**Global environmental and social spillover effects of EU’s food trade**

# SUPPLEMENTARY INFORMATION

Arunima Malik1,2\*, Guillaume Lafortune3, Salma Dahir3, Zachary A. Wendling3, Christian Kroll4, Sarah Carter5, Mengyu Li1, Manfred Lenzen1

*1ISA, School of Physics, The University of Sydney, NSW, Australia*

*2Discipline of Accounting, Sydney Business School, The University of Sydney, NSW, Australia*

*3Sustainable Development Solutions Network (SDSN), Paris Office, France*

*4IU International University of Applied Sciences, Germany*

*5Thermal Ergonomics Laboratory, Sydney School of Health Sciences, Faculty of Medicine and Health, NSW, Australia*

\*Corresponding author: Dr Arunima Malik, arunima.malik@sydney.edu.au, +61 2 9351 5451

# Mathematical formulation – measuring spillovers

The starting point for quantification of spillover effects is a set of MRIO matrices – inter­mediate demand (**T**), final demand (**Y**) and value-added (**v**). These are monetary matrices that are based on data collected by statistical agencies. For example, each country has their own statistical agency. In Australia, the Australian Bureau of Statistics produces and makes available input-output tables for further use by government, academia and industry (ABS, 2019). An explanation of the fundamentals for input-output analysis are explained in detail elsewhere (Miller & Blair, 2010). Here we briefly explain the three key matrices that feature in MRIO databases:

The intermediate demand matrix captures intra-industry and inter-industry transactions between regions; the value-added matrix contains information on primary inputs needed for the production of goods and services (e.g., labour input); and the final demand matrix captures expenses related to the final consumption of goods and services. The **T** and **Y** matrices of a MRIO database harbour data on imports and exports by region and sector, for example if any of the EU member states import food from an Asian economy for further processing, then this transaction is captured in the **T** matrix; and final consumption of a processed food item imported from the USA is captured directly in the **Y** matrix. MRIO databases there­fore capture supply chains that originate in the RoW and feed into supply chains in the EU, before finally ending up with final consumers in the EU; and also supply chains that originate and form part of further processing in the RoW and end up in the EU. The MRIO database used for this study is obtained from (Lenzen et al., 2021).

Input-output calculations proceed by calculating the total output **x** of an MRIO database by using row summation operators (i.e., summing all elements in a row to obtain a column vector): , where is the row summation operator for the matrix **T**, and the row summation operator for matrix **y**. Next, the direct coefficients matrix **A** (inputs needed to produce 1$ of output of a sector) is calculated using , where is the inverse of the diagonal total output vector **x**. We integrate a new matrix – **Q** (physical ac­counts) – with the economic input system. This matrix is essential for featuring data on environmental, social and economic indicators into an economic dataset. Each row of the **Q** matrix holds data on a specific indicator. This study features data on seven distinct indicators: carbon dioxide (CO2), sulphur dioxide (SO2), nitrous oxide (NOX), particulate matter (PM), land, employment, and income, taken from the Hotspot Analysis Tool for Sustainable Consumption and Production (SCP-HAT (2021)). Further details on the construction of these indicators are provided in the “Measuring Spillovers” section of the article.

The direct intensities matrix **q** (impacts per dollar of output **x**) is calculated as: . The power of input-output analysis lies in the ability to capture all upstream supply chains using a total requirements matrix . The matrix **L** can be used to calculate the total intensities . The total intensities hold information on both the direct and indirect impacts (e.g., in kg CO2e) em­bodied in 1$ of final demand/final consumption of a commodity. The impacts embodied in the food products bought by the EU can be calculated by taking the final demand of crops, livestock, aquaculture, meat and fish products, cereal-based products, food crop products, cocoa, chocolate, sugar, oil and fats, dairy products, alcoholic and other bever­ages and tobacco products by each of the 27 EU member states. This specific final demand vectors for each EU country can be post-multiplied by the total intensities to calculate consumption-based footprints as , where⊗ denotes element-wise multiplication or impacts according to last point of sale and final consumption; and as impacts from producing region/sector to final consumption.We calculate both domestic impacts (i.e., impacts that happen within EU, or between EU coun­tries) or spillover effects (i.e., impacts that take place outside of EU’s borders).

A list of sectors considered in the assessment are mentioned below:

Growing Wheat

Growing Maize

Growing cereals n.e.c

Growing leguminous crops and oil seeds

growing rice (paddy)

Growing of vegetables melons, roots, tubers, non-perennial fruits

Growing of sugar cane

Growing of tobacco

Growing of fibre crops

Growing of non-perennial crops n.e.c.

Growing of grapes

Growing of perennial /tree fruits

Growing of beverage crops

Growing of spices, aromatic, drug, and pharmaceutical crops

Growing perennial crops n.e.c. and plant propagation

Raising of ruminant animals

Raising of swine/pigs

Raising of poultry

Raising of animals n.e.c. - support for animal production - mixed farming - Hunting gathering and related services

Post-harvest and support activities for crop production

Wood production

Wood production related services

Wild fish capture

Aquaculture

Hard coal production

Lignite and peat production

Extraction of petroleum

Extraction of natural gas

Ferrous ores extraction

Mining of uranium ores

Mining of Aluminium ore

Mining of copper dominated ores

Mining of gold dominated ores

Mining of lead/zinc/silver dominated ores

Mining of nickel dominated ores

Mining of tin dominated ores

Mining of other non-ferrous ores n.e.c.

Quarrying of stone, sand and clay

Mining of chemical and fertilizer minerals

Extraction of salt

Mining and quarrying n.e.c. and support for petroleum natural gas and mining

Processing, preserving, and manufacture of meat and fish-based products

Processing and manufacture of cereal based products

Processing, preserving, and manufacture of food crop products n.e.c - mixed food and feeds n.e.c

Sugar refining and Manufacture of cocoa, chocolate, and sugar confectionery

Processing and manufacture of fibre-based products and hide (natural or other) based products

Manufacture of vegetable and animal oils and fats

Manufacture of dairy products

Manufacture of Alcoholic and other beverages

Manufacture of tobacco products

Sawmilling and planning of wood - Wood based manufacturing excl. pulp and paper

Wood pulp and paper production and printing

Manufacture of coke oven products

Manufacture of refined petroleum products

Manufacture of nitrogenous fertilizers

Manufacture of non-nitrogenous and mixed fertilizers

Manufacture of basic petrochemical products n.e.c.

Manufacture of basic inorganic chemicals n.e.c.

Manufacture of pharmaceuticals, medicinal chemical and botanical products

Manufacture of rubber and plastic products n.e.c.

Manufacture of clay building materials

Manufacture of other ceramics n.e.c.

Manufacture of cement, lime and plaster and articles made there-of

Manufacture of other non-metallic mineral products n.e.c.

Manufacture and casting of basic iron and steel

Manufacture and casting of basic Aluminium

Manufacture and casting of basic Copper

Manufacture and casting of basic Gold

Manufacture and casting of basic Lead/Zinc/Silver

Manufacture and casting of basic nickel

Manufacture and casting of basic tin

Manufacture of basic non-ferrous metals n.e.c.

Manufacturing of fabricated metal products, machinery and transport equipment n.e.c., and repair and installation of machinery and equipment

Manufacture of computer, electronic, and optical products

Manufacture of electrical equipment including metal wiring and cables

Manufacture of motor vehicles, trailers, and semi-trailers

Manufacture of furniture and other manufacturing n.e.c

Electric power generation, transmission, and distribution

Manufacture of gas; distribution of gaseous fuels through mains

Water collection, treatment and supply, Sewerage, and Steam and air conditioning supply

Waste collection, treatment, and disposal

Materials recovery

Construction of all buildings

Construction of roads and railways, utilities, and other civ. engineering inc. demolition and site preparation

All Wholesale and retail trade, plus repair of motor vehicles and motorcycles

Land transport and transport except via pipelines

Transport via pipeline and n.e.c, Warehousing, and support activities for transportation

Water transport

Air transport

Accommodation and food service activities

Publishing activities, Telecommunications, Information, and communication n.e.c.

Financial, Insurance, and Real estate activities

Professional, scientific, and technical activities

Public administration, Social security, Defence and public order, and Administrative and support service activities n.e.c.

Education

Human health and social work activities

Arts, entertainment and recreation, Repair of computers, personal and household goods, and Other service activities n.e.c.

**Figure S1 Environmental impacts embodied in the final demand of key agricultural and food manufacturing commodities**. The values shown in the bar graphs capture all direct and indirect supply chain impacts for the final demand of food, e, g., energy, fuel, and transportation-related carbon dioxide emissions embodied in ‘Meat and Fish product’ manufacturing are captured in the bar for this category.

****

**Figure S2 Trends in consumption-based impacts, both domestic and imports.** Impacts taking place outside of the EU (from imports, excluding exports) are called ‘Spillovers’ in this study.

**Table S1 Comparison of per-capita spillover effects for the European Union with two economies (USA and Russia) across all seven indicators.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Region/Country | Carbon dioxide(Kg per capita) | Sulphur dioxide(Kg per capita) | Nitrous oxide(Kg per capita) | Particulate Matter(Kg per capita) | Land(ha per capita) | Employment(people per capita) | Income(USD per capita) |
| European Union | 168 | 0.5 | 0.6 | 0.3 | 0.2 | 0.04  | 156 |
| United States of America | 63 | 0.2 | 0.3 | 0.1 | 0.1 | 0.02 | 107 |
| Russia | 31 | 0.1 | 0.1 | 0.04 | 0.06 | 0.01 | 47 |





**Figure S3. Contribution of 27 European Union Member states to international spillover effects. The numbers reflect percentages for the role of EU states in driving spillover effects in countries outside of the EU, calculated using the total footprints of the EU for various indicators.** (Source: Authors’ illustration).

**Table S2 An overview of intra-EU trade – an example of two key EU member states for selected commodities (ATLAS, 2021)**

|  |  |
| --- | --- |
| EU member state | Imports (intra-EU trade) |
| Germany | Avocadoes (Spain); Grapes (Italy); Onions and shallots (Netherlands); Peaches and nectarines (Spain); Tomatoes (Belgium); Carrots and turnips (Belgium);  |
| France | Apples (Italy); Apricots (Spain); Bananas and plantains (Netherlands); Barley (France); Cherries (Austria); Cocoa (France) |

**Box S1. The Four Pillar Framework for food companies’ alignment with the SDGs**

The Four Pillar Framework published by SDSN and partners emphasizes the importance of four major pillars to monitor and address negative environmental (and social) impacts of food companies:

1. Pillar 1 highlights the impact of a **company’s products**, services, and strategies on human wellbeing and the planet’s sustainability. For the food processing companies, this Pillar helps bring into focus the contributions to healthy and sustainable dietary patterns through their products and strategies. This includes whether food products are healthful, whether product marketing promotes health, and whether product use is conducive to well-being and supportive of improved living standards
2. Pillar 2 includes the environmental and social impacts of **business operations** and the responsibility of companies to respect human rights, which improves the livelihoods of communities, workers, producers, and their families.
3. Pillar 3 highlights the company’s role in and responsibility to drive sustainable development across its **value chain**, including suppliers, producers, clients, and other business relationships, and in the broader ecosystems of which it is part. This Pillar focuses on company activities to support the realization of the SDGs through interactions with these actors, and collaboration to promote, incentivize, and ensure more sustainable practices and better livelihoods within its own value chain as well as within the relevant industries, sectors, and communities that its operations and business relationships influence.
4. Pillar 4 brings into focus how companies are governed and how they engage with the systems and rules that govern them. **Good corporate citizenship** is the foundation for the holistic changes in corporate practices needed to align with the SDGs. This pillar highlights company strategies that contribute to or diminish social goods or societal well-being, and activities that support or undermine the crafting and effective deployment of law and policy that advances sustainable development. It considers company engagement in responsible tax and litigation practices, and the extent to which corporate governance and management systems are geared towards incentivizing SDG-aligned conduct.

Figure B1. The four-pillar framework for agri-food companies’ alignment with the SDGs



Source: Sachs J. et al., 2021. “Fixing the Business of Food 2021: Aligning food company practices with the SDGs”, Barilla Center for Food & Nutrition, UN Sustainable Development Solutions Network, Columbia Center on Sustainable Investment, Santa Chiara Lab University of Siena.

**References**

ABS. (2019). *Australian National Accounts: Input-Output Tables* (5209.0). Retrieved from Canberra, Australia:

ATLAS. (2021). *The Atlas of Economic Complexity:* [*http://atlas.cid.harvard.edu/*](http://atlas.cid.harvard.edu/) (Vol. 2021).

Lenzen, M., Geschke, A., West, J., Fry, J., Malik, A., Giljum, S., . . . Schandl, H. (2021). Implementing the Material Footprint to measure progress towards SDGs 8 and 12. *Nature Sustainability, accepted*.

Miller, R. E., & Blair, P. D. (2010). *Input-Output Analysis: Foundations and Extensions*. Englewood Cliffs, NJ, USA: Prentice-Hall.

SCP-HAT. (2021). *Hotspot analysis tool for sustainable consumption and production:* [*http://scp-hat.lifecycleinitiative.org/*](http://scp-hat.lifecycleinitiative.org/).