendix 1 – Data used to select commodities

I. Scottish Household Expenditure

The Office for National Statistics (ONS) provides estimates, by region, of average weekly household expenditure which are compiled regularly from the Living Costs and Food Surveys. For Scotland, the top-ten expenditure categories within the 'Food' category, for 2011[59], are shown in Table A1.

Table A1. Top-ten categories within 'Food' classifications, by average weekly household expenditure, within Scotland for 2011. Source: ONS Living Costs and Food Survey 2013.

Food type	Average Weekly Household[60] Expenditure (£)
Other meat and meat preparations	6.40
Bread, rice and cereals	5.20
Buns, cakes, biscuits *etc.*	3.20
Fresh vegetables	3.20
Fresh fruit	2.80
Other food products	2.50
Milk	2.30
Fish and fish products	2.20
Poultry (fresh, chilled or frozen)	2.00
Beef (fresh, chilled or frozen)	1.90

II. Regional Trade Statistics

HMRC provide Overseas Trade Statistics allocated to UK regions to SITC[61] Level 2. As in the Phase 1 study, these exclude imports that may ultimately be consumed in Scotland but are imported via the rest of the UK. For 2011, food imports into Scotland, by mass (largest to smallest) are shown in Table A2.

Table A2. Top-ten food imports into Scotland (at SITC2 classification level), by mass, for 2011. Source: HMRC Regional Trade Statistics.

SITC Category	Mass (tonnes)
08 - Feeding stuff for animals (not inc. unmilled cereals)	1,179,778
04 - Cereals & cereal preparations	282,483
05 - Vegetables & fruit	159,025
06 - Sugar, sugar preparations & honey	137,689
01 - Meat & meat preparations	105,457
03 - Fish, crustaceans, molluscs & aq. inverts & preps thereof	57,259

[59] See ONS Family Spending: http://www.ons.gov.uk/ons/rel/family-spending/family-spending/2013-edition/index.html
[60] The ONS defines a household as 'a person living alone, or a group of people (not necessarily related) living at the same address who have the address as their only or main residence, and either share cooking facilities and share a living room or sitting room or dining area.'
[61] Standard International Trade Classification; a standard classification of goods, maintained by the United Nations, enabling exports and imports to be compared between countries and years.

09 - Miscellaneous edible products & preparations	46,493
02 - Dairy products & birds' eggs	44,722
00 - Live animals other than animals of division 03	38,900
07 - Coffee, tea, cocoa, spices & manufactures thereof	2,333

III. UK Overseas Trade Statistics

Both Household Expenditure data and Regional Trade Statistics reveal the particular importance of feedstuffs (i.e. used for meat/dairy production) and cereals to the Scottish trade economy, but provide this detail at a highly aggregated level. Unfortunately, more detailed information is not available regionally and therefore UK-level information from HMRC has to be relied on to gain additional insight into specifically which goods may be likely to contribute to Scottish-specific imports. Top-ten UK imports by mass for the top four SITC Level 2 groups (above) – for 2011 - are provided in Tables A3 to A6.

Table A3. Top-ten imports into the UK (at SITC5 classification level) within SITC2 level group '08 - Feeding stuff for animals (not inc. unmilled cereals)', by mass, for 2011. Source: HMRC Overseas Trade Statistics.

SITC Category	**Mass (tonnes)**
081.31 - Oil-cake & solid residues resulting from the ext of fats or oils: of soya beans	1,909,587
081.99 - Preparations of a kind used for animal food, nes	1,012,449
081.19 - Veg residues & by-pdt, veg mat & waste, whether or not in pellet form, of a kind used for animal food, nes	542,308
081.38 - Oil-cake & solid residues resulting from the ext of fats or oils: of palm nuts or kernels	463,151
081.53 - Brewing or distilling dregs and waste	397,582
081.95 - Dog or cat food, put up for retail sale	390,777
081.35 - Oil-cake & solid residues resulting from the ext of fats or oils: of sunflower seeds	321,454
081.39 - Oil-cake & solid residues resulting from the ext of fats or oils: other	285,525
081.52 - Beet-pulp, bagasse and other waste of sugar manufacture	144,300
081.36 - Oil-cake & solid residues resulting from the ext of fats or oils: of rape or colza seeds	142,662

Table A4. Top-ten imports into the UK (at SITC5 classification level) within SITC2 level group '04 - Cereals & cereal preparations', by mass, for 2011. Source: HMRC Overseas Trade Statistics.

SITC Category	**Mass (tonnes)**
044.90 - Maize (not including sweet corn), unmilled, other than seed	953,685
041.20 - Other wheat (including spelt) and meslin, unmilled	901,842
048.49 - Bakers products, inc bread, pastry, rice paper, crispbread, biscuits, waffles, wafers *etc*, nes	456,803
042.20 - Rice husked but not further prepared (cargo rice or brown rice)	296,383
042.31 - Rice, semi-milled or wholly milled, whether or not polished, glazed, parboiled or converted (exc broken rice)	231,134
048.30 - Macaroni, spaghetti & similar pdt(pasta) uncooked, not stuffed or o/w prd, couscous, whether or not prepared.	139,326
043.0 - Barley, unmilled	128,810
048.42 - Sweet biscuits, waffles and wafers, gingerbread and the like	123,610
042.32 - Broken rice	104,686
048.11 - Prepared foods obtained by the swelling or roasting of cereals or cereal products (eg corn flakes)	89,407

Table A5. Top-ten imports into the UK (at SITC5 classification level) within SITC2 level group '05 - Vegetables & fruit', by mass, for 2011. Source: HMRC Overseas Trade Statistics.

SITC Category	**Mass (tonnes)**
057.30 - Bananas (including plantains), fresh or dried	1,054,414
056.61 - Potatoes prepared or preserved otherwise than by vinegar or acetic acid, frozen	476,385
057.40 - Apples, fresh	459,222
054.59 - Other vegetables, fresh or chilled, nes	434,041
059.10 - Orange juice	429,931
054.40 - Tomatoes, fresh or chilled	414,541
054.51 - Onions and shallots, fresh or chilled	362,208
054.69 - Veg & mixtures of veg o/t sweetcorn (uncooked or cooked by steaming or boiling in water), frozen, nes	333,510
056.72 - Tomatoes prepared or preserved otherwise than by vinegar or acetic acid, whole or in pieces	290,394
057.11 - Oranges, fresh or dried	284,770

Table A6. Top-ten imports into the UK (at SITC5 classification level) within SITC2 level group '06 - Sugar, sugar preparations & honey', by mass, for 2011. Source: HMRC Overseas Trade Statistics.

SITC Category	Mass (tonnes)
061.11 - Cane sugar, raw, in solid form, not containing added flavouring or colouring matter	881,078
061.51 - Cane molasses resulting from the extraction or refining of sugar	462,044
061.93 - Glucose (dextrose) and glucose syrup, not ctg fructose or ctg, in the dry state, <20% by wgt of fructose	287,685
061.29 - Beet or cane sugar and chemically pure sucrose in solid form, nes	243,075
061.12 - Beet sugar, raw, in solid form, not containing added flavouring or colouring matter	186,271
062.29 - Sugar confectionery, nes	151,890
061.59 - Beet sugar molasses and other molasses (eg corn molasses) resulting from the ext or refining of sugar	114,474
061.94 - Glucose and glucose syrup, ctg, in the dry state, at least 20% but not more than 50% by weight of fructose	76,296
061.99 - Other sugars (inc invert sugar), syrups and sugar products of heading 061.90, nes	39,676

Appendix 2 – Information on the environmental extensions used within this study

Within this project, the same environmental extension data has been used as in the Defra project, which can readily be linked to the country location and commodity data within the IOTA model. Land use information has been updated to 2011 (to align with the commodity production information – also from 2011), but datasets on water use and fertiliser use have not been updated since the Defra report was published, and therefore remain unchanged. In addition to the fact that a minimal level of additional data manipulation is necessary to link it to the IOTA model, these data were initially chosen because of the clear links between these extensions and the drivers of biodiversity impacts by agriculture which include habitat change (land use and water use) and pollution (fertiliser use). Additional information on the integration of environmental extensions is available within the Defra report[62].

I. Land use

Within the FAOSTAT database, in addition to information on units of production for primary agricultural commodities, there also exists associated yield and land area data, which is compiled mainly from government and agency provided national statistics, and via FAO questionnaires. This data is available on an annual basis, with the most recent data available for 2012. The 2011 data was used within this report to match the date of the most recent physical trade information available from FAOSTAT. Yield information can be multiplied by the quantities required for consumption (calculated from the IOTA model) to estimate the land area required within a country to fulfil final demand. This is subject to the assumption that all production takes places according to the national average value provided by FAOSTAT.

Figures provided within FAOSTAT for annual crop products refer to harvested areas, whereas permanent crop figures may also refer to the total planted area, with FAO acknowledging that for some permanent crops, yield data is less reliable due to the reliance on planted areas (and the scarcity of data for some permanent crops in some countries; e.g. cocoa and coffee).

For cereals, area and production data refers to crops harvested for dry grain and therefore excludes any production for hay or silage. Some countries report for sown or cultivated areas, rather than those areas that are eventually harvested. In such cases, data may therefore overstate the actual area used for eventual commodity production, although FAO deem the difference between these figures and estimates of harvested areas to be small.

For vegetable commodities, area and production data relates mainly to that grown for consumption by humans and anything grown explicitly for animal feed is excluded. For some countries, estimates for vegetables are unavailable, and generally estimates refer to crops grown in the field or market gardens (and therefore exclude kitchen garden production for household consumption). Where countries do not provide official data, estimates may be made by FAO. Although kitchen garden production may be an important part of total production in some countries, within the context of the IOTA model – which analyses impacts associated with trade and supply chains – we expect utilised commodities to be associated with larger production systems where data is more likely to be reported.

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62 http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=17829

For fruit, area and production data refer to the production of fresh fruit, whether for food, feed or processing. Fruit statistics are unavailable for many countries, and generally refer to plantation crops or orchard crops grown for sale. FAO believe the statistics available therefore give a reliable indication of the influence of these crops within international trade.

Statistics for bananas refer to all edible fruits of the genus *Musa* except *Musa paradisiaca* (plantain). However, several countries do not make a distinction between bananas and plantains and therefore only publish overall estimates. Where this occurs, but there is an indication that data refer mainly to bananas, this data is included; no countries with excluded data are significant exporters. Some countries report statistics in terms of bunches as opposed to weight (which means that the stalk will be included in estimates of weight) which must be taken into account when making comparisons between countries.

It should be noted that if a crop is harvested more than once during the year due to successive cropping (i.e. the same crop is planted or sown more than once per year on the same piece of land) then the area is counted as many times as the crop is harvested. If harvest occurs successively from the same standing crop, then the harvested area is reported only once.

II. Water use

Data on water use associated with production of crops is sourced from the Water Footprint Network's WaterStat database (http://www.waterfootprint.org/?page=files/WaterStat) which quantifies water consumption (a 'water footprint') associated with averaged spatially explicit global crop production between 1996 and 2005, expressed in terms of cubic metres of water per tonne of crop production. This water data is produced using a dynamic weather model which takes into account daily soil water balances and climate within 5 by 5 arc minute grid cells. Water pollution is associated with the use of nitrogen fertiliser in production, and is also estimated for each grid cell. This data is also available for larger geographic areas, e.g. estimates of water use at country level are provided, which can then be used within the IOTA model.

Data for Blue, Green and Grey Water footprints are available. The Blue Water footprint refers to the volume of surface and/or groundwater consumed in production of a commodity (i.e. for agricultural commodities this refers to water used for irrigation), and Green Water refers to rainwater consumed. Grey Water refers to the volume of freshwater required to assimilate pollutant loads (currently nitrogen loads only) created by production, which is also based upon ambient water quality standards (and may therefore vary between countries).

The WaterStat database contains information for most crop types present within FAOSTAT, although some gaps exist at the country level, i.e. data is available for some countries but not others.

III. Fertiliser use

Due to its inclusion of nitrogen loads, the Grey Water footprint is a proxy for nitrogen pollution from fertilisers. However, FAO provide, within their FertiStat database, survey-based fertiliser data on country-average nitrogen (N), phosphorus (P) and potassium (K) fertiliser application rates per unit area, which can therefore be linked to land area information resulting from IOTA. Data is available for some individual crops (e.g. wheat, rice, soya bean) but in many cases it is only available for crop groups. For example, data for 'Tomatoes' is not available and therefore the 'Vegetables' group is used as a proxy in this study. Coverage of individual commodities between countries is variable – but is subject to several gaps – and many statistics date back as far as 1995, with most recent data from

2003/2004. Because the source year is variable between data points, we display the source year information in data outputs for fertiliser use.

Appendix 3 – Detailed HMRC and FAO data

More detailed FAO and HMRC data are shown in Table A7. Totals associated with each commodity are used in Table 4.1.

Table A7. HMRC import and FAO production data for raw and derived products, with associated IOTA commodities (tonnes). Totals for HMRC and FAO data are those used in Table 4.1.

IOTA Commodity	HMRC Imported Commodities	HMRC Totals	FAO Product Descriptions	FAO Totals
Wheat	081.26 - Bran, sharps & other residues, whether or not in pellet form, derived from sifting, milling or wkg of wheat	98,517	Wheat and products	14,193,134
	041.20 - Other wheat (including spelt) and meslin, unmilled	862,408		
	046.10 - Flour of wheat or meslin	65,862		
	041.10 - Durum wheat, unmilled	39,435		
	046.20 - Groats and meal of wheat	2,903		
Paddy Rice	042.10 - Rice in the husk (paddy or rough rice)	10,645	Rice (Paddy Equivalent)	683,664
	042.20 - Rice husked but not further prepared (cargo rice or brown rice)	296,383		
	042.31 - Rice, semi-milled or wholly milled, whether or not polished, glazed, parboiled or converted (exc broken rice)	231,134	Rice (Milled Equivalent)	456,004
	042.32 - Broken rice	104,686		
Maize	081.24 - Bran, sharps & residues, whether or not in pellet form, derived from sifting, milling or wkg of maize (corn)	19,043	Maize and products	1,095,924
	044.90 - Maize (not including sweet corn), unmilled, other than seed	953,685		
	047.11 - Maize (corn) flour	47,043		
	047.21 - Groats and meal of maize (corn)	22,934		
	044.10 - Maize seed, unmilled	11,481		
	421.69 - Refined maize (corn) oil and its fractions	4,130	Maize Germ Oil	26,046
	421.61 - Crude maize (corn) oil	599		

IOTA Commodity	HMRC Imported Commodities	HMRC Totals	FAO Product Descriptions	FAO Totals
Potatoes	056.61 - Potatoes prepared or preserved otherwise than by vinegar or acetic acid, frozen	476,385	Potatoes and products	7,468,132
	054.10 - Potatoes, fresh or chilled (not including sweet potatoes)	267,871		
	056.76 - Potatoes prepared or preserved otherwise than by vinegar or acetic acid, not frozen	50,100		
	056.42 - Flakes, granules and pellets of potatoes	22,893		
	056.41 - Flour and meal of potatoes	19,449		
Sugarcane	061.11 - Cane sugar, raw, in solid form, not containing added flavouring or colouring matter	881,078	Sugar Cane	51
	061.51 - Cane molasses resulting from the extraction or refining of sugar	462,044		
Soya beans	098.41 - Soya sauce	19,575	Soya beans	904,651
	081.31 - Oil-cake & solid residues resulting from the ext of fats or oils: of soya beans	1,909,587	Soya bean Cake	2,347,356
	421.19 - Refined soya bean oil and its fractions	78,229	Soya bean Oil	219,804
	421.11 - Crude soya bean oil, whether or not degummed	55,649		
	222.20 - Soya beans used for the extraction of 'soft' fixed vegetable oils (exc flours and meals)	772,278		
Oil Palm Fruit	081.38 - Oil-cake & solid residues resulting from the ext of fats or oils: of palm nuts or kernels	463,151	Palm kernel Cake	644,781
	422.21 - Crude palm oil	300,000	Palm Oil	638,239
	422.29 - Refined palm oil and its fractions	95,515		
	422.41 - Crude palm kernel or babassu oil	33,962	Palm kernel Oil	62,286
	422.49 - Refined palm kernel or babassu oil and their fractions	18,150		

IOTA Commodity	HMRC Imported Commodities	HMRC Totals	FAO Product Descriptions	FAO Totals
Sunflower Seed	421.51 - Crude sunflower seed or safflower oil	155,417		
	421.59 - Refined sunflower seed or safflower oil and fractions thereof	102,875	Sunflower seed Oil	283,651
	222.40 - Sunflower seeds used for the extraction of 'soft' fixed vegetable oils (exc flours and meals)	66,275	Sunflower seed	70,679
	081.35 - Oil-cake & solid residues resulting from the ext of fats or oils: of sunflower seeds	321,454	Sunflower seed Cake	541,913
Tomatoes	054.40 - Tomatoes, fresh or chilled	414,541	Tomatoes and products	1,245,280
	056.72 - Tomatoes prepared or preserved otherwise than by vinegar or acetic acid, whole or in pieces	311,674		
	056.73 - Tomatoes prepared or preserved otherwise than by vinegar or acetic acid, nes	164,298		
	059.92 - Tomato juice	6,866		
	098.42 - Tomato ketchup and other tomato sauces	174,653		
Bananas	057.30 - Bananas (including plantains), fresh or dried	1,054,414	Bananas	888,368