# JNCC Report 743

# Understanding the Global Environmental Footprint and Impacts of Welsh Consumption

***Project report***

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# Summary

This project aimed to improve understanding of the global environmental footprint and impacts of commodities that are consumed within Wales, but that may be produced anywhere in the world. Understanding this is key to addressing both the climate and nature emergencies, and to meeting the requirements set out in Wales' Well-being of Future Generations Act. In order to answer these questions, several different metrics were calculated, including:

- **The Ecological Footprint** (see Section 2 of the main report for full details)
  - **What is it?** This is an estimate of "the total area of productive land and water ecosystems required to produce the resources that the population consumes and assimilate the waste that it produces, wherever on Earth that land and water may be located."
  - **How was it calculated?** Two separate methods were used, and results for both were presented. Both methods were based on the Global Footprint Network's standardised methodology for calculating an Ecological Footprint. However, the Welsh specific data used to downscale results from a UK perspective to a Welsh perspective were different in each. One method made use of a data source that only currently exists for 2019 but allows for a more detailed analysis, whilst the other method used simpler input data that is available across a longer timeframe. The latter method will be used in the milestone reporting against the Well-being of Future Generations Act, due to the need to be able to show change throughout time. The former method provides a potential future improvement if additional years become available in the more detailed underlying data in future. Both methods used differ slightly from the previous Welsh Ecological Footprint calculation which took place in 2015 and provided data for 2011, and so to understand change through time users should refer to the time series calculated here, rather than directly comparing the latest results in this report with those presented in the previous report.
  - **What were the results?**
    - Based on the method using the detailed 2019 data, Wales' Ecological Footprint was found to be 10.7 million global hectares in 2019, or 2.84 global hectares per capita. This is almost twice the estimated biocapacity of Wales. In other words, if the entire world population lived like the citizens of Wales, humanity would require **1.8 Earths**.
    - Based on the method that allows for the calculation of a time series and that will be used in the Wellbeing of Future Generations Act reporting, Wales' Ecological Footprint was found to be 12.3 million global hectares in 2018, or 3.93 global hectares per capita. This is just over twice the estimated biocapacity of Wales. In other words, if the entire world population lived like the citizens of Wales, humanity would require **2.08 Earths**.
    - Based on this second method that allows calculation of a time series, Wales' Ecological Footprint **decreased by 31.5%** between 2004 and 2018 (5.74 gha per capita in 2004, 5.94 gha per capita in 2007, 4.62 gha per capital in 2011, 4.43 gha per capita in 2014, and 3.93 gha per capita in 2018).
    - For comparison, the UK's Ecological Footprint was estimated to be 4.03 gha per capita in 2018.

- **A waste component of the Ecological Footprint** (see Section 3 of the main report for full details)
    - **What is it?** This is the proportion of the overall footprint associated with waste (i.e. resources that enter the economy and are ultimately turned into waste), in order to help quantify resource efficiency.
    - **How was it calculated?** Ecological Footprinting methods described above were applied to Welsh specific waste data from various sources.
    - **What were the results?** It was estimated that **6.35%** of the overall Ecological Footprint for Wales is associated with waste. 'Hotels and catering' and 'construction' were the two sectors with the highest waste components to their Ecological Footprints (24% and 14% respectively). A comparative figure has not been calculated for the UK.
- **A Material Footprint** (see Section 4 of the main report for full details)
    - **What is it?** This is an estimate of the total tonnes of material extracted or produced to support consumption. This includes material discarded at previous stages in the supply chain (e.g. the tonnes of ore extracted to create metal is included, not just the tonnes of metal in the final product).
    - **How was it calculated?** Similar methods were used to the calculation of the UK Material Footprint, but different underlying data were used.
    - **What were the results?** Wales' Material Footprint was estimated to be **33,554 thousand tonnes** in 2019, or 10.73 tonnes per capita. The 33,554 thousand tonnes make up 3.2% of the estimated UK total. Whilst some of the difference between the UK and Welsh results is due to the fact that Wales has a much smaller population than the UK overall, some of it is also due to the fact that each individual within Wales has a smaller Material Footprint than each individual within the UK on average; Welsh Material Footprint per capita is estimated to be 68% of UK Material Footprint per capita.
- **The Global Environmental Impacts of Consumption indicator** (see Section 5 of the main report for full details)
    - **What is it?** This is a set of estimates of the biodiversity loss, deforestation and water impacts associated with consumption. It breaks down each impact by commodity type and location.
    - **How was it calculated?** Methods developed for the UK Global Environmental Impacts of Consumption indicator were used. As with the Ecological Footprint, this was downscaled for Wales in two different ways based on two different data sources as described above. The ranges presented in the results below relate to the differences from the results based on each method.
    - **What were the results?** It is estimated that Welsh consumption of agricultural crop commodities (and in some cases cattle and timber) in 2018 was associated with impacts including:
        - **Predicted loss of 1.2 to 1.6 species.**
        - **669 to 884 ha** of tropical and subtropical deforestation (the equivalent of 94-124 football pitches).
        - Emission of **335 to 439 thousand tonnes of $CO_2$** associated with this deforestation.
        - Use of **7 to 9 billion cubic metres** of scarcity-weighted water.
        - Use of **314 to 414 thousand ha** of land for crop harvests.

      These estimates are between **39.5%** and **57.8%** per capita of the equivalent UK results. When Results are also presented relating to the breakdown of each of the above in terms of the commodities associated with the impact and where in the world the impacts are taking place. For example, for the species loss metric, **wheat, rice, maize, barley, palm oil, coffee, coconuts,** and **sugar cane** are the commodities associated with the highest impact. The **UK,**

**India, Indonesia**, **the Philippines, Viet Nam, Nigeria, Thailand** and **Spain** were the countries in which the most species loss associated with Welsh consumption was taking place.

All approaches to estimating the footprint or impact of consumption will have **limitations** and be associated with **uncertainty**. For example, data tracing exact trade flows back to their countries of origin do not exist, so approaches rely on modelling. In particular, as a devolved nation, Wales faces additional data challenges when calculating consumption metrics when compared to the UK or other countries internationally. Trade data between countries within the UK are not typically recorded. This makes distinguishing Welsh impacts from impacts associated with other UK countries difficult. Results should therefore be treated as estimates that can help to show overall scale, direction, and breakdown of impacts, rather than precise numbers suitable for analysing subtle changes. Users should also be aware that each indicator also has specific caveats associated with its own method, which are explored in more detail in the main report.

Three commodity case studies (livestock, timber, and palm oil) were also undertaken to give a more in-depth analysis of other data sources available (see Section 6 of the main report for full details). It is estimated that the Welsh livestock sector is responsible for the production of 4,918 tonnes of soy and 37,168 tonnes of maize, which in turn are associated with approximately 4.28 ha and 2.86 ha of annual deforestation risk, respectively. Sourcing from Brazil accounts for more than 70% of risk associated to both soy and maize. For timber, it was found that Welsh consumers are exposed to a significant deforestation risk linked to dependency on overseas timber, whereas the Welsh timber industry itself is not highly exposed. There is potential to reduce exposure via further domestic production. For palm oil embedded in products coming into Wales and the wider UK, sustainability certification is still quite unclear. Given the interlinkages between the UK and Welsh processed food, cosmetics and consumer goods sectors, there is likely limited direct influence by Welsh-specific supply chain actors on embedded palm oil deforestation risk.

Detailed methods for the calculation of each of the above metrics are also included in the appendices of the report. The underlying data are also published alongside the main report in the form of two accompanying datasheets. An Annex, providing a simple breakdown of the different consumption-based metrics available and the key differences between each, is also published alongside the report.

Overall, it is clear that Welsh consumption continues to have a large footprint and significant environmental impacts globally. However, the situation is improving with trends decreasing since 2004. The detailed understanding that the analyses in this report provide could be used to help target action towards the sectors/commodities and production locations associated with the highest footprints and impacts, in order to continue reducing this further.

# Contents

# Glossary

**Biocapacity:** "The capacity of ecosystems to regenerate what people demand from those surfaces. Life, including human life, competes for space. The biocapacity of a particular surface represents its ability to regenerate what people demand. Biocapacity is therefore the ecosystems' capacity to produce biological materials used by people and to absorb waste material generated by humans, under current management schemes and extraction technologies. Biocapacity can change from year to year due to climate, management, and also what portions are considered useful inputs to the human economy. Biocapacity is usually expressed in global hectares" (GFN nd).

**Carbon Footprint:** an estimate of carbon emissions by an individual, organisation or population. Typically, this is expressed in tonnes of $CO_2$ or $CO_2$ equivalents. Wales has published an estimate of the carbon footprint associated with Welsh consumption separately from this project (Welsh Gov 2023). However, in the context of the current report, carbon footprint refers to a separate calculation made as a component of the Ecological Footprint. The carbon component of the Ecological Footprint does not estimate the tonnes of $CO_2$ released into the atmosphere, but rather the area of land that would be required to sequester this carbon, expressed in global hectares.

**Ecological deficit and reserve:** a country's biocapacity deficit or reserve is the gap between the country's Ecological Footprint and biocapacity. It is measured in global hectares. An ecological deficit occurs when footprint exceeds biocapacity and an ecological reserve occurs when biocapacity exceeds footprint. Both describe resource balances however, at the country level, deficit does not necessarily imply the existence of negative environmental impacts globally because biocapacity can be imported, and a reserve does not imply the absence of negative environmental impacts.

**Ecological Footprint (EF):** the biocapacity consumed or demanded through an activity. In the context of this report, it refers to the biocapacity demanded by activities of a population, whether Wales, the UK or the world. The Ecological Footprint adds up all competing demands on ecosystem regeneration. It includes the production of food and fibres, carbon sequestration, space for shelter, roads, quarries and other human infrastructure, etc.

**Ecological Footprint of Waste ($EF_{waste}$):** the proportion of the overall Ecological Footprint that is associated with waste (i.e. the Ecological Footprint of materials that enter the economy and ultimately enter the waste stream).

**Global Environmental Impacts of Consumption (GEIC) indicator:** a set of estimates of the biodiversity loss, deforestation and water impacts associated with consumption. It breaks down each impact by commodity type and location.

**Global Footprint:** an estimate of the land area required to support consumption by a country/organisation/individual at a global scale. This can be calculated in various different ways, for example using the Ecological Footprint method or the cropland area estimate within the GEIC indicator. The Ecological Footprint results presented in Section 2 of this report will be used as the Global Footprint within the Well-being of Future Generations Act's reporting framework.

**Global hectare (gha):** the standard unit for Ecological Footprint and biocapacity accounting. It is defined as a biologically productive hectare with world average productivity. Using it allows for the comparison of Ecological Footprint and biocapacity over time and across geographies.

**Government consumption:** The Ecological Footprint can be broken down based on the type of spending behind the footprint – household, government and GFCF. This can help to understand underlying causes of the Footprint and target action accordingly. Government consumption pertains to short-term consumption by governments, such as public services, schools, policing, defence.

**Gross Fixed Capital Formation (GFCF)**: The Ecological Footprint can be broken down based on the type of spending behind the footprint – household, government and GFCF. This can help to understand underlying causes of the Footprint and target action accordingly. Gross fixed capital formation includes long-term assets purchased by households (e.g. new houses, white goods), firms (e.g. machinery), and governments (e.g. transport infrastructure).

**Household consumption:** The Ecological Footprint can be broken down based on the type of spending behind the footprint – household, government and GFCF. This can help to understand underlying causes of the Footprint and target action accordingly. Household consumption refers to short-term consumption by households, such as food, housing maintenance, goods, and services paid for and consumed within a fiscal year.

**Input-Output tables:** tables showing the sales and purchases between producers and consumers within an economy.

**Material Footprint (MF):** an estimate of the total tonnes of material extracted or produced to support consumption. This includes material discarded at previous stages in the supply chain (e.g. the tonnes of ore extracted to create metal is included, not just the tonnes of metal in the final product).

**Overshoot:** is used to describe both the state and the gap between the global Ecological Footprint and biocapacity. At the global level, this is synonymous with "ecological deficit" however a global deficit or overshoot implies a combination of ecosystem degradation, natural capital loss and accumulation of waste, as opposed to national ecological deficits, which can be met through trade.

**Regeneration:** Regeneration is used here in the biological sense. It refers to the bioproductive ability of the environment to support life and generate biomass through photosynthesis. From an ecological perspective, this is often measured and referred to as the net primary production of an ecosystem. It is often referred to as a currency of life because it is the energetic basis of almost all life on earth. See also the biocapacity definition above, or Appendix 3 for additional information.

Readers may also with to refer to the Global Footprint Network's glossary or the GEIC indicator's FAQs or technical documentation if they come across other terms that they are unfamiliar with throughout the report.

# 1 Introduction

## 1.1 Rationale

As a planet, we are in the midst of two ecological emergencies: the climate emergency and the nature crisis. Despite progress being made, globally we are currently on track for 3°C of warming, even if current pledges are met (UNEP 2019). Furthermore, in the past 100 years, natural habitats have declined by 30% and now one million species are at risk of extinction (IPBES 2019). Since 1970, global species abundance has declined by an average of 69% (WWF 2022a). These environmental emergencies are also humanitarian emergencies: 3°C of warming and mass species extinctions would make large areas of the planet uninhabitable and cause collapses in ecosystem services, majorly disrupting global food and water supplies.

The world is currently operating with an ecological deficit, consuming more than the biocapacity of its natural resource base (Figure 1). This is known as overshoot and has now been the case for over half a century. Human activities are now the dominant biological and geological force, dwarfing all other biological demands on the biosphere. Some scientists have therefore named the times we live in the "Anthropocene". Ecological overshoot is marked by demand exceeding the capacity of the biosphere, and the scale of overshoot has led to declines in biodiversity, excess greenhouse gases in the atmosphere, and heightened competition for food and energy. These symptoms are becoming more prominent with unusual heat waves, forest fires, droughts, and floods.

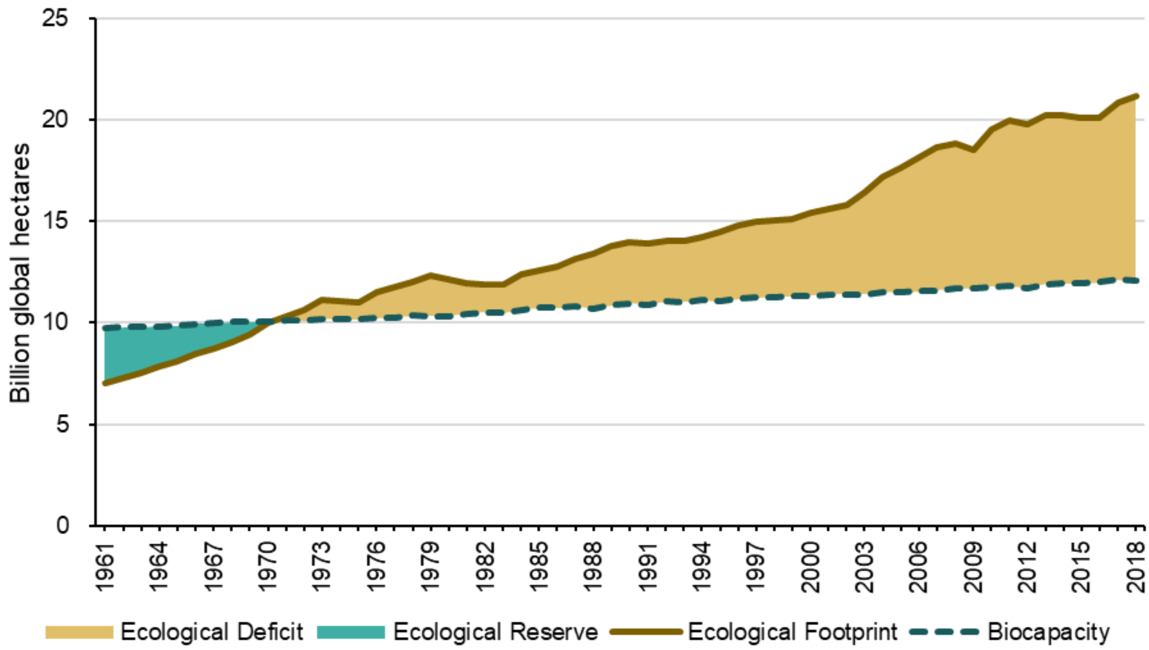


**Figure 1.** World Ecological Footprint and biocapacity 1961-2018 in billion global hectares. Ecological Footprint is the amount of bioproductive land area needed each year to sustain our production and consumption and absorb our waste. Biocapacity is the amount of bioproductive land area that can be renewed each year. Both are expressed in global hectares, a productivity-adjusted measure of land area.

The trend of increasing ecological overshoot is key context for the sustainability of all populations. Resource efficient economies will be best positioned for success in the future context.

The United Kingdom is also currently operating with an ecological deficit, consuming over 4 times the biocapacity of its natural resource base (Figure 2). To understand the resource context of Wales, global and regional trends relative to the UK and rest of the world must also be considered.

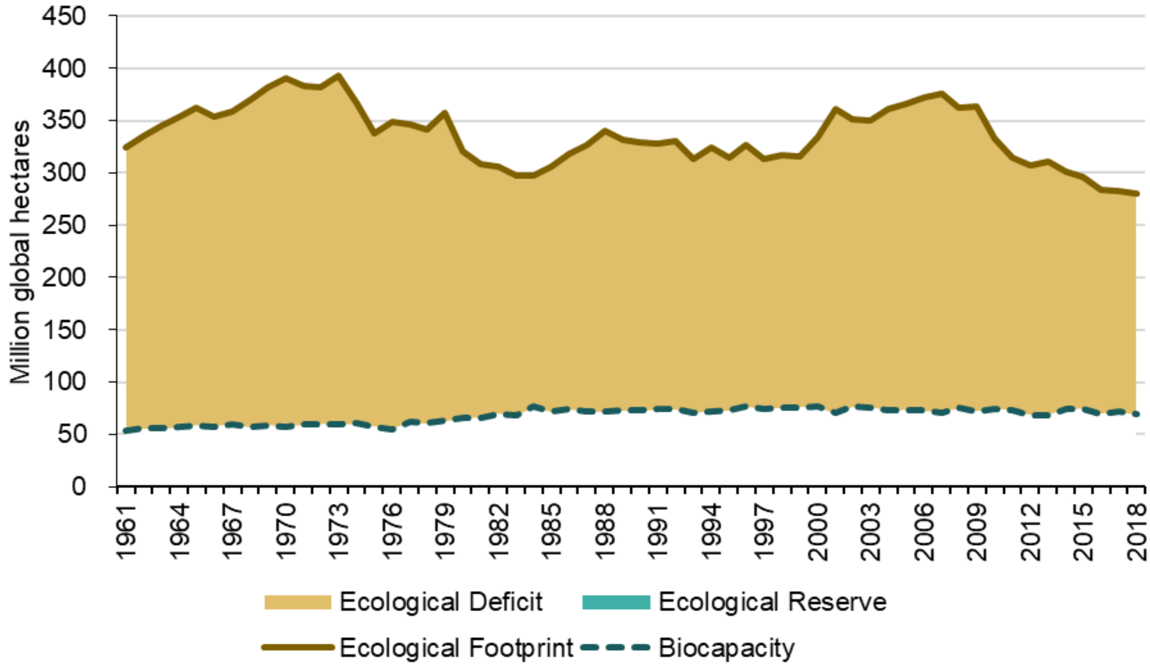


**Figure 2.** Ecological Footprint and biocapacity of the United Kingdom 1961 to 2018, expressed in millions of global hectares, a productivity-adjusted measure of land area.

The pressures leading to the Anthropocene make clear that the ability of the biosphere to provide goods and services that enable thriving economies is fuelled by regeneration. Regeneration is using bioproductive land and water to replace natural resources that are consumed and to absorb waste that is produced. This is true not only for the land required for the provision of food and fibres, but also for the sequestration of humanity's most prominent waste product, greenhouse gases.

As well as affecting regenerative potential, human consumption can lead to a range of more specific environmental impacts, such as deforestation and biodiversity loss. For example, it is estimated that globally, 6.4 to 8.8 million hectares per year of tropical forest are lost in order to expand production of agricultural commodities (Pendrill *et al.* 2022). Those consuming goods associated with these impacts may be located on the other side of the globe to where the impacts are taking place, meaning they are difficult to trace.

It is therefore necessary to understand both how consumption balances with regeneration of natural resources to understand the scale of the problem associated with Welsh consumption, and to understand more detailed information about the specific impacts of Welsh consumption and where they are taking place, to direct action.

## 1.2 Policy context

The Welsh Government have recognised how crucial it is that globally, as a nation and as individuals we reduce the impact we have on the environment, with targets of net zero carbon, one planet resource use and zero waste by 2050.

The concept of a global footprint heavily informed the early policy development on sustainable development in Wales, culminating in the 'One Wales One Planet' sustainable development scheme in 2009. This included a commitment that "Within the lifetime of a generation we want to see Wales… where our ecological footprint is reduced to the global average availability of resources - 1.88 global hectares per person".

This approach then featured as part of the policy development work for the Well-being of Future Generations (Wales) Act 2015 (National Assembly for Wales 2015). A key feature of the Act is intergenerational justice and living within global environmental limits. The one planet resource use goal was made explicit in "Beyond Recycling", Wales' circular economy strategy that was published in March 2021 (Welsh Government 2021a). Included in the accompanying Beyond Recycling Indicators document is a commitment to develop a materials footprint for Wales to help measure progress towards the one planet resource use goal (Welsh Government 2021b).

The Global Footprint is now one of the 50 national indicators used to measure progress against the seven well-being goals for Wales (Well-being of Future Generations Act). It is reported on annually in the Annual Well-being of Wales Report (Welsh Government 2022a). A national milestone relating to this national indicator was set in December 2022: "Wales will use only its fair share of the world's resources by 2050". A Global Footprint is an estimate of the land area required to support consumption by a country at a global scale. This can be calculated in various ways, for example using the Ecological Footprint method or, for agricultural commodities, the cropland area estimate within the GEIC indicator. The Ecological Footprint results presented in Section 2 of this report will be used by Welsh Government as the Global Footprint within the Well-being of Future Generations Act's reporting framework. An Ecological Footprint is an estimate of how much regeneration (bioproductive land and water area) would be required to produce natural resources that are consumed and to absorb waste that is produced. From here-on-in, the report will use the term Ecological Footprint when referring to the specific metric that was calculated, rather than Global Footprint which could refer to a variety of metrics.

There is also an interest in gaining a more detailed understanding of specific hotspots of consumption impact in order to target action and gain an understanding of specific impact types, especially biodiversity.

Understanding and improving the sustainability of consumption is a topic rising up policy agendas internationally. For example, Sustainable Development Goal 12 is to "ensure sustainable consumption and production patterns." Similarly, Target 16 of the Convention on Biological Diversity's Kunming Montreal Global Biodiversity Framework includes wording to "ensure that people are encouraged and enabled to make sustainable consumption choices" and to "reduce the global footprint of consumption in an equitable manner." The Ecological Footprint, the Material Footprint and the Global Environmental Impacts of Consumption indicator were three of the indicators included in the framework as component indicators against this target. Reporting on these three metrics from a Welsh perspective would therefore not only help to meet Wales' internal policy and legislation, but also demonstrate Wales' progress towards international targets.

## 1.3 Background and context

A variety of projects aimed at understanding the environmental impacts of Welsh consumption have already been undertaken. This project built on and, where possible, aligned with this existing body of work.

### 1.3.1 Ecological Footprint

Ecological (Global) Footprint accounting has been developed to map both the demand on, as well as the availability of, biological regeneration. Such accounting can be applied at any scale: for humanity, a country, a region (like Wales), a city, a household, a business activity, or even a single product. While the resource question has remained the same, i.e., how much regenerative capacity of ecosystems is occupied by human activities, the accounts have matured over time, with the National Footprint and Biocapacity Accounts now being produced independently by a dedicated organization, in collaboration with York University in Toronto.

The last estimates of Wales' Ecological Footprint were calculated in 2015 for 2011 (Welsh Government 2015). These are the estimates that have been used in the Annual Well-being of Wales Report each year since publication. The work built on previous economic and carbon footprint studies for Wales including 'The Ecological Footprint of Wales: Scenarios to 2020' (Dawkins *et al.* 2008). It estimated that in 2011, Wales' Ecological Footprint was 10.05 million global hectares (gha), or 3.28 global hectares per capita (gha/c). This was estimated to be roughly 1.2 to 1.8 times the global average. The work was a one-off study, based on combining data from the Global Footprint Network's Ecological Footprint data with financial flow data (from multi-regional input-output (MRIO) modelling). This report updates this to provide data to 2018, including recalculating this historical data to ensure methodological consistency throughout the time series. A Carbon Footprint (an estimate of carbon emissions from a consumption perspective) was also calculated alongside the previous Ecological Footprint in 2015. An updated estimate of consumption emissions using a revised methodology has been produced, covering the years 2001 through to 2020 (Welsh Government 2023). This work was undertaken as part of a separate project, and so results are not presented as part of this report.

### 1.3.2 Biodiversity loss

A recent experimental statistic known as the Global Environmental Impacts of Consumption indicator, and an associated interactive dashboard (SEI/JNCC 2022), have been released estimating the biodiversity loss associated with UK consumption of agricultural crop commodities. Results can be broken down by commodity type and by the producer country in which the impact is estimated to have taken place, leading to greater scope for targeting policy interventions. As well as biodiversity loss, data are presented for tropical deforestation, GHG emissions from this deforestation and scarcity weighted water use. Data are presented at a UK scale, but this project built on the methods used to downscale it to provide data from a Welsh perspective.

### 1.3.3 Welsh Input-Output data

Input-Output tables for Wales for 2019 have been developed by Professor Calvin Jones (Cardiff University) and were used in this project to downscale consumption statistics. Input-Output tables show the sales and purchases between producers and consumers within an economy. This allows for analysis of both how the economy functions and how it fits into other systems. For example, Welsh Input-Output tables can allow for analysis of the Welsh economy's relationship to the UK or the global economy, as well as the natural environment or climate. More information about the development of the Input-Output tables for Wales can be found in a blog post.

### 1.3.4 Waste statistics

Wales has detailed waste data, including the 2018 Industrial and Commercial waste survey (Natural Resources Wales 2018), data on waste collected by local authorities (Waste Data Flow 2021), 2015 data on the composition of residual local authority collected waste, the 2019 Construction and Demolition Waste Survey and 2018 data on the composition of residual industrial and commercial waste. Two previous calculations of the Ecological Footprint of Welsh waste have been undertaken (not published), by Arup and SLR Global

Environmental Solutions. These projects have defined the Ecological Footprint of waste as a measure of “the embodied footprint impacts of materials in the waste stream,” accounting for “the environmental consequences of what people in Wales buy, use and then throw away, with those consequences considered throughout the supply chain”. In the past, these have been undertaken separately from the Ecological Footprint calculation. This project, however, aimed to undertake this analysis as part of the overall footprint calculation in order to ensure alignment of methods and comparability.

## 1.4 Aims and scope

Based on the rationale and policy context outlined above, and building on the existing body of work, this project aimed to improve understanding of the environmental impacts of Welsh consumption. It did so by producing:

- A Global / Ecological Footprint for Wales, including a breakdown showing how much of the total is linked to waste.
- A Material Footprint for Wales.
- A downscaled version of the UK’s Global Environmental Impacts of Consumption (GEIC) indicator, providing metrics of biodiversity loss (as well as tropical deforestation, GHG emissions from this deforestation, and scarcity-weighted water use).
- A set of case studies exploring additional data and context for a selection of three commodities (livestock, timber, and palm oil).

This report contains a chapter for each of the metrics listed above. Each chapter introduces the metric, presents and discusses the results, and outlines what changes the metric will be sensitive to. An additional chapter is included for the case studies. Full technical methodological detail for how each metric was calculated can be found in the Appendices.

# 2 Ecological Footprint

## 2.1 Headline results

Wales' Ecological Footprint was found to be 10.7 global hectares in 2019. This is just over twice the estimated biocapacity of Wales. In other words, if the entire world population lived like the citizens of Wales, humanity would require **2.08 planets**. Wales' Ecological Footprint decreased by 31.5% between 2004 and 2018 (the latest year for which relevant data are available). It should be noted that two separate methodologies were used – one making use of a data source that only currently exists for 2019, and the other using different and slightly simpler datasets to enable the production of a time series (see below for details).

## 2.2 Introduction

### 2.2.1 What do Ecological Footprint and biocapacity accounts measure?

Ecological Footprint and biocapacity accounts have two sides. The biocapacity side quantifies the biological regeneration rate of ecosystems.  This amount can then be compared to human demand on biocapacity, also known as an Ecological Footprint. These accounts allow researchers to quantify the size of human economies compared to the regeneration capacity of the entire planet or any of its regions. Note that some portion of the planet's biocapacity is also needed to maintain biodiversity (Wilson 2016).

To make biocapacity operational, it is measured in planetary surface area, which in turn is scaled by its relative biological productivity. The resulting measurement unit is a "global hectare," which is a biologically productive hectare with world-average productivity.

The Ecological Footprint tracks how much mutually exclusive, biologically productive area is necessary to meet people's demand for nature's products and services (Borucke *et al.* 2013; Lin *et al.* 2018; Wackernagel *et al.* 2019, 2021). The demands on nature that compete for biocapacity include:

i) food, fibre, timber;
ii) space for roads and other human infrastructure (for example, quarries, buildings, etc);
iii) energy production (from hydropower to biomass); and iv) waste absorption, including carbon dioxide ($CO_2$) from fossil fuels and cement production. The measurement unit for Ecological Footprint is also global hectares.

### 2.2.2 National and sub-national accounts

National Footprint and Biocapacity Accounts, based on United Nations statistics, are now independently produced annually by the Footprint Data Foundation, in collaboration with York University, Toronto. Results for 2018 show that human demand exceeded the planet's regeneration by at least 73% (York University *et al.* 2021). This underestimates the gap, because Footprints do not include everything (for instance methane/$CH_4$ is not yet incorporated for lack of robust data), and biocapacity is exaggerated as UN datasets underreport on damage. For sub-global Ecological Footprint calculations, one needs to distinguish between the consumption footprint versus the production footprint. The difference between the two is the footprint of net-imports.

### 2.2.3 What results reveal

At the most aggregate level, Ecological Footprint and biocapacity accounts provide an integrated or holistic view of the natural resource demand of a population and the extent to which demand fits within the biocapacity of a city, country, region or world. Globally, a key insight provided is a quantification of the scale of transformation needed for humanity's resource demand to fit within the means of our planet. Global and National trends exemplify how quickly economies can respond. Since impact emerges from the build-up of the deficits (similar to debt building up from the persistence of financial deficits) the future is becoming more predictable. It is going to be a future in which all of us will live in a world with far more climate change, and fewer resources. This is true for any imaginable scenario.

Faster reaction to these trends will limit exploitation of fossil fuels more rapidly, while also slowing down the change of our climate. Slower response will ease the energy squeeze in the short run, at the cost of far more climate change, and eventual, but later abandonment of fossil fuel use. In either case, this future in which climate change and resource constraints are more prominent forces is approaching more rapidly than companies, cities, and countries may be able to adapt. This makes monitoring human demand against available biocapacity crucial if regions or countries want to navigate this shifting context proactively.

### 2.2.4 Limitations

Ecological footprint and biocapacity accounting provide a quantitative estimate of the size of an economy through the lens of regeneration, based on the premise that biocapacity represents a fundamental and overarching limiting factor to humanity. Ecological Footprint and biocapacity can help to inform on the underlying principles of sustainability:

- Harvest/Appropriation must not exceed regeneration.
- Waste production must not exceed assimilation.

Therefore, it aims to capture all human activity to the extent that it appropriates or requires regeneration. For example, human infrastructure would require wood (forest products footprint) for building the physical structure, but also may be built upon bioproductive land area (built-up footprint). These elements, plus the waste $CO_2$ produced, can be mapped to the amount of biocapacity required. In the context of global overshoot (consuming more than can be supported), reduction in total demand will be necessary for solutions to be impactful, however, complementary aspects of quality should also be considered. Additional measures related to the quality of natural systems, such as biodiversity or toxic pollutants, offer additional insight into the health or ability of natural systems to sustain optimal function and support life. The degree to which demand for regeneration results in degradation of natural capital stocks, production of toxic pollutants, or loss of biodiversity are not captured directly in footprint and biocapacity results.

Generally, footprint and biocapacity accounts are acknowledged to underestimate the biocapacity deficits; in other words, Ecological Footprints are generally underestimates of total demand while biocapacity may be overestimated. Underestimates in Ecological Footprint generally reflect the nature of usable input data. Methane ($CH_4$) production is not currently included in footprint results. Overestimates in biocapacity can occur due to masking of the state of ecological damage to ecosystems (such as soil erosion or groundwater depletion) if agricultural yields are artificially bolstered for increased production.

- A common misinterpretation is that Ecological Footprint and biocapacity provide a comprehensive measure of environmental sustainability; however, the results aim to comprehensively capture all aspects of human demand for biocapacity (Grazi *et al.* 2007). Global Footprint Network has compiled criticisms and limitations and discusses them in detail on their website (Global Footprint Network 2021). The focus on biocapacity and bioproductive land area also means that the Ecological Footprint does not account for specific impacts such as biodiversity loss or the effects of plastic pollution on seabirds and marine mammals.

## 2.3 Results

Two approaches were taken to downscale UK data to provide results for Wales. One relied on Welsh Input-Output (IO) data (see section 2.3.1), and the other took a top-down approach (see section 2.3.2). Results for both approaches are presented below (full methodological details for both approaches are presented in Appendix 1). As Welsh IO data are only available for one time point it is only calculated for the year 2019, whereas using the top-down approach it was possible to create a time series due to the availability of data for five time points between 2004 and 2018.

### 2.3.1 Input Output (IO) Based approach

The IO based approach is based on the economic model which characterises the internal structure of the Welsh economy in 2019 from production industries, intermediate economy and final consumers. This allows us to trace the flow of biocapacity from harvest or production to its destination, whether consumed within Wales or exported to other countries. This analysis presents results using 2019 data; however, usage of IO models is generally acknowledged to be dependent on the rate of change in economic relationships within an economy and for practical purposes, applicable within a range of several years surrounding the model year. Adopting this approach, **the total Ecological Footprint of Wales is about 10.7 million gha, or 2.84 gha per capita**. Among the six land-use categories, the carbon footprint is the largest, accounting for 8,742,017 gha (81%, or 2.28 gha per capita), followed by the cropland footprint, 830,198 gha (8%, or 0.23 gha per capita), and forest products footprint, 468,847 gha (4%, or 0.13 gha per capita, see Figure 3).

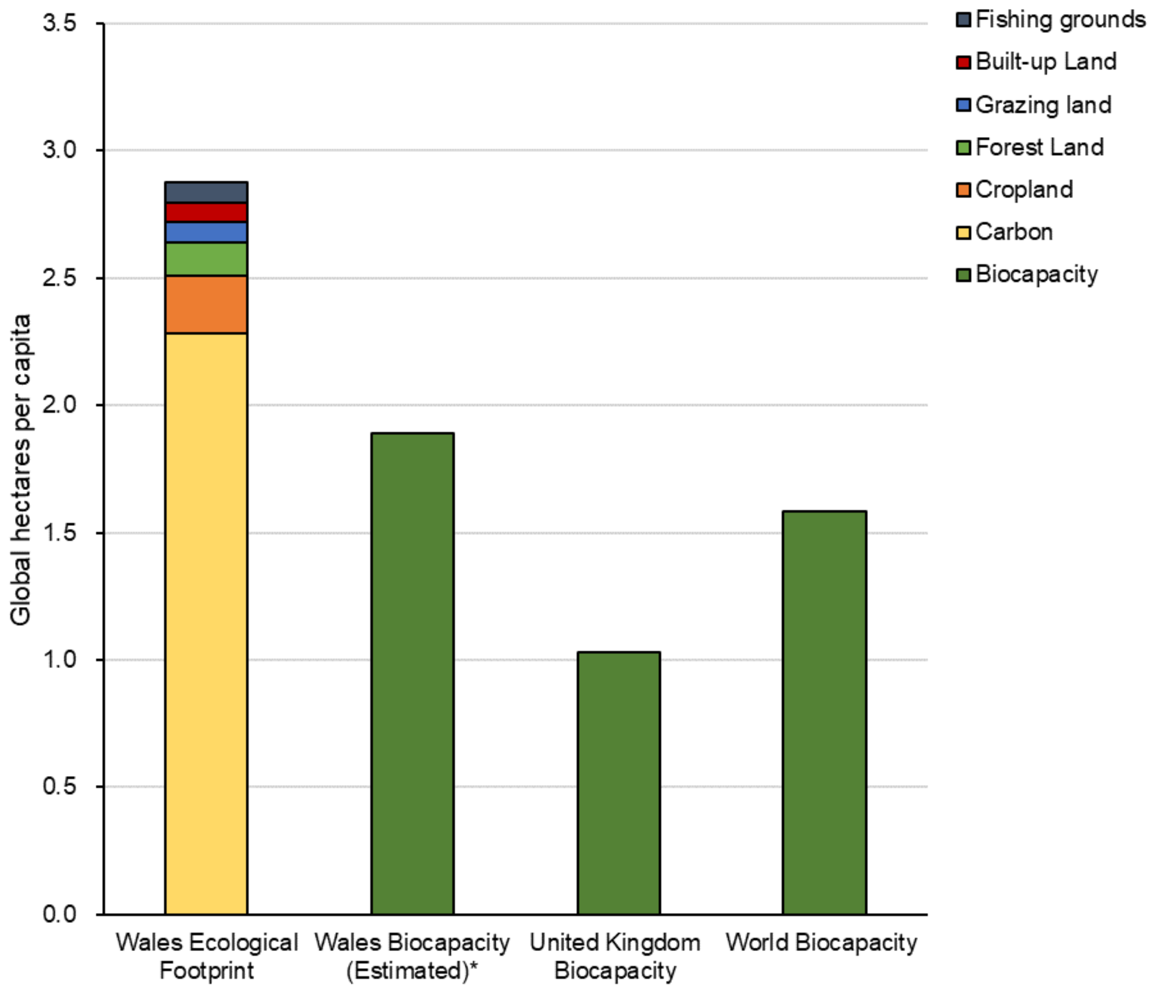


**Figure 3.** Per person Ecological Footprint and biocapacity of Wales (gha) by six land-types (from bottom to top, carbon, cropland, forest land, grazing land, built-up land and fishing grounds), compared to per person biocapacity of the UK and World for 2018. The biocapacity of Wales is estimated based on the average productivity of land in the UK. Comparing the Ecological Footprint (the biocapacity consumed) to the biocapacity that is available in each geographic context gives insights into sustainability. Carbon refers to the land required to sequester carbon emissions associated with Welsh consumption.

Comparing the per capita Ecological Footprint of Wales to the per capita biocapacity of Wales reveals the level of regional ecological deficit or credit status. According to our study, the per capita Ecological Footprint for Wales for 2019 is calculated as 2.84 gha, which is 1.51 times higher than the biocapacity available per person in Wales (1.89 gha). This indicates that Wales is in an ecological deficit situation and depends on resources and services from outside of Wales' borders. The per capita Ecological Footprint of Wales can be compared to the world-average biocapacity available for each person (1.58 gha), which shows that if the entire world population lived like the citizens of Wales, humanity would require 1.8 planets.

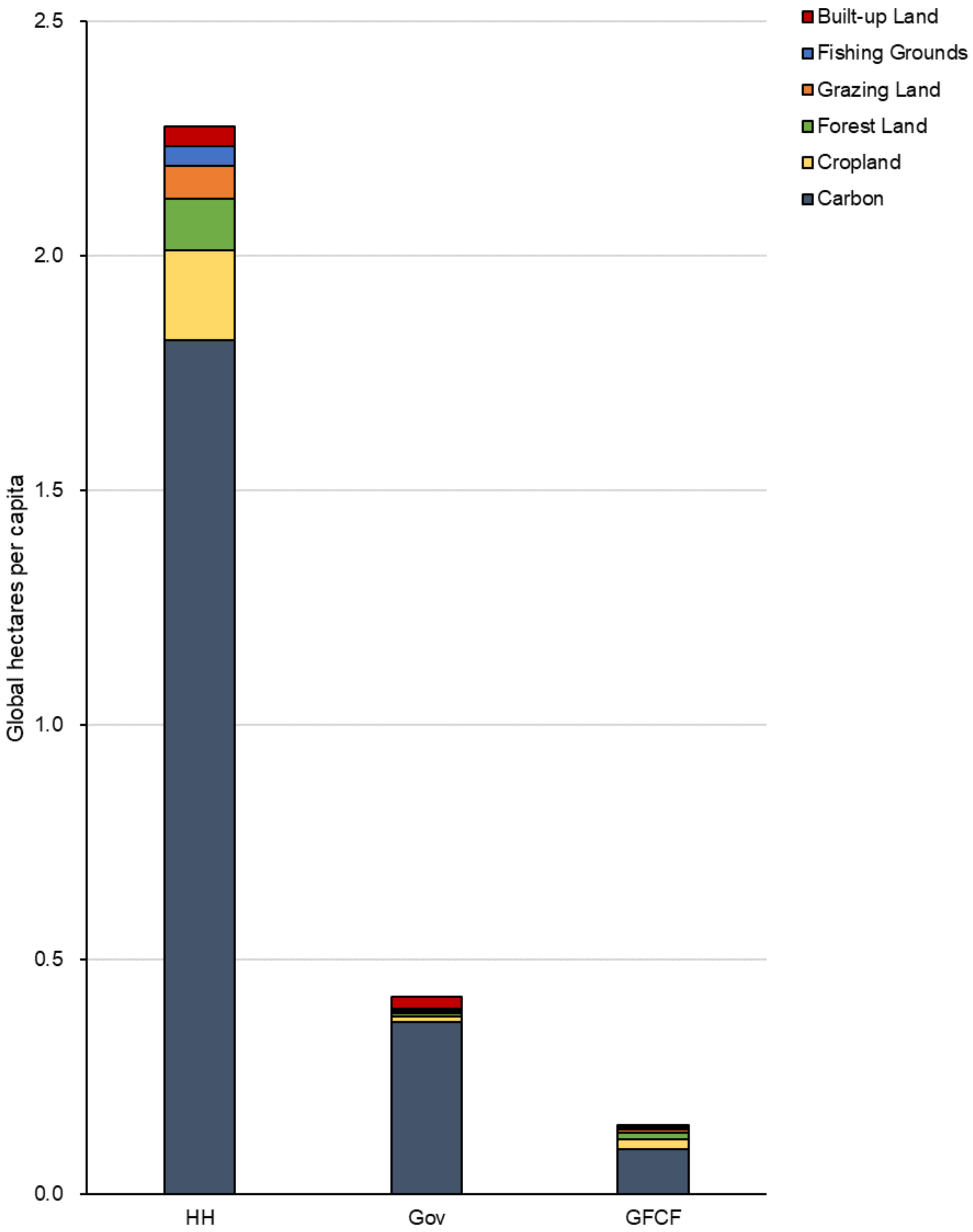


**Figure 4.** Per person Ecological Footprint of Wales (gha) by household (HH), government (Gov) and gross fixed capital formation (GFCF) and by 6 land-types (from bottom to top, carbon, cropland, forest land, grazing land, fishing grounds, and built-up land) in 2018. Carbon refers to the land required to sequester carbon emissions associated with Welsh consumption, expressed in global hectares.

The evaluation of the Ecological Footprint of Wales, utilizing three final demand categories, serves to identify the domestic demand which exerts the greatest contribution, as well as its characteristics with respect to the six land use types (Figure 4). Household consumption refers to short-term consumption by households, such as food, housing maintenance, goods, and services paid for and consumed within a fiscal year. Government consumption pertains to short-term consumption by governments, such as public services, schools, policing, defense. Lastly, gross fixed capital formation includes long-term assets purchased by households (e.g. new houses, white goods), firms (e.g. machinery), and governments (e.g. transport infrastructure).

The Ecological Footprint associated with household consumption was found to be the largest of the three final demand categories, accounting for approximately 80% of the total Ecological Footprint. In contrast, EF for government expenditure and GFCF, were found to account for 15% and 5% of the total Ecological Footprint, respectively. The carbon footprint (the land required to sequester carbon emissions associated with Welsh consumption, expressed in global hectares) was found to be dominant in all final demand categories, with a high proportion of approximately 80% for household consumption, 87% for government consumption, and 64% for GFCF. In the case of household consumption, the proportion of cropland was found to be second highest after carbon. Of the total cropland, 84% was induced by household consumption.

Figure 5 represents the Ecological Footprint of 21 industrial sectors in Wales. By industrial sector, electricity, gas, steam, and air conditioning supply sectors have the largest footprint, 2,589,735 gha, or 29% of the total. The transport and storage sector has the second largest footprint of 1,364,257 gha, or 15%, followed by the Other services and the agriculture, forestry, and fishing sectors, which have footprints of 979,430 gha, or 11%, and 905,236 gha, or 10%, respectively.

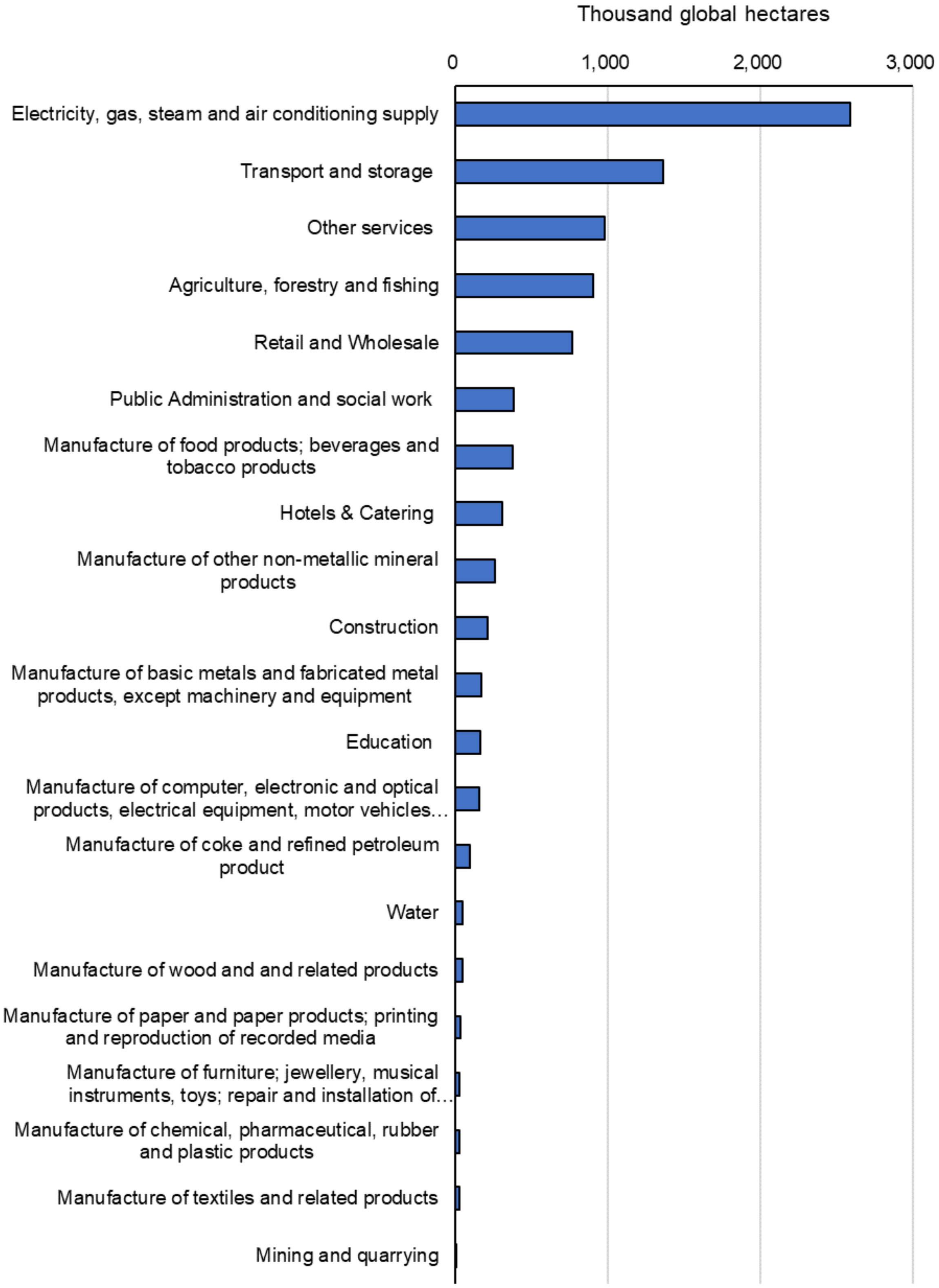


**Figure 5.** Total Ecological Footprint of Wales (gha), broken down by 21 industrial sectors. Note: A table in the accompanying datasheet also provides this information breaking each industry down by the six land use types making up the Ecological Footprint.

### 2.3.2 Top-down approach

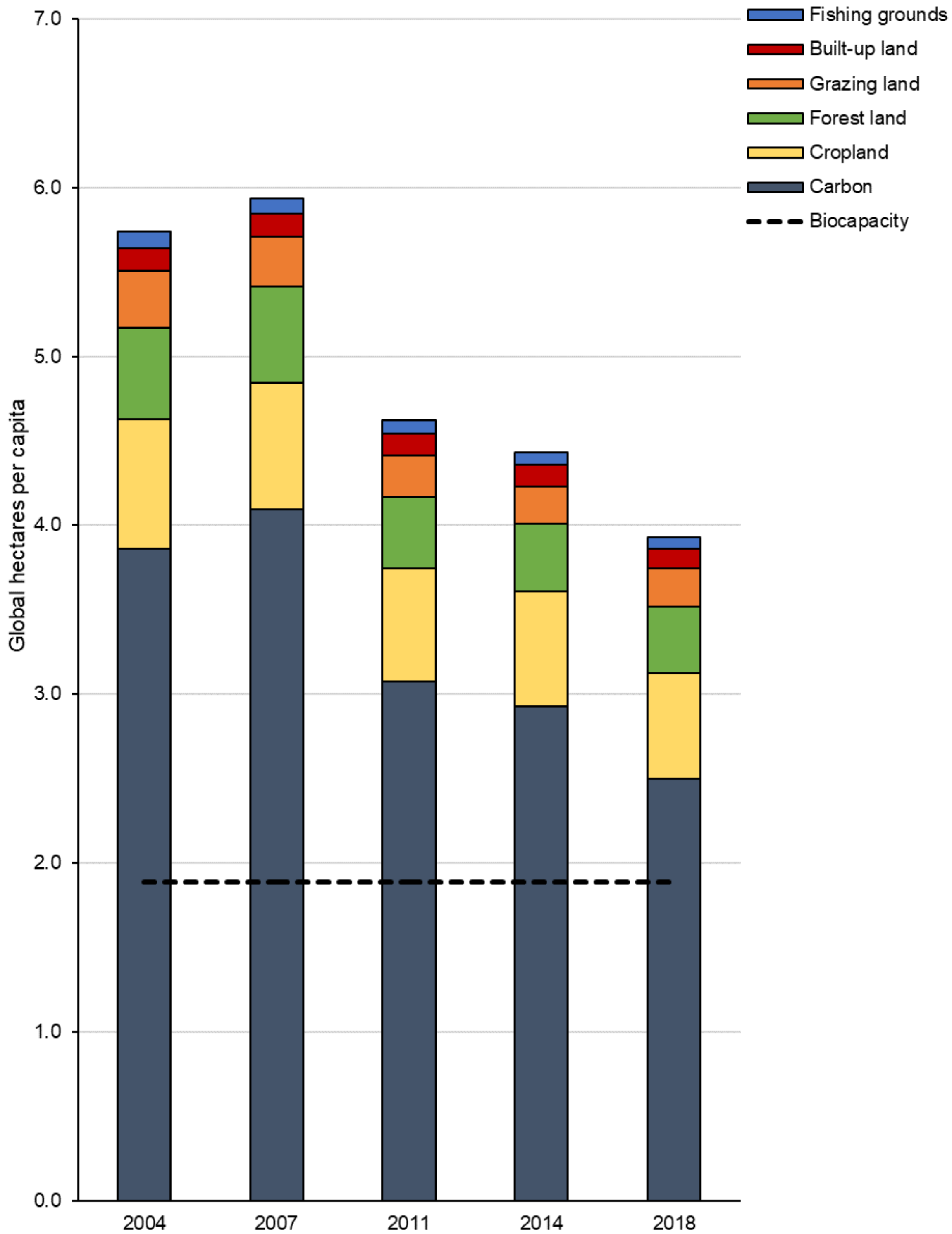


**Figure 6.** Per capita Ecological Footprint for Wales (gha) by 6 land-types (from bottom to top, carbon, cropland, forest land, grazing land, built-up land, and fishing grounds) in 2004, 2007, 2011, 2014, 2018. The dotted horizontal line represents the Wales-average biocapacity per person in 2018, which is estimated based on the average productivity per area of the UK.

Figure 6 represents the annual changes in the Ecological Footprint of Wales, based on the coarser top-down approach. Looking at the data, it can be seen that Wales' Ecological Footprint has continuously decreased between 2004 and 2018. **The Ecological Footprint was 5.74 global hectares per person in 2004 (17.0 million gha in total), and after increasing in 2007, showed a consistent decrease over the remaining assessment years, 2011, 2014 until reaching the lowest value (3.93 gha per capita) in 2018 (12.3 million gha in total), representing a 31.5% reduction over the 14-year period.** During this time, the Ecological Footprints of Wales' cropland, pasture, forest land, fishing grounds, construction land, and carbon all decreased. Notably, the carbon footprint decreased significantly from 3.86 to 2.50 gha per capita, representing a 35.2% reduction.

A horizontal line is used to represent the Wales-average biocapacity per person (1.89 gha) estimated for the year 2018. Throughout the time period covered by this research, Wales has consistently been in an ecological deficit status, with levels ranging from 2.08 to 3.15 times higher than the ecosystem within Wales can supply.

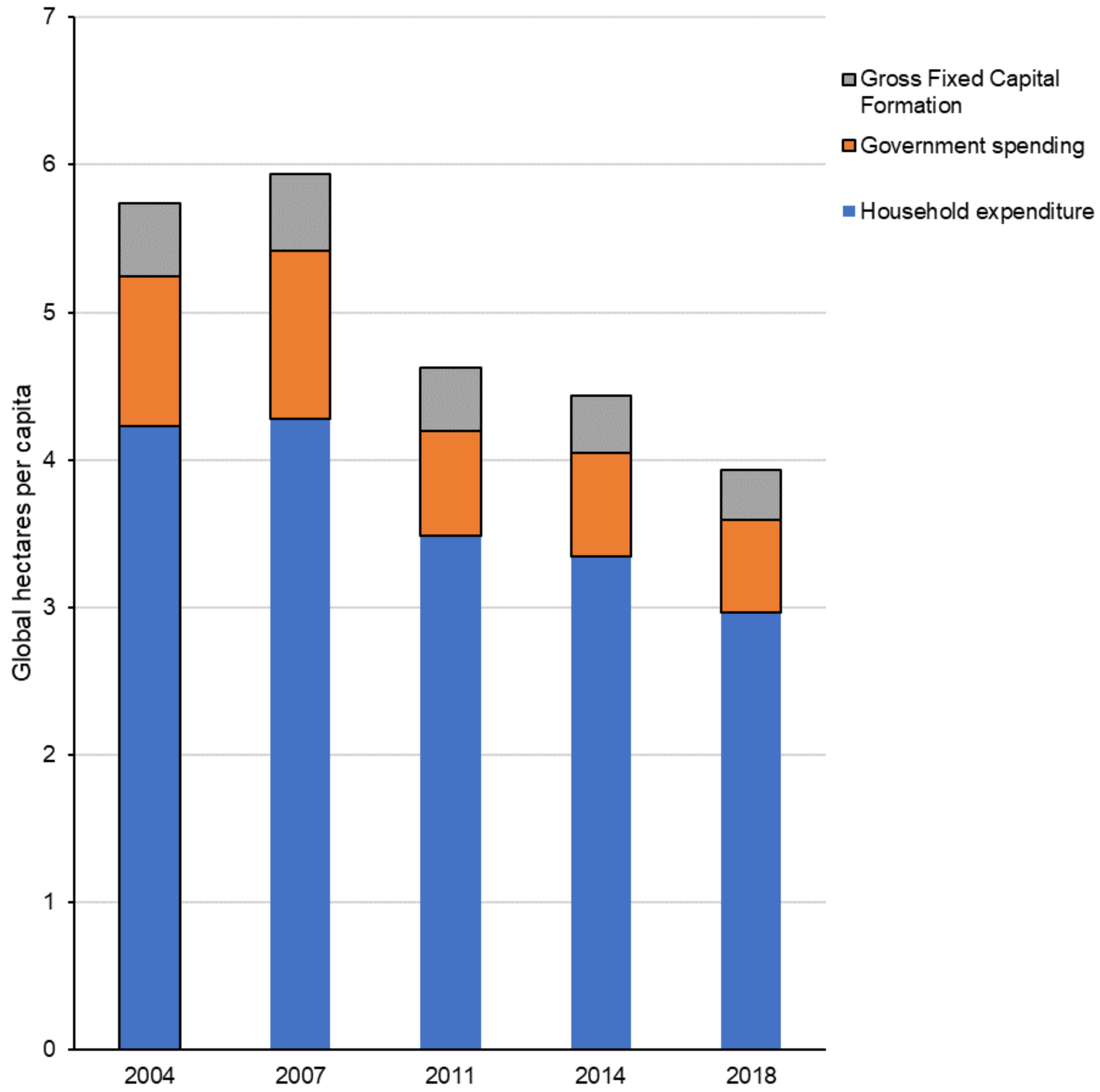


Figure 7. Per capita Ecological Footprint for Wales (gha) by 3 final demands in 2004, 2007, 2011, 2014, and 2018. Household expenditure is the bottom section of each bar, government spending the middle section and GFCF the top section.

Figure 7 shows the Ecological Footprint of Wales in terms of final demand, broken down into three categories: household expenditure, government spending, and gross fixed capital formation.

Between 2004 and 2018, the Ecological Footprint of Wales due to household expenditure has decreased by 31.9%, from 4.23 to 2.97 gha per capita. The Ecological Footprint due to government spending has also decreased, but at a lower rate than household expenditure, decreasing by 37.6% from 1.01 gha per capita in 2004 to 0.63 gha per capita in 2018. On the other hand, the Ecological Footprint due to gross fixed capital formation is relatively small, decreasing by 32.0% from 0.50 gha per capita in 2004 to 0.34 gha per capita in 2018. It is not possible to identify the exact reasons behind the decrease, but it is possible that factors such as the financial crash of 2008 and potentially electricity decarbonisation efforts may have played a role.

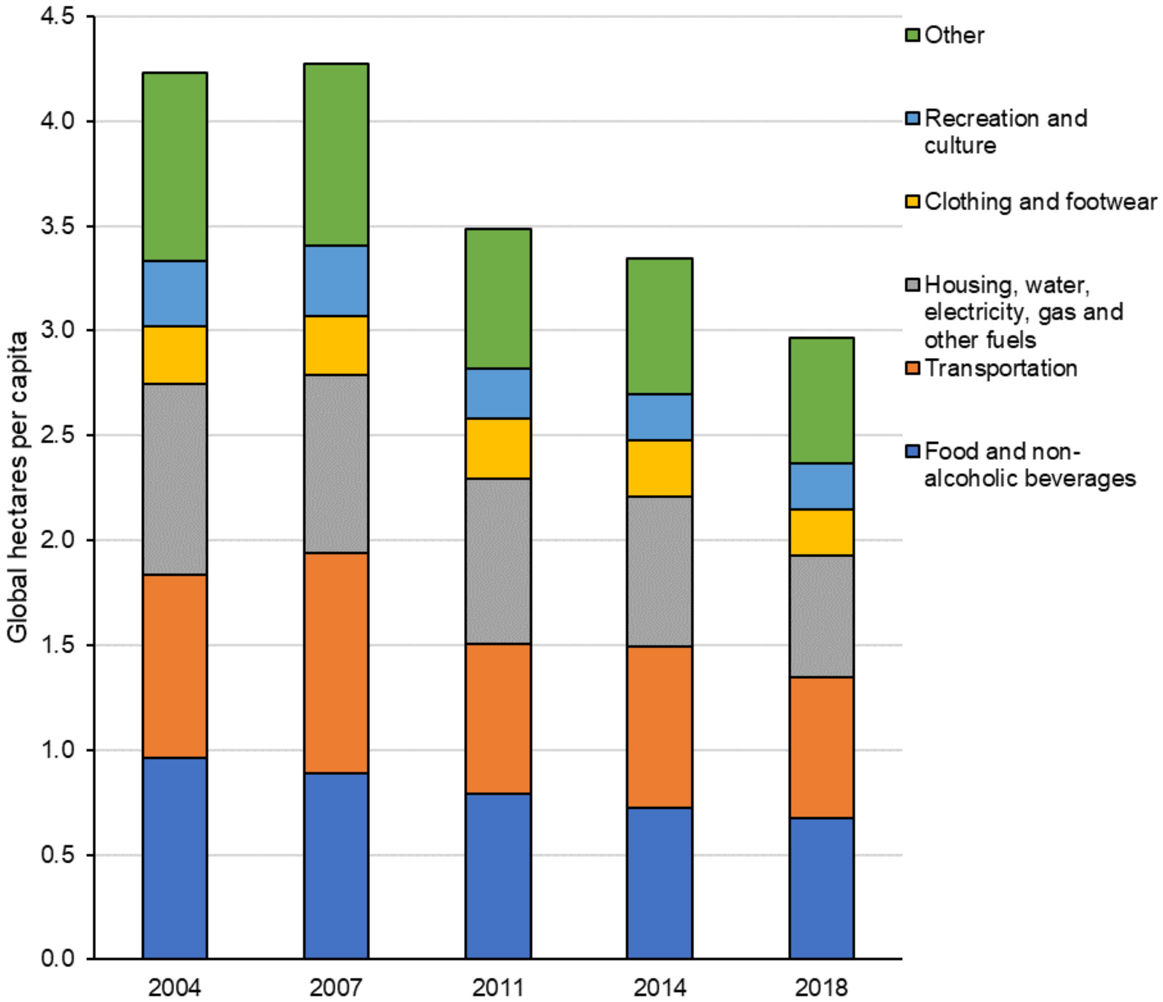


**Figure 8.** Ecological Footprint per capita for Wales (gha) by classification of individual consumption by purpose (COICOP) in 2004, 2007, 2011, 2014, and 2018. From bottom to top, the bars show the global hectares per capita for food and non-alcoholic beverages; transportation; housing, water, electricity, gas and other fuels; clothing and footwear; recreation and culture; and other. Other includes all other consumption categories within the COICOP classification. Note: A table in the accompanying datasheet also provides the information breaking 'other' down into each component category.

Figure 8 illustrates the changes in per capita Ecological Footprint in Wales due to household consumption. Firstly, the largest category is food and non-alcoholic beverages, which has decreased by 29.2% from 0.96 gha per capita in 2004 to 0.68 gha per capita in 2018.

Similarly, the category of housing, water, electricity, gas, and other fuels has also decreased, from 0.91 gha per capita in 2004 to 0.58 gha per capita in 2018, a reduction of 36.3%.

On the other hand, categories such as alcoholic beverages, tobacco, and narcotics, as well as clothing, footwear, transportation, restaurants, and hotels, have experienced slight fluctuations, but have not undergone significant changes overall.

### 2.3.3 Comparing the Top-Down Approach and Input-Output Approach for Ecological Footprint Assessment: Methodological Considerations and Implications

A range of calculation approaches exist to calculate the Ecological Footprint of Wales. Among the approaches used here, top-down (TD) and input-output (IO), both have the advantage of including the full upstream supply chain within the footprint. The challenges common to both approaches are also similar in the sense that they both heavily rely on the availability of input data.

The top-down approach has potential advantages in cost efficiency and scalability, consistency for multiple analyses, and developing efficient Key Performance Indicator (KPI) - monitoring frameworks. The top-down approach is based on the per-capita footprint of the larger territory, in this case the UK. With no additional input data, it assumes that the per-capita footprint of the sub-national unit, Wales, is equal to that of the UK. As additional information is gathered the result is further refined. In this report, 51 categories of consumer spending; consumer price indices to adjust for regional price differences; energy efficiency to adjust for emissions per unit of spending; and government spending were used to refine and calculate the Ecological Footprint of Wales at five time points from 2004 to 2018. As an alternative to consumer spending data, the availability of significant KPIs from statistical offices may also be used as input for annual monitoring of the Ecological Footprint.

The IO based approach has the advantage in providing sector level resolution and more significantly, can be used to analyse sector-sector flow of footprints. However, currently it is only possible to create a time series using the top-down approach. It is therefore the results from the top-down approach that will be used in Welsh Government's Wellbeing of Future Generations Act Milestone reporting (Welsh Government 2022a).

Differences between the methods that were used here and the methods that were used in a previous study of the Ecological Footprint of Wales (Dawkins *et al.* 2008) are discussed in Appendix 1. These methodological differences explain the slight discrepancy between the results presented in the previous study (giving an EF for Wales of 3.28 gha per capita in 2011) and those presented here (giving an EF for Wales of 3.49 gha per capita in 2011).

## 2.4 Discussion

The results provided several different ways of breaking down results to examine the Ecological Footprint of Wales, including land use type, industrial sector, final demand category, and household consumption category. Overall, the metric can be viewed as a measure of productivity-weighted land area consumption. Therefore, the metric is most sensitive to changes in consumption that place greater demand on ecosystem bioproduction, such as $CO_2$ emissions. On a global scale and for almost all global populations, the Ecological Footprint associated with energy use, particularly fossil fuels, represents our greatest demand on nature when considering the area of land that would be required to sequester the associated emissions. From this perspective, relative changes to consumption-based emissions would have the largest effect on Ecological Footprint results. Among consumption categories, those with the largest energy consumption tend to be major drivers of the carbon footprint. These include household energy use, and energy used for transportation. The carbon footprint is sensitive to changes in energy efficiency. Because results are presented from the consumption perspective, domestic energy efficiency changes will affect only part of the carbon footprint, while the remainder will be affected by energy efficiency changes in the global supply chain of imported goods and services.

The energy (productivity) transfer efficiency when using cropland products as feed for animals is an order of magnitude lower than that of direct human consumption, and therefore the metric is sensitive to shifts in diet. For beef production, results may actually be less sensitive than presented since $CH_4$ emissions are not currently calculated as part of the carbon footprint. For the same reason, shifts from plant-based to meat-based diets would also affect the crop-land footprint if livestock are fed by cropland products. The cropland footprint is the second largest land use component of the Ecological Footprint of Wales.

The top-down results assume that changes in relative consumer spending (price index adjusted) between the populations of UK and Wales reflect real differences in consumption and results are therefore sensitive to relative changes in spending and purchasing power.

# 3 Waste Component of the Ecological Footprint

## 3.1 Headline results

It is estimated that **6.35%** of the overall Ecological Footprint for Wales is associated with waste. 'Hotels and catering' and 'construction' were the two sectors with the highest waste components to their Ecological Footprints (24% and 14% respectively).

## 3.2 Introduction

For the purposes of this report, waste refers to "any substance or object which the holder discards or intends or is required to discard," as per the EU Waste Framework's definition.

From a resource perspective, sustainability accounting treats the human economy as a subsystem of the environment that both harvests and consumes resources from the environment and produces waste products that must be assimilated by the environment. Ecological Footprint and biocapacity accounting view this relationship through the lens of regeneration (using bioproductive land and water to replace natural resources that are consumed and absorb waste that is produced). For consistency in data and accounting, and to avoid double counting, the various demands on regeneration are counted at the point of harvest, extraction, or waste emission. The Ecological Footprint associated with food, for example, includes the total amount of resources that was harvested to produce the final amount that is consumed, inclusive of the amount that may have been wasted in the supply chain.

Waste is not a traditional category of the Ecological Footprint as high-level results are most often presented from the consumption perspective, but also can be broken down into production, imports, exports in the case of apparent consumption (physical accounts) and supply chain segments when in the case of consumption by final demand (IO based accounts). Whilst waste generation occurs across all subcomponents and stages, and is a direct consequence of consumption, it is not typically considered separately in consumption-based accounting. Economies also use resources and energy for the processing of waste. For the purposes of quantifying the resource efficiency of an economy, here we adopt the definition of the Ecological Footprint of Waste ($EF_{waste}$) as that which is associated with resources that enter the economy and are ultimately turned into waste; in other words, the embodied Ecological Footprint of resources that enter the waste stream. This is consistent with the definition used in the Ecological Footprint Impacts of the Welsh Waste Strategy (ARUP 2009).

The data available on waste associated with Wales relate to the waste produced in Wales, rather than the waste associated with Welsh consumption. Data are not available on the waste that is produced elsewhere in the world as part of supply chains for goods that are ultimately consumed in Wales. Similarly, Welsh waste data will include some waste that is discarded during the process of producing goods for export. Therefore, the Ecological Footprint of Waste is not directly comparable to the Ecological Footprint itself, as the Ecological Footprint is focused on the biocapacity required for Welsh consumption rather than on activities taking place within Wales. However, presenting the Ecological Footprint of Waste as a proportion of the total Ecological Footprint helps to give an understanding of the extent of the difference that could be made in a zero waste economy.

Full methods behind the results presented in this section can be found in Appendix 2.

## 3.3 Results

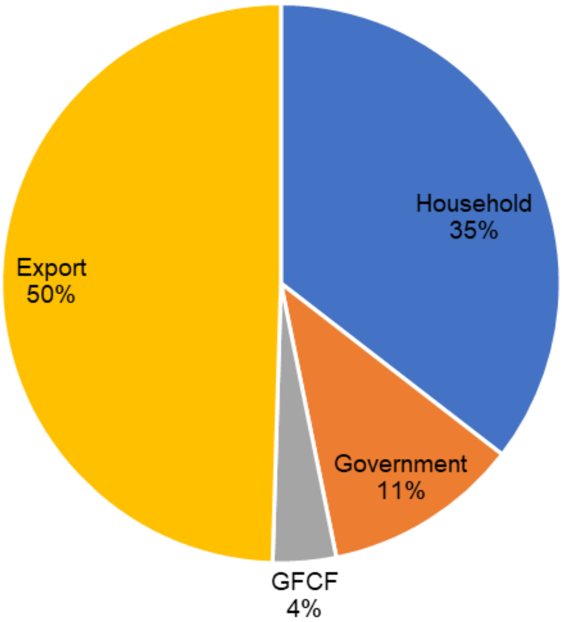


**Figure 9.** Pie chart of the Ecological Footprint of Waste (%) in Wales by 4 final demand types: household consumption, government consumption, gross fixed capital formation, and export. Note that export refers to waste produced in Wales during the process of producing goods that are subsequently exported (not waste that is exported itself).

In a broader context, the Ecological Footprint of Waste associated with consumption in Wales provides a limited context of all waste generated in Wales. Tracing the flow of all $EF_{waste}$ to its destination (noting that this is tracing the goods associated with the waste, not the waste itself) shows that 50% of the $EF_{waste}$ generated in Wales is embedded in exported goods and services and consumed outside Wales or by visitors (Figure 9). The remaining 50% is associated with consumption by households, governments, and gross fixed capital formation (GFCF) and makes up 35%, 11%, and 4% of the total $EF_{waste}$ generated in Wales. These categories refer to the waste produced associated with spending by each of these three groups (they are not traditional categories of waste as they have been broken down based on the economic data for comparability with the EF). Household consumption refers to short-term consumption by households, such as food, housing maintenance, goods, and services paid for and consumed within a fiscal year. Government consumption pertains to short-term consumption by governments, such as public services, schools, policing, and defence. Lastly, gross fixed capital formation includes long-term assets purchased by households (e.g. new houses, white goods), firms (e.g. machinery), and governments (e.g. transport infrastructure).

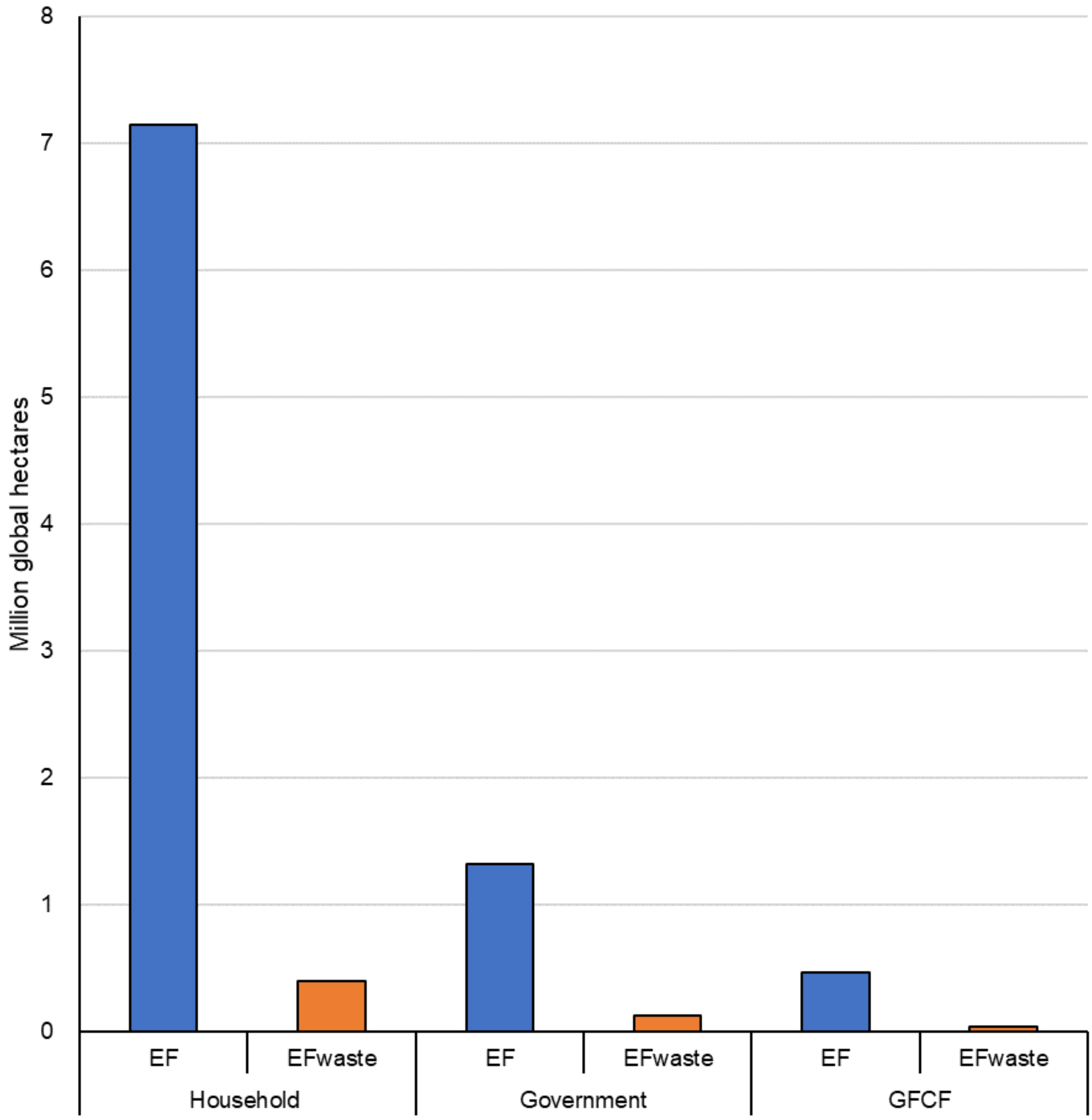


**Figure 10.** Total Ecological Footprint (gha) for Wales' domestic final demand and each corresponding Ecological Footprint of Waste in 2014 (gha). Note that here the waste figures have been converted into global hectares for comparability with the EF (i.e. how many hectares of average productivity were required to produce the material that was wasted and assimilate the carbon that was produced during the material's production?).

Overall, $EF_{waste}$ derived by domestic final demand in Wales accounts for 6.35% of the total Ecological Footprint. Figure 10 provides a detailed analysis of $EF_{waste}$ of how this differs for various final demand sectors, encompassing household consumption, government expenditure, and fixed asset investments. The corresponding $EF_{waste}$ provides insight into the quantity of waste generated by these activities.

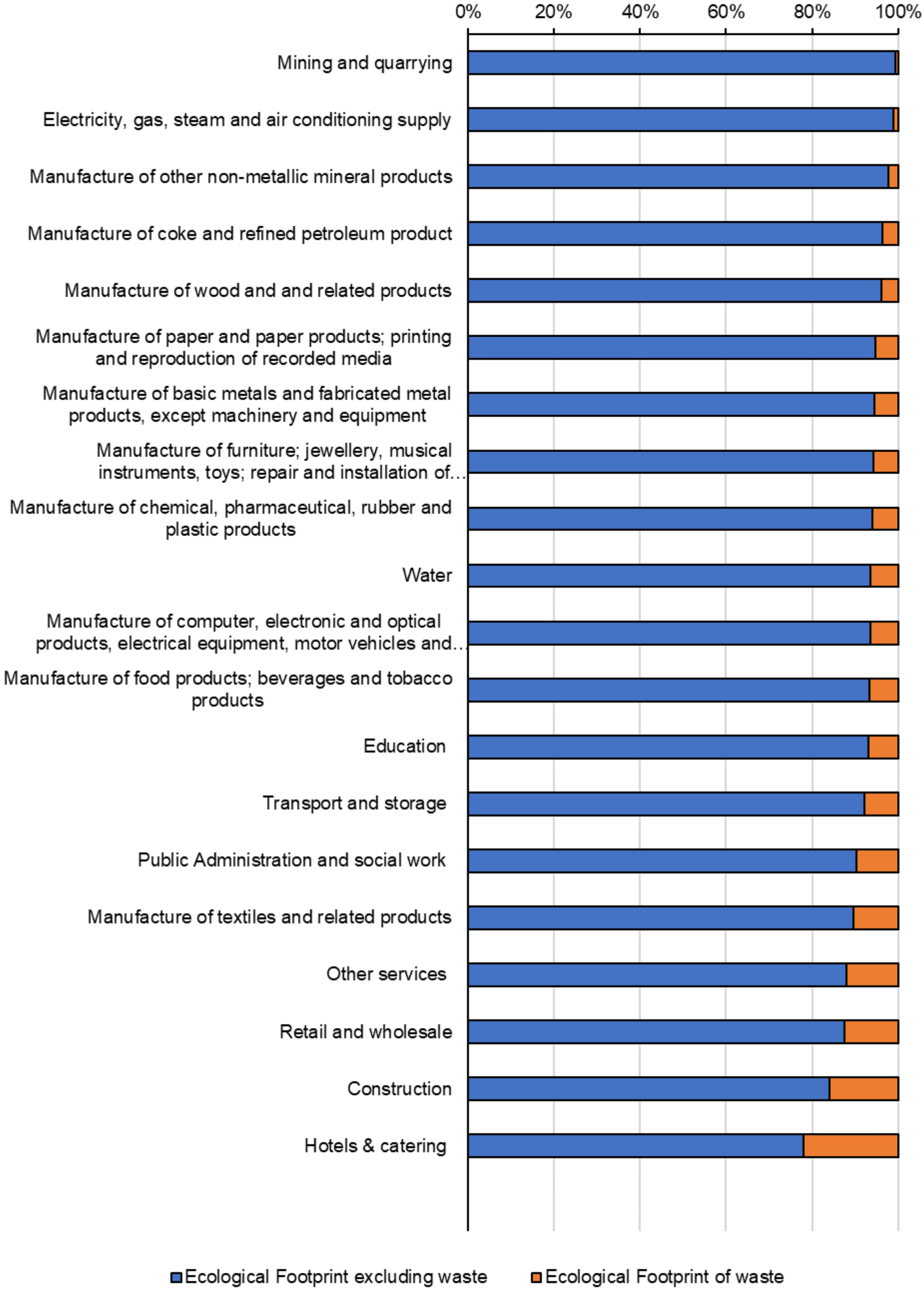


**Figure 11.** The percentage of the total Welsh Ecological Footprint that is made up of non-waste (shown on the left of each bar) and waste (on the right of each bar), for 21 sectors.

When $EF_{waste}$ is disaggregated into industrial sectors, two sectors stood out with a relatively large proportion of the total Ecological Footprint associated with waste. Consumption associated with the hotels and catering sector had the largest proportion, 22% of the Ecological Footprint coming from waste, followed by the construction sector, with 16% of the Ecological Footprint coming from waste (Figure 11).

Secondly, certain industries such as food processing, textile manufacturing have a relatively high proportion of to the total Ecological Footprint associated with waste, accounting for 7-11% of the Ecological Footprint. These industries in Wales need to explore more sustainable production methods to minimize their environmental impact.

Lastly, service industries such as the retail and wholesale and the other services sectors also have a relatively high proportion of to the total Ecological Footprint associated with waste, accounting for approximately 7 to 12% of the Ecological Footprint. These industries in Wales are required to focus on effective resource utilization and appropriate waste disposal methods.

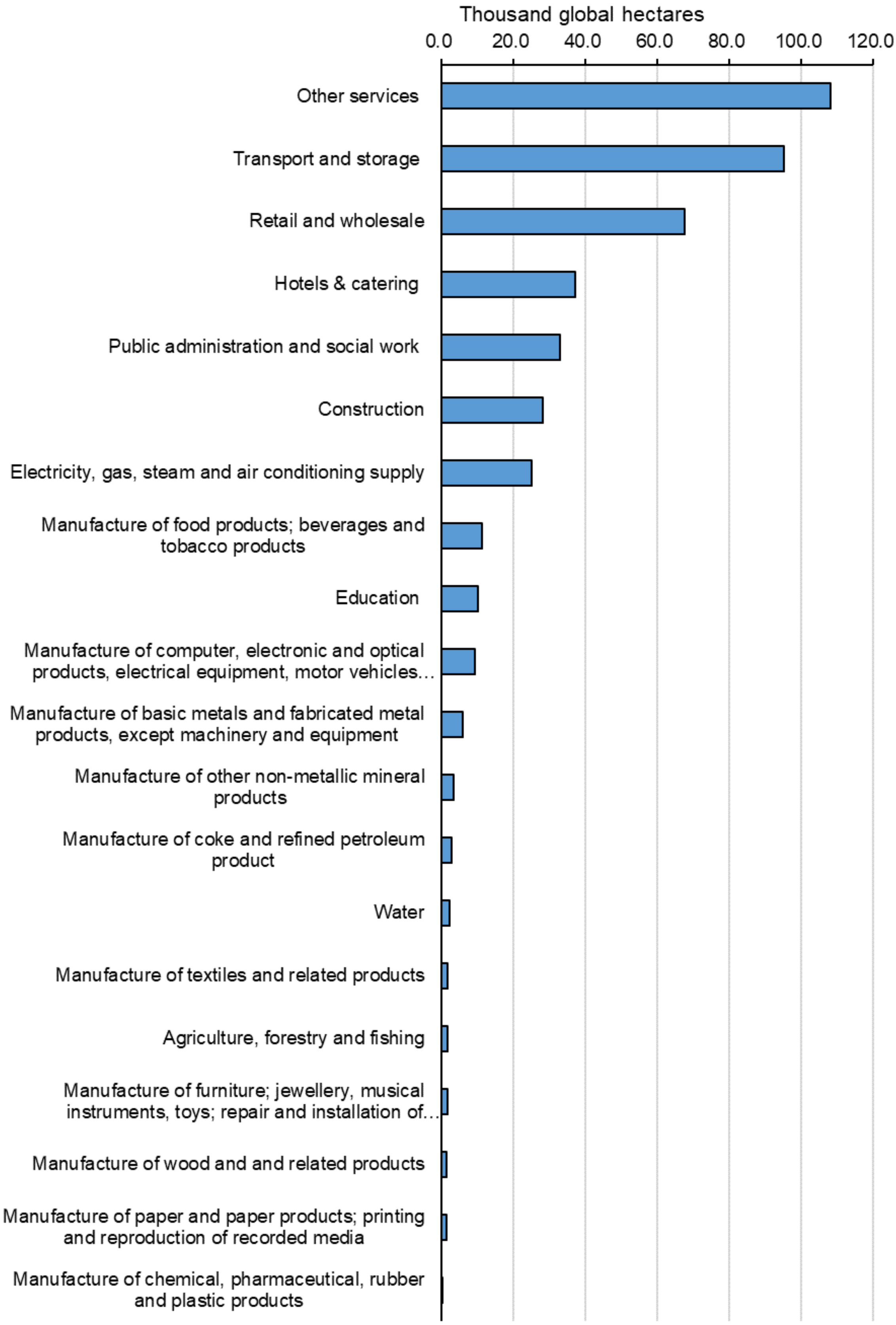


**Figure 12.** The Ecological Footprint of Waste by 21 sectors, expressed in thousand global hectares. Note: A table in the accompanying datasheet also provides the information broken down by $EF_{waste}$ relating to carbon and $EF_{waste}$ relating to biomass.

Figure 12 represents the amount of waste in Wales from the perspective of Ecological Footprint inherent in the waste and is shown by industry sector. $EF_{waste}$ (in gha) is divided into biomass-derived and carbon-derived (see datasheet).

Sectors such as the Transport, Retail and Wholesale, Hotels & Catering, Public Administration and Social Work, and Other services sectors show very high carbon-derived $EF_{waste}$ , indicating a significant impact on the environment. It is believed that in these sectors, not only reducing waste, but also initiatives such as improving energy efficiency are important.

In terms of the biomass-derived footprint of waste, the Manufacture of Food Products, Beverages, and Tobacco Products, Retail and Wholesale, and Hotels & Catering sectors show a high concentration in the total $EF_{waste}$. The respective ratios of biomass-derived $EF_{waste}$ in these sectors are 51%, 44%, and 27%, respectively.

On the other hand, the Mining and Quarrying sector has a very small biomass-derived footprint and relatively low carbon-derived $EF_{waste}$. Also, in the Electricity, Gas, Steam and Air Conditioning Supply sector, the biomass-derived footprint is very small. In these sectors, the energy source issue appears to be more important than the waste issue.

## 3.4 Discussion

The perspective of the EF of waste illustrates interesting differences in terms of waste intensity by sector.

- While the construction sector had the largest associated waste by mass, its $EF_{waste}$ was only the sixth largest of the 21 sectors, most likely because many construction materials, such as ores, aggregates, and minerals, have relatively low Ecological Footprint per tonne of material.
- Similar to the Ecological Footprint section, $EF_{waste}$ will be sensitive to waste products that place larger demand on biological production. The largest components would be due to carbon emissions.
- Biomass is a second major category associated with $EF_{waste}$ and, therefore, this metric will be sensitive to waste related to agricultural products and forest products.
- Elements of waste not covered by this analysis:
  - Ecological Footprint associated with waste processing.
- Ecological Footprint of waste not produced by Wales but imported and consumed in Wales.The allocation of the carbon footprint component to $EF_{waste}$ assumes the waste product has the same carbon intensity per tonne as all outputs from a sector. However relative reductions in waste from a sector may not necessarily reduce the carbon footprint by the same proportion.

The $EF_{waste}$ could be decreased by reducing, reusing, and recycling. The sectors that would be most effective to target with waste management policies if aiming to reducing the $EF_{waste}$ are Transport and storage, Retail and wholesale, and Hotels and catering, as they have the highest $EF_{waste}$ currently. Sectors in which waste makes up a high proportion of the total Ecological Footprint, such as Construction, could also be useful to target. With households making up a much larger proportion of the final demand than government spending or GFCF, households could also be useful to target, for example through information campaigns or further increasing kerbside recycling services. More targeted analyses such as using Life Cycle Assessment type approaches to understand the impacts of specific products within these sectors in more detail could be useful to inform waste policy in future.

# 4 Material Footprint (MF)

## 4.1 Headline results

Wales' Material Footprint was estimated to be 33,554 thousand tonnes in 2019, equating to 10.73 tonnes per capita. The 33,554 thousand tonnes make up 3.2% of the estimated UK total. Whilst some of the difference between the Welsh and UK results is because Wales has a much smaller population than the UK overall, some of it is also because each individual within Wales has a smaller material footprint than each individual within the UK on average; Welsh Material Footprint per capita is estimated to be 68% of UK Material Footprint per capita.

## 4.2 Introduction

### 4.2.1 What does the Material Footprint show?

The Material Footprint, also referred to as Raw Material Consumption (RMC), is a framework to measure the mass of extracted material associated with the final demand or consumption of products and services in an economy. Excluding water and air, the Material Footprint tracks all solid, liquid, and gaseous raw material flows that are used as inputs into the economy and is subdivided into four categories: biomass, metal ores, non-metallic minerals, and fossil fuels.

### 4.2.2 Limitations

The Material Footprint is often used as a crude proxy of overall pressure on the environment. It can be assumed that the use of more material will likely have more impact. However, it does not provide estimates of specific impact types. It is possible therefore that high usage of a low-impacting commodity would result in a high Material Footprint but a low environmental impact, and vice versa. It should also be noted that the methods used to produce this Welsh Material Footprint differ slightly from the methods used to calculate the Office for National Statistics' UK Material Footprint, so care should be taken if comparing the two. More details on the method used can be found in Appendix 3.

## 4.3 Results

Figure 13 illustrates the Material Footprint generated by three final demand categories (households, government, and GFCF), broken down into four sub-components: biomass, material ores, non-metal ores, and fossil fuel. The Total Material Footprint amounted to 33,554 thousand tonnes. This makes up 3.2% of the estimated UK total, or 68% of the total per capita. Of this, households generated 20,792 thousand tonnes, government generated 5,586 thousand tonnes, and GFCF generated 7,176 thousand tonnes. When converted to percentages, households account for 62%, government for 17%, and GFCF for 21%.

Analysing the Material Footprint by four components, fossil fuels account for the largest amount at 14,942 thousand tonnes, followed by non-metal ores at 11,221 thousand tonnes. In contrast, the production of biomass is 6,641 thousand tonnes, and the production of metal ores is 751 thousand tonnes.

Fossil fuel is the primary contributor to household Material Footprint (11,289 thousand tonnes), accounting for approximately 54% of household-related Material Footprint, followed by biomass Material Footprint (5,627 thousand tonnes, 27%). Material Footprint derived from government spending mainly consists of fossil fuel and metal ores related Material Footprint, which account for 2,899 and 2,155 thousand tonnes, respectively. Finally, the Material

Footprint generated by GFCF has a significant non-metal ores component (5,708 thousand tonnes), which represents 80% of GFCF-related Material Footprint.

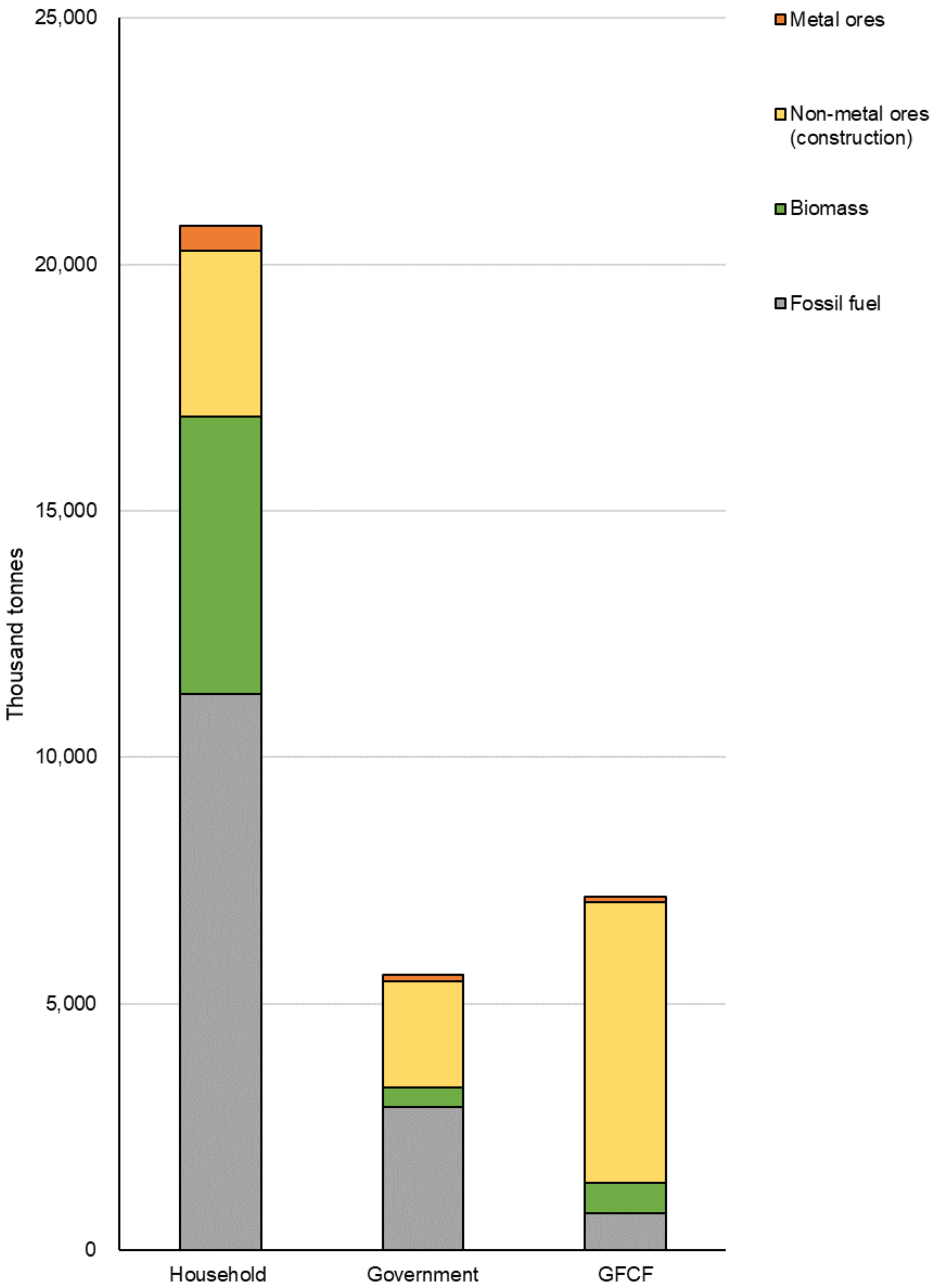


**Figure 13.** Total Material Footprint (thousand tonnes) in Wales by 3 final demand categories, broken down into 4 sub-components (from bottom to top, fossil fuel, biomass, non-metal ores (construction) and metal ores).

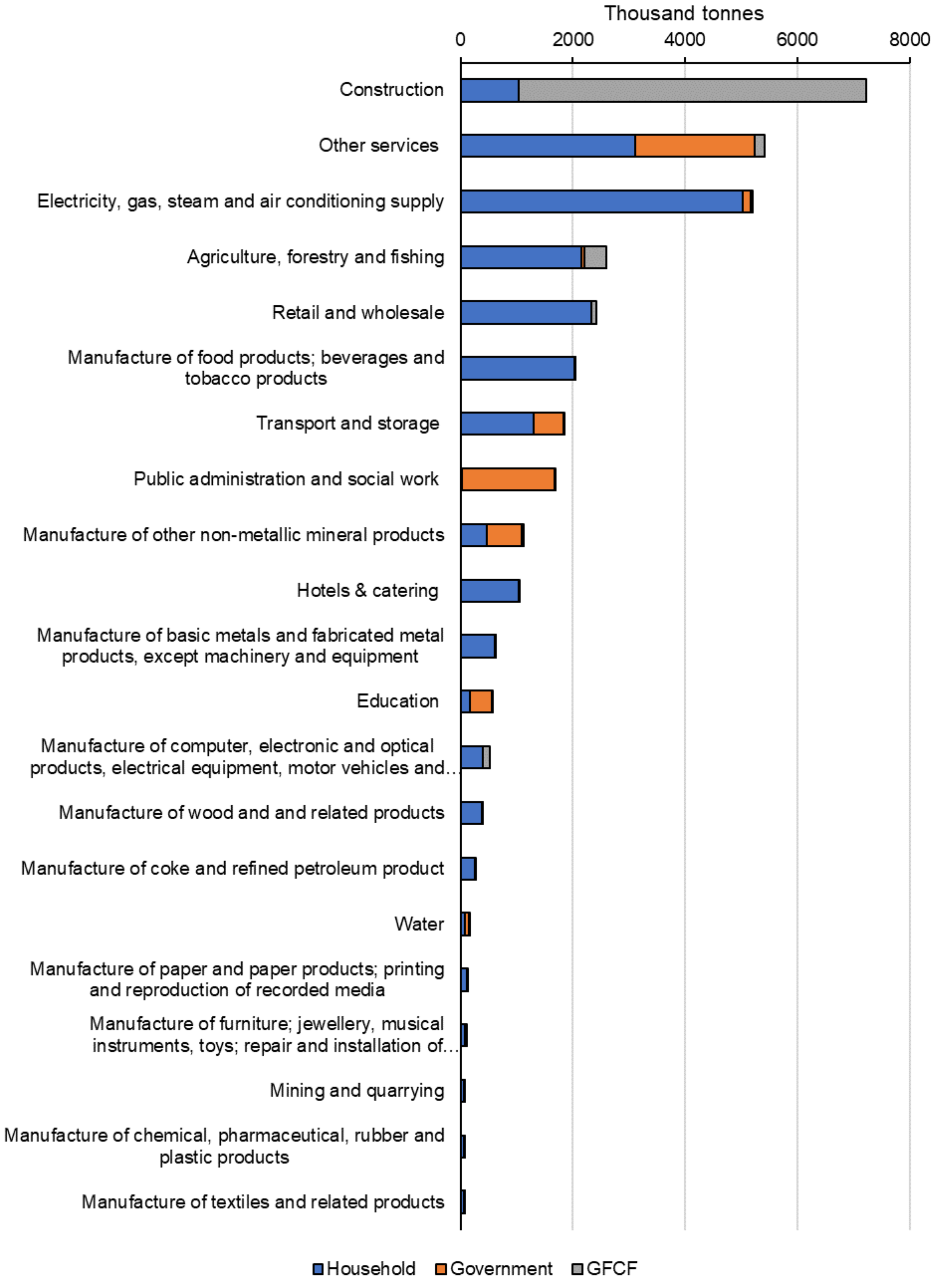


**Figure 14.** Total Material Footprint (thousand tonnes) for Wales by 21 industrial sectors, broken down into 3 domestic final demand categories: household (left of each bar), government (middle), and gross fixed capital formation (right). See also the accompanying datasheet.

When examining the Material Footprint by three final demand categories across 21 sectors, the results indicate clear patterns in which final demand contributes to which sectors (Figure 14). This provides a basis for determining the appropriate approach to reducing the Material Footprint by sectors, based on the type of final demand, to achieve sustainable consumption and production.

Household demand is the primary driver across sectors, with the Electricity, gas, steam, and air conditioning supply sector forming a large proportion of the total (5,031 thousand tonnes, accounting for 97% of the total Material Footprint for this sector). The Other services, the Retail and Wholesale, and the Agriculture, Forestry, and Fishing sector also drive a large component of the Material Footprint, with absolute values of 3,119, 2,329, and 2,151 thousand tonnes, respectively. These values contribute to 71%, 96%, and 83 % of the total Material Footprint in their corresponding sectors.

Government spending mostly contributes to the Other services and the Public administration and social work sector, accounting for 39% and 98% of these sectors, respectively, and contributing 2,120 and 1,653 thousand tonnes to the total Material Footprint in the sector.

The Construction sector, which has the highest Material Footprint among the 21 sectors at 7,232 thousand tonnes, is primarily driven by GFCF final demand, accounting for 6,200 thousand tonnes and 86% of the sector’s total Material Footprint.

Material Footprint varies significantly across different sectors (Figure 15). The following insights can be gleaned from the data:

As a whole, the Construction sector requires the highest amount of Material Footprint, which is approximately 7,232 thousand tonnes, accounting for 21 % of Wales’ Material Footprint. The high amount of Material Footprint is primarily due to non-metal ores related Material Footprint, 6,496 thousand tonnes, resulting from the significant consumption of building materials, machinery, and other materials required for construction projects.

The Agriculture, Forestry, and Fishing sector produce the largest amount of biomass-related Material Footprint, accounting for 2,114 thousand tonnes.

The Electricity, Gas, Steam, and Air Conditioning Supply sector generates the highest amount of fossil fuel Material Footprint, with a total of 5,212 thousand tonnes, representing nearly 15% of the industry's Material Footprint. This sector consumes substantial amounts of fossil fuels such as coal, oil, and gas for energy production. The Transport and Storage sector is the second-largest producer of fossil fuel-related Material Footprint.

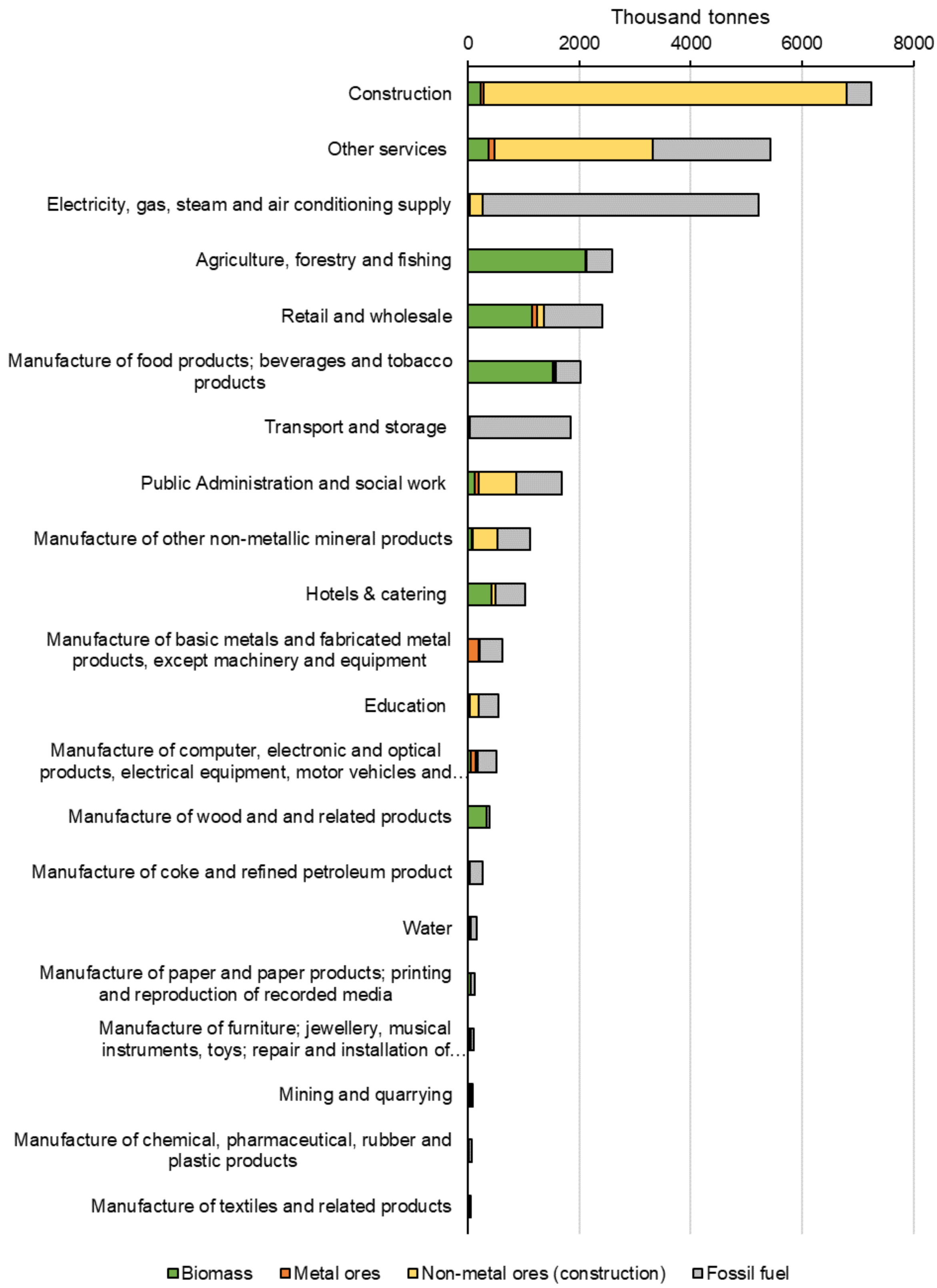


**Figure 15.** Total Material Footprint (thousand tonnes) for Wales by 21 industrial sectors, broken down into 4 sub-components: biomass (left of each bar), material ores (middle left), non-metal ores (middle right), and fossil fuel (right). See also the accompanying datasheet.

## 4.4 Discussion

The Material Footprint is a measure that translates all consumption into the total mass of the raw material equivalent and is presented in tonnes. It is the metric that measures Wales' performance against the one planet resource use by 2050 target set in the Welsh Government's circular economy strategy, Beyond Recycling.

The dominant driving factor for the Material Footprint is the consumption of high mass materials (in their final form) and materials that require the extraction of high mass materials within the supply chain (e.g. ores whereby higher volumes are extracted at earlier stages of the supply chain so are not visible to the final consumer). The two largest categories of the Welsh Material Footprint are fossil fuels and biomass.

Both changes in overall consumption and changes in efficiency of consumption would result in changes to the Material Footprint enabling Wales to move on a pathway towards its 2050 resource use goal. Examples would include developing a truly circular economy, increased servitisation (i.e. providing services rather than short life products), increased energy efficiency or transition from fossil fuel to solar energy use. While the largest fossil fuel Material Footprint is associated with the 'electricity, gas, steam and air conditioning supply' sector and 'transport and storage' sector, goods and services can also have significant embodied $CO_2$ emissions. Shifting construction material from wood to concrete or vice-versa may also result in relative changes to the Material Footprint and its composition.

Although not directly comparable (as based on different methods and from 2017, as the most recent year for which global data are available, rather than 2019), for broader context, the global Material Footprint in 2017 was 12.2 tonnes per capita. Although historically the UK has had a very high Material Footprint per capita compared to the rest of the world, recent increases in other countries (principally middle-income countries) coupled with a stabilising UK footprint (and a lower Welsh footprint per capita than the UK as a whole) mean that Wales MF per capita is closer to the global average than it once was. The extent to which the difference between the Welsh and global MF per capita is due to differing methods compared to actual differences cannot be established and so this comparison should viewed with caution. It should also be noted that current world average MF is increasing and unsustainable, so being close to the world average MF does not infer a sustainable level.

# 5 Global Environmental Impacts of Consumption (GEIC) Indicator

## 5.1 Headline results

Headline results for the Welsh GEIC indicators for 2018 and a comparison with equivalent UK statistics are shown in Table 1. The Welsh population in 2018 was 4.7% of the UK population, explaining a significant amount of the difference between the Welsh total and UK total, but Welsh consumption is also notably lower per capita than UK consumption.

**Table 1.** Estimated impacts of Welsh consumption across all GEIC impact metrics for Phase 1 (a) simple calculation) and Phase 2 (b) more complex calculation) versions of results, expressed as a total, per capita, a percentage of the UK total and a % of UK results per capita. Results relate to the year 2018.

**a) Phase 1 results**

| Metric | Welsh consumption | Welsh consumption per capita | % of UK total | % of UK results per capita |
|---|---|---|---|---|
| Production (tonnes) | 3,420,000 | 1.09 | 2.73 | 57.8 |
| Cropland harvested area (ha) | 413,000 | 0.13 | 2.57 | 54.6 |
| Tropical and subtropical deforestation (ha) | 884 | 0.0003 | 2.46 | 52.2 |
| Deforestation emissions including peat drainage (tCO2) | 439,000 | 0.14 | 2.44 | 51.8 |
| Deforestation emissions excluding peat drainage (tCO2) | 325,000 | 0.10 | 2.43 | 51.6 |
| Blue water (m3) | 180,000,000 | 57.6 | 2.40 | 51.1 |
| Green water (m3) | 1,770,000,000 | 565 | 2.53 | 53.9 |
| Scarcity-weighted blue water (m3) | 8,950,00,000 | 2860 | 2.43 | 51.5 |
| Species loss (species) | 1.58 | 0.0000005 | 2.52 | 53.6 |
| Species-richness weighted area (species-ha) | 144,000,000 | 46.1 | 2.50 | 53.1 |

**b) Phase 2 results**

| Metric | Welsh consumption | Welsh consumption per capita | % of UK total | % of UK results per capita |
|---|---|---|---|---|
| Production (tonnes) | 2,460,000 | 0.80 | 1.96 | 42.2 |
| Cropland harvested area (ha) | 314,00 | 0.10 | 1.95 | 41.3 |
| Tropical and subtropical deforestation (ha) | 669 | 0.0002 | 1.86 | 36.9 |
| Deforestation emissions including peat drainage ($tCO_2$) | 335,000 | 0.11 | 1.86 | 40.6 |
| Deforestation emissions excluding peat drainage ($tCO_2$) | 249,000 | 0.08 | 1.86 | 39.7 |
| Blue water ($m^3$) | 139,000,000 | 44.5 | 1.86 | 39.5 |
| Green water ($m^3$) | 1,350,000,000 | 431 | 1.93 | 41.1 |
| Scarcity-weighted blue water ($m^3$) | 6,860,000,000 | 2190 | 1.86 | 39.5 |
| Species loss (species) | 1.20 | 0.0000004 | 1.91 | 40.8 |
| Species-richness weighted area (species-ha) | 111,000,000 | 35.4 | 1.92 | 40.8 |

## 5.2 Introduction to the GEIC indicator

The 'Global Environmental Impacts of Consumption' indicator estimates environmental impacts (including biodiversity loss, scarcity-weighted water use and deforestation) caused by countries' or territories' consumption. The indicator is based on a modified (hybridised) form of MRIO (multi-regional input-output) modelling. MRIOs report the monetary inputs and outputs across different countries/territories and their commercial sectors (e.g. oilseeds, cattle farming, paddy rice, etc.) which can be used to assess the financial connections between different sectors and economies across the globe. The MRIO data are hybridised with physical production and trade data (tonnes of each commodity) from the Food and Agricultural Organisation, using the Stockholm Environment Institute's IOTA (Input Output Trade Analysis) modelling framework (Croft *et al.* 2018) to provide commodity specific estimates of production embedded within final consumption activities. These data are then combined with country/territory-specific datasets from the literature, linking commodity production to the associated environmental impacts within relevant production countries/territories (for more detail, see the full technical documentation). The main advantages of the hybridisation process are that it provides greater regional and commodity specificity and resolution than standard MRIO approaches (which is important when attempting to link to environmental impacts that can be highly commodity and place-specific), and a greater ability to account for commodities as they become embedded within products throughout the supply chain than standard physical trade data.

Key elements of the Global Environmental Impacts of Consumption Indicator:

- Links consumption to environmental impacts using modelled global origin-to-consumption physical trade flows.
- Commodity specific (impacts for a given consumer country/territory can be broken down by how much each commodity contributes to the total).
- Spatially explicit (impacts for a given consumer country/territory can be broken down by how much each producer country/territory contributes to the total).
- Goes beyond pressures (e.g. tonnes of material, hectares of land use) to also estimate associated impacts (e.g. hectares of tropical/subtropical deforestation, predicted species loss, scarcity weighted water use).

The indicator is being developed by JNCC and SEI under contract to Defra, with additional support from Trase and the Global UKRI Challenges Research Fund's Trade and the Environment Hub. To date, from the perspective of UK-related consumption activities, the indicator has only been available for the United Kingdom as a whole (i.e. individual nations within the UK have not been represented explicitly within the results). This project has developed a Welsh-specific version of the GEIC indicator by 'downscaling' the IOTA modelling framework in two different ways - via the integration of Welsh-specific expenditure, agriculture, and energy data (Phase 1) and via the integration of Welsh input-output data (Phase 2). The result is an assessment of the environmental impacts associated with Welsh consumption activities (with Phase 1 and Phase 2 results presented as separate versions). Details of the methodological process required to downscale the IOTA framework to Wales to generate Welsh-specific results are contained in Appendix 4. Details of the IOTA methods more generally, and the derivation of the environmental impact information linked to the hybrid-MRIO structure (which are identical in Welsh-downscaled and UK-scale GEIC results) are available (Croft *et al.* 2022).

It is important to stress that the results generated and shared here represent an initial exploration of downscaling the UK GEIC results for Wales with the data currently available, and do not represent results of equal or comparable confidence to the UK results themselves. Whilst the Phase 1 and Phase 2 methods represent a "simpler" and "more advanced" approach, respectively, both are subject to considerable constraints and limitations in terms of implementation and application, and results should accordingly be treated with caution.

Specifically, considerable reliance on the UK data were required to gap fill, interpolate, and extrapolate to complete estimations for the Welsh consumption results, and the Wales-specific data that were available often required significant manipulation and adjustment to fit and align into the broader global data space. A key consequence of this is that, within the methods adopted across the two approaches, different constraints have had to be adhered to which have a significant effect on the results. Importantly, the differences between the two sets of results, particularly in absolute terms, should not be interpreted too literally; the Phase 2 results typically have an overall magnitude between 72% and 77% of those from Phase 1. This difference should not be seen as necessarily reflecting a more accurate overall figure. Rather, whilst differences between absolute values should therefore be interpreted as being subject to considerable uncertainty, the methods from Phase 2 are believed to better represent the relative distributions of sources, commodities and impacts to the Welsh consumption footprint, and thus the results are useful for understanding linkages, dependencies and associated impacts, even if the absolute numbers are not deemed overly reliable.

Ultimately, although the results have been developed in a mathematically robust and logical manner, it is suggested that they should be seen as highly experimental and knowingly limited in accuracy due to the fundamental data paucity and inconsistency underpinning them. It is advised that, at this stage, they should be viewed and assessed in relative rather than absolute terms (i.e. as a hotspotting and ranking exercise from a Welsh consumption-perspective), rather than as means to apply accurate and meaningful numbers to specific supply chain flows and impacts. In terms of what GEIC offers, namely commodity/country granularity of supply and impacts, it is these allocations (i.e. which commodities and countries are most 'significant' from supply chain and impact perspectives) which are arguably the most important and useful component of the results.

## 5.3 Overview of Phase 1 results, Phase 2 results and UK average

Estimates obtained using Phase 2 methods have an overall magnitude between 72% and 77% of those obtained using Phase 1 methods. In particular, the per capita impacts of Welsh consumption estimated using Phase 1 methods are between 0.5 and 0.6 times that of the UK average across all impact types, while those estimated using Phase 2 methods are around 0.4 times that of the UK average (Figure 16). This discrepancy is large but – as described above – should be treated with caution given the requirement for balancing steps in the development of a Welsh-specific version of GEIC. Additional investigation would be needed to understand the drivers for the differences between results and the degree to which model assumptions in the illustrated implementations affect outputs.

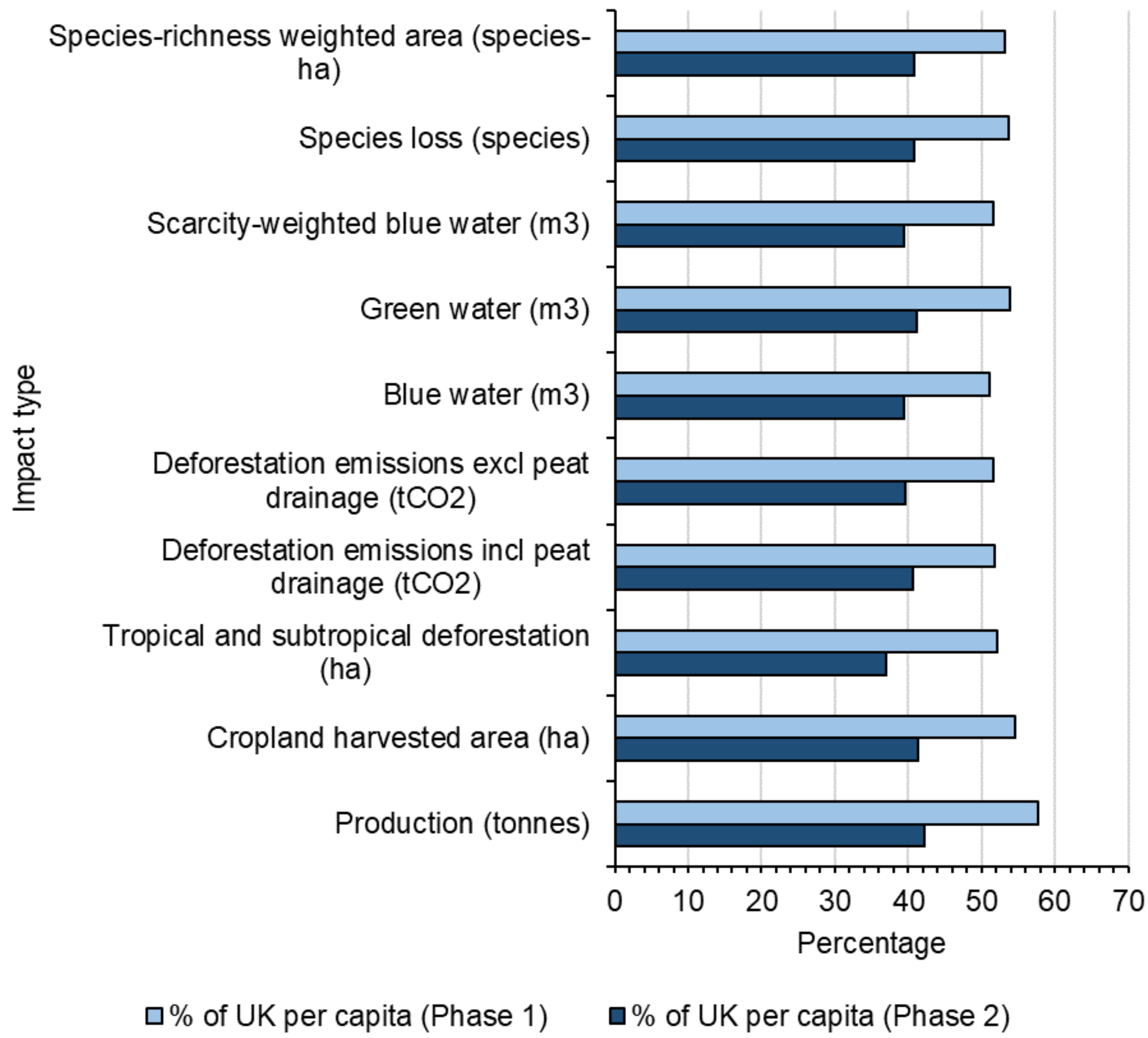


**Figure 16.** Per capita impacts of Welsh consumption as a percentage of the UK average for each impact type and each method used to calculate them (Phase 1 and Phase 2).

## 5.4 GEIC material footprint

These results provide the material requirements that Wales has for the commodities included in the GEIC indicator framework (i.e. agricultural crops, cattle-related materials and timber (industrial roundwood)). Due to this commodity scope and the application of an alternative hybrid-MRIO methodology in this section of the report, these results should not be compared directly to the Wales Material Footprint results described above, or the UK Material Footprint, but are useful for understanding how specific biomass-based material dependencies might interact with the impacts described in sections below. The Material Footprint does not measure an impact itself, but is often used as a crude proxy for overall pressure on the environment, and can be used to put the other impact metrics detailed below into context (e.g. is the impact of a particular commodity big because a lot of it is being consumed, or because the production of that commodity has high impacts in relation to other commodities).

The total GEIC material footprint for Wales for 2018 is estimated at 3.4 million tonnes (Phase 1 results) or 2.5 million tonnes (Phase 2 results). This equates to 1.09 tonnes (Phase 1) or 0.9 tonnes (Phase 2) per capita. Figures 17 and 18 show that the compositions by source and material of the UK and Welsh GEIC Material Footprints are largely similar. The biggest difference is the percentage of material that is UK-sourced: both Phase 1 and Phase 2 methods suggest that this is higher in Wales (28% and 25%, respectively) than in the whole of the UK (21%). Both Welsh results suggest a relative contribution of wheat that is higher than the UK average.

Figure 19 provides a treemap diagram of the breakdown of the Welsh material footprint (Phase 2 results shown, year 2018) by commodity and country. For many of the most important commodities in terms of their total contribution to the material footprint (e.g. wheat, industrial roundwood, sugar beet, barley, potatoes) supply from the UK dominates. Notable exceptions are sugar cane (where Brazil in particular is a key source), maize (where Ukraine and France, the US and Brazil are key sources), oil palm (Indonesia, Malaysia) and soybeans (United States and Brazil). For each commodity, the estimated spatial distribution of the material footprint of Welsh consumption is similar but not identical to that of the UK. Since Wales exists within the UK, similarities are of course expected, but they may be exaggerated by the reliance on UK aggregate data when implementing the downscaling methods. Differences occur due to the use of Welsh-specific final demand and trade data, which propagate through the model to determine upstream impacts.

This metric ultimately provides an overview of what quantities and sources of material the Welsh economy is dependent upon. Therefore, the metric would be sensitive to:

- Changes in overall consumption/purchases of materials by consumers, reflected in increased or decreased expenditure within the MRIO structure being used to estimate changes in the total amount consumed in tonnes.
- Changes in production and prices, which will influence the quantity of commodity entering the global supply chain, how this is traded internationally, and the physical quantity that relative levels of expenditure will procure.
- Changes in the sourcing patterns of materials, as captured via either physical trade flows, inter-sectoral MRIO transactions, or both within the hybrid MRIO structure. This means that the metric would be sensitive if switching supply between sectors or regions with different material-use efficiencies. For example, if diets were trending away from beef and the cattle sector, with an associated increase in plant proteins, this would represent a change from a sector with low-material use efficiency (many tonnes of input are needed per unit output) to a sector with higher material use-efficiency. Similarly, if shifting supply from a country with low material-use efficiency to one with

high material-use efficiency, this would be reflected in the results. However, consideration must be given to the fact that if there is still a buyer willing to accept the less efficient products elsewhere (e.g. due to price or convenience), changing sourcing patterns risks simply displacing impacts into other markets and therefore not creating any difference overall.

- Increases in material-use efficiency by the sectors within the global economy on which Wales' consumption depends. For example, the metric would show change if a new process is developed that means it is possible to produce the same amount with less raw commodity input.

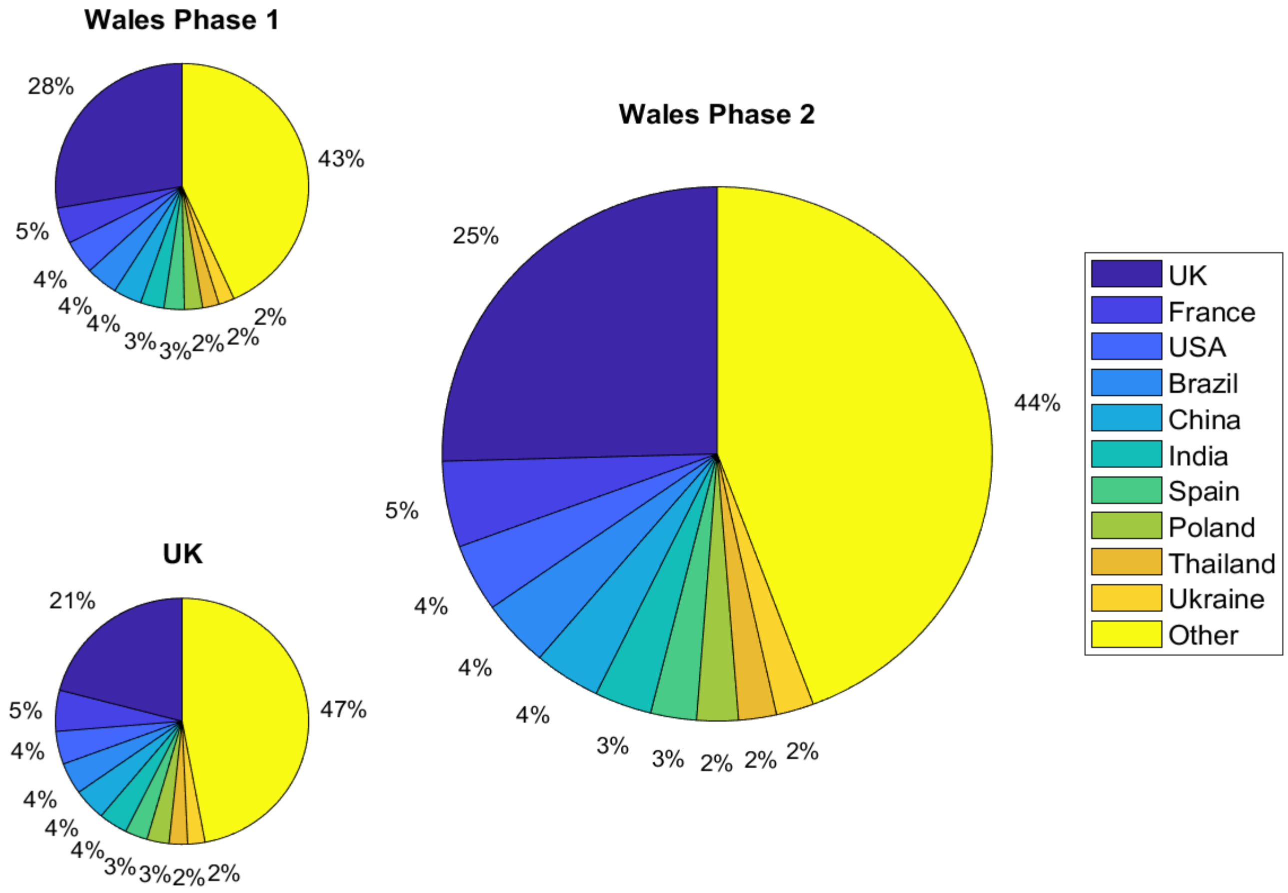


**Figure 17.** Pie charts representing the composition by country of GEIC material footprint (tonnes) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. At this level, the results from the Phase 1 and Phase 2 methods are relatively similar, with the biggest difference being the estimated percentage of Welsh material footprint that comes from within the UK; the results obtained using Phase 1 methods are slightly higher than that obtained using Phase 2 methods. In both cases, this component is larger than the UK average. 'Other' covers the rest of the world; a more detailed breakdown of results to a wider range of countries can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with UK as the biggest slice shown (top left) and Ukraine the smallest.

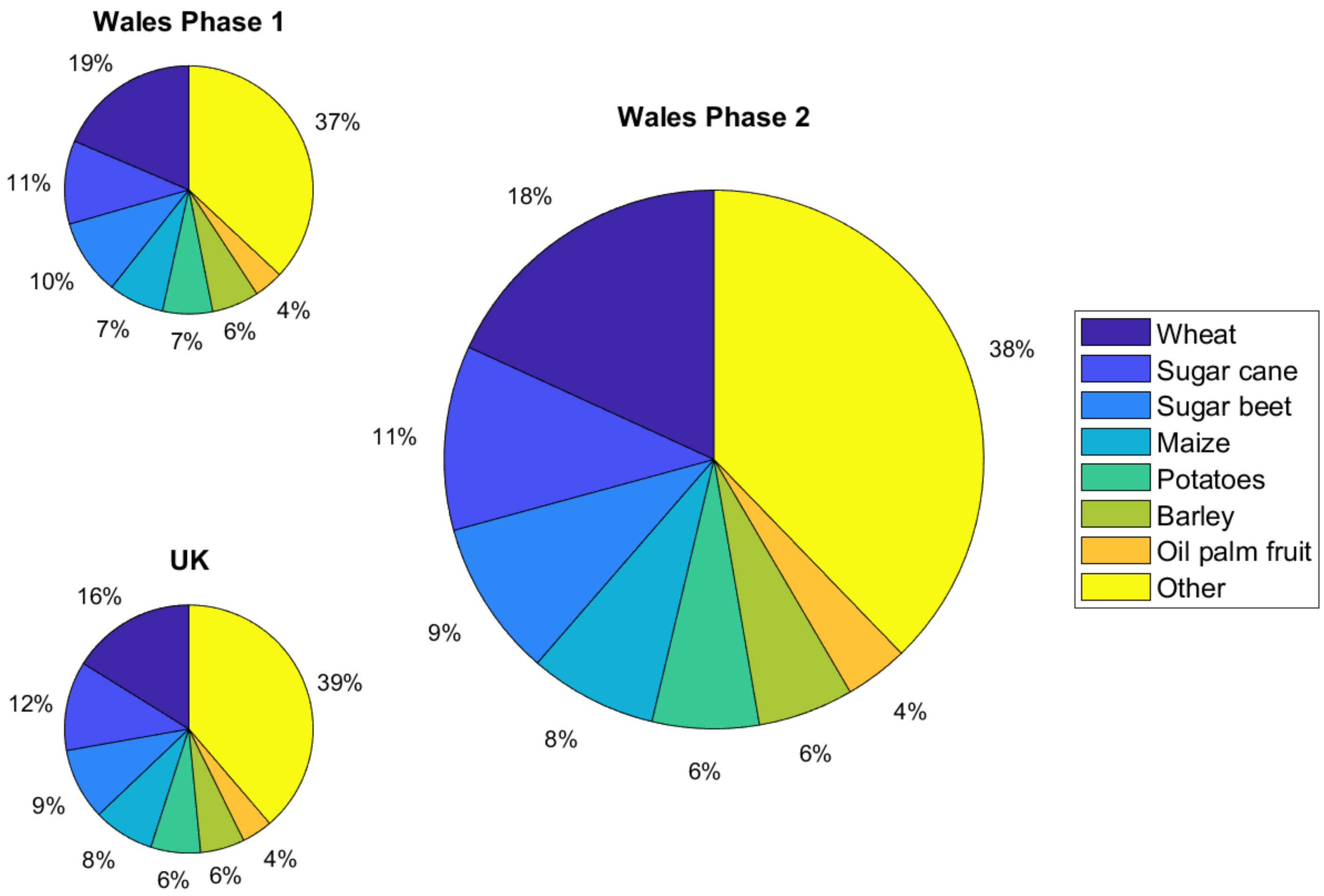


**Figure 18.** Pie charts representing the composition by commodity of material footprint (tonnes) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers all other agricultural crops, timber and cattle related products beyond those listed in the key; a more detailed breakdown of results to a wider range of commodities can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with wheat as the biggest slice shown (top left) and oil palm fruit the smallest.

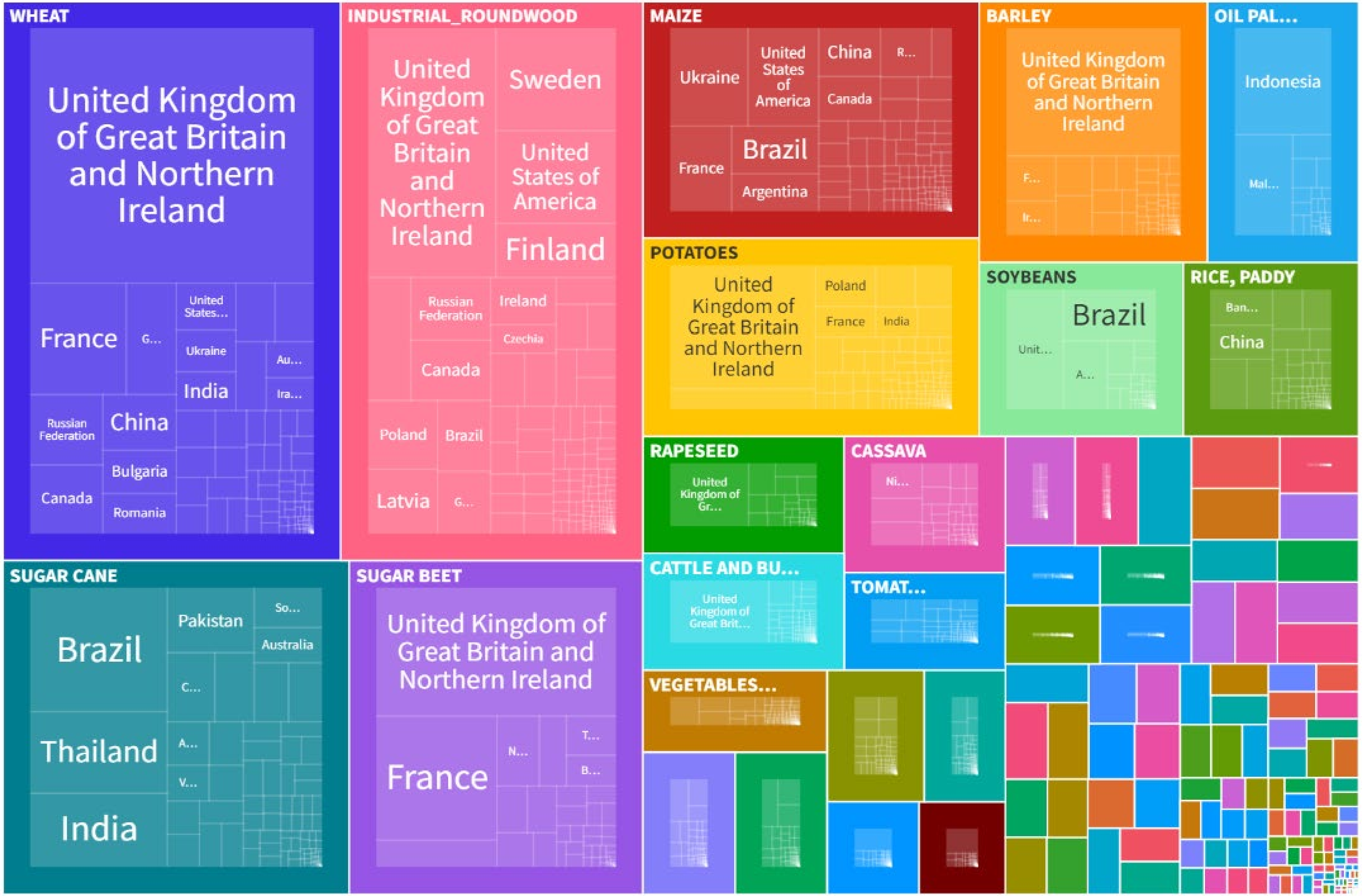


**Figure 19.** Treemap of Welsh GEIC material footprint (tonnes), arranged and coloured by commodity. The area of each rectangle is proportional to its contribution to the Welsh material footprint. Note: Full details and numerical results can be found in the accompanying dataset.

## 5.5 Crop land use

Results for land use utilise reported statistics on the cropland area harvested from FAO which (alongside FAO production data, tonnes) provide intensities of land area required per unit of crop production. These intensities are applied to the calculated mass flows (material footprint) data. More details can be found in Croft *et al.* (2022). When applied to the Welsh GEIC indicator framework, this provides estimates of Wales' consumption-based land use associated with crop products. Note this metric is currently applied to crop commodities only, meaning that timber and cattle-related products are not covered by the metric.

The total GEIC cropland harvested area for Wales for 2018 is estimated at 413,614 hectares (Phase 1 results) or 313,880 hectares (Phase 2 results). In common with the equivalent results for the material footprint, both sets of Welsh results suggest a higher contribution of UK land area and wheat-linked land area compared to the UK average, with Phase 1 results suggesting the largest relative cropland contribution is from land within the UK (Figures 20 and 21).

Figure 22 provides a treemap diagram of the breakdown of the Welsh cropland harvest area footprint (Phase 2 results shown, year 2018) by commodity and country. This illustrates the dominance of wheat as a core component of the footprint, with UK production forming a significant proportion but international land providing the bulk of supply. Rapeseed and barley footprints are also primarily UK supplied, but with significant overseas components. In contrast, supplies of soybean and maize rely almost exclusively on overseas land area.

In addition to the attributes described above for the material footprint metric, which are also relevant to this metric, the cropland area metric will also be sensitive to:

- Changes in the yields associated with crop production systems, with higher yields reducing land requirements per unit output.
- Switching in sourcing patterns between sectors or regions with different yield intensities. For example, it would pick up if supply of a given commodity were switched from a country with high yields (which would give a lower land use estimates) to a country with low yields (higher relative land use per unit production).

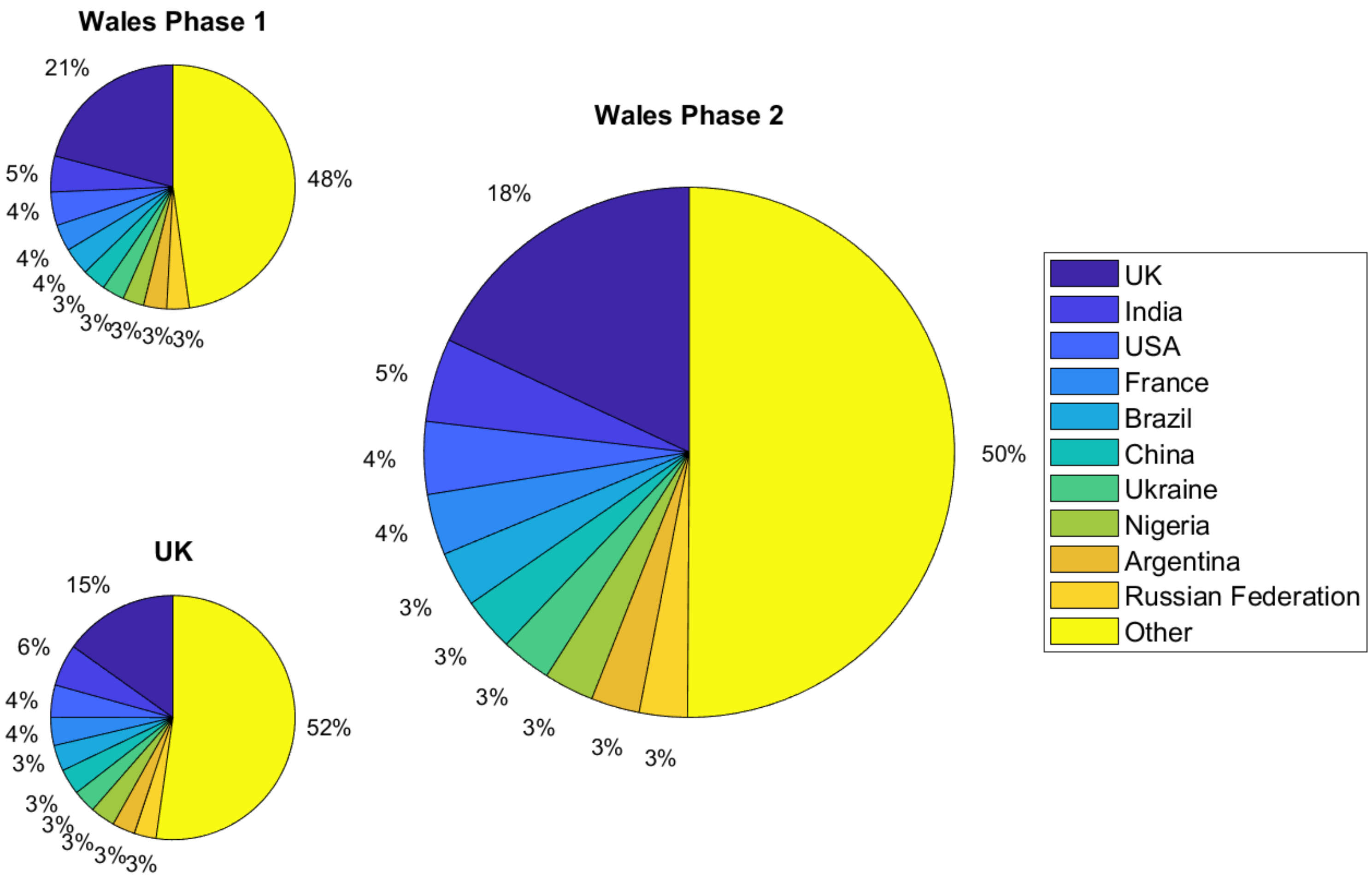


**Figure 20.** Pie charts representing the composition by country of cropland harvest area (ha) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers the rest of the world; a more detailed breakdown of results to a wider range of countries can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with UK as the biggest slice shown (top left) and Russian Federation the smallest.

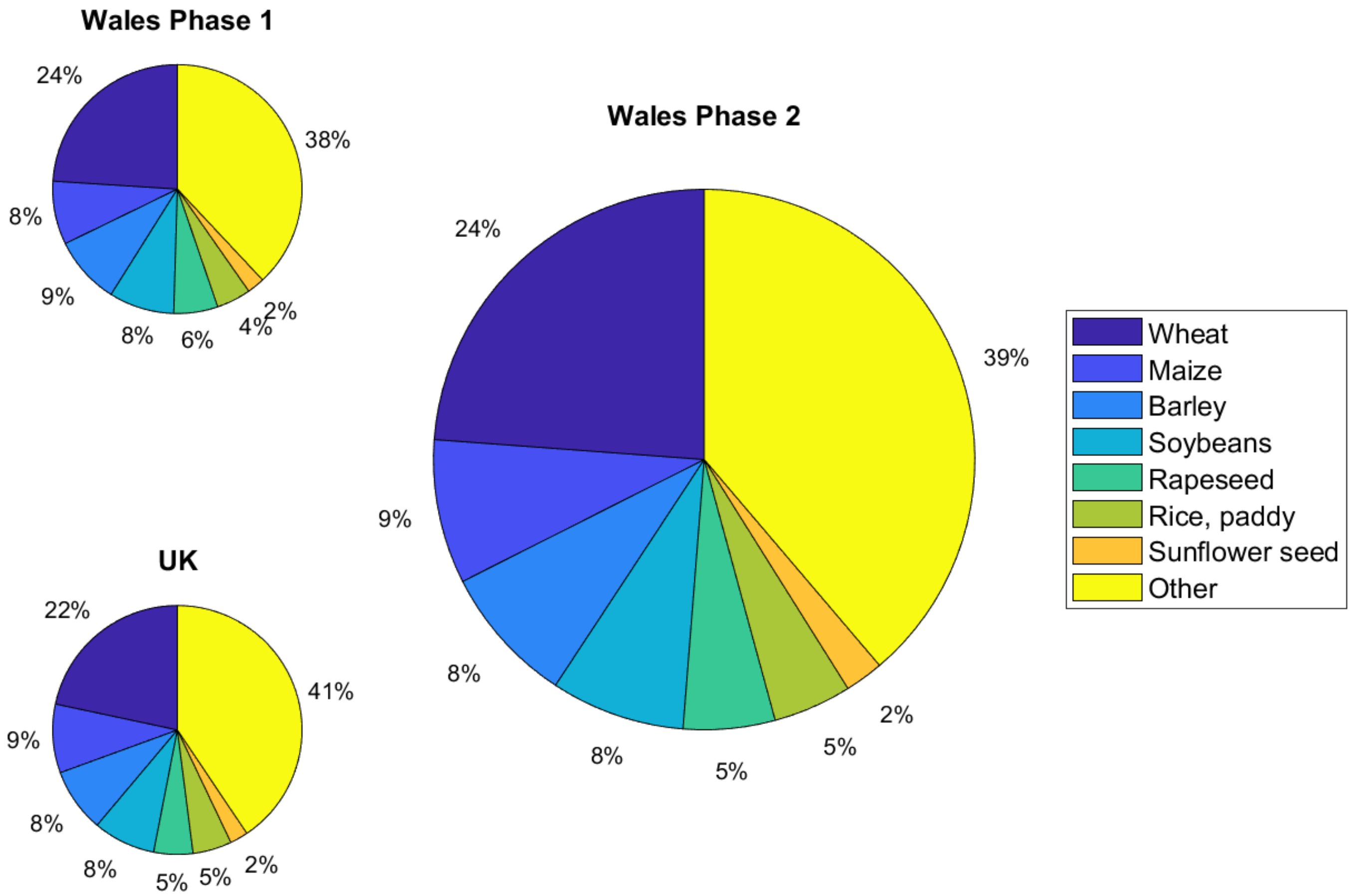


**Figure 21.** Pie charts representing the composition by commodity of cropland harvest area (ha) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers all other agricultural crops, timber and cattle related products beyond those listed in the key; a more detailed breakdown of results to a wider range of commodities can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with wheat as the biggest slice shown (top left) and sunflower seed the smallest.


**Figure 22.** Treemap of Welsh GEIC cropland harvest area footprint (hectares), arranged and coloured by commodity. The area of each rectangle is proportional to its contribution to the Welsh cropland harvest area footprint. Note: Full details and numerical results can be found in the accompanying datasheet.

## 5.6 Deforestation and deforestation-related carbon emissions

Results for deforestation are derived from the Pendrill *et al.* (2022) dataset that uses a 'land balance' approach to combine remote-sensing derived deforestation data with estimates of crop and pasture expansion (non-geospatial). This currently covers tropical and subtropical deforestation activities only, due to difficulties in attributing (e.g. temperate deforestation to agricultural activities), where much forest loss is temporary and associated with fire and/or managed forestry activities. More details can be found in Croft *et al.* (2022). When applied to the Welsh GEIC indicator framework, this provides estimates of Wales' consumption-based exposure to tropical and subtropical deforestation.

The total GEIC tropical and subtropical deforestation footprint for Wales for 2018 is estimated at 884 hectares (Phase 1 results) or 669 hectares (Phase 2) results. In general, it appears that results associated with Welsh consumption obtained using Phase 1 and Phase 2 methods are closely aligned in terms of their country and commodity composition, both to each other and to the UK average (Figures 23 and 24). This implies that the two methods provide results that are relatively consistent when used as a hot-spotting tool for the sources and commodity drivers linked to tropical deforestation. Results for the composition of deforestation emissions are also relatively consistent across the methods (not shown). The total GEIC tropical and subtropical deforestation emissions footprint (including peat) for Wales for 2018 is estimated at 438,585 tonnes $CO_2$ (Phase 1 results) or 334,775 tonnes $CO_2$ (Phase 2 results).

Figure 25 provides a treemap diagram of the breakdown of the Welsh deforestation footprint (Phase 2 results shown, year 2018) by commodity and country. This illustrates the important association of a variety of countries (Brazil, Australia, Angola, Mozambique) with cattle production - the largest single commodity contribution to the Welsh footprint. Indonesia dominates the deforestation risk profile of the second largest contributor, palm oil, with deforestation in Colombia also notable. For industrial roundwood, soy, and maize, Brazil is the largest contributor. For coffee, Colombia stands out.

The Welsh GEIC data also provides emissions estimates associated with the deforestation activities. Figure 26 provides a treemap diagram of this breakdown (Phase 2 results shown, year 2018) by commodity and country for emissions, including those from peat. From an emissions perspective, palm oil is the largest contributing commodity.

In addition to the attributes described above for the material footprint metric, which are also relevant to this metric, the deforestation metric will also be sensitive to:

- Changes in the amount of subtropical and tropical deforestation detected via remote sensing.
- Relative rates of expansion or contraction of cropland (and individual crops), pasture and plantations, as reported nationally to (or estimated by) FAO.
- Switching in sourcing from tropical and subtropical areas to temperate areas (where agri-commodity deforestation data are not currently available within the GEIC indicator framework).
- Switching in sourcing patterns between sectors or regions with different deforestation intensities. For example, it would pick up if supply of a given commodity were switched from a country with high deforestation rates (which would give a high deforestation estimate for it based on the land balance model) to a country with low deforestation rates. As above, it is important to consider displacement effects in this situation. It would also be sensitive if switching supply from a commodity associated with significant deforestation (e.g. because its area of production is expanding in countries with high deforestation rates) to a commodity with a low deforestation intensity value

(e.g. because its area of production is shrinking or it is only found in low deforestation regions)
- Decreases in the deforestation intensity estimated for the sectors within the global economy on which Wales' consumption depends. For example, the metric would show change if a new process is developed that means it is possible to produce the same amount with less area, and therefore less expansion into forested areas is required to meet demand.
- Saturation in forest left available to expand into. If deforestation is not stopped, at a certain point in time this metric will begin to show reductions in deforestation simply because there is little or no forest left to expand into.

In addition, for the carbon emissions, the emissions will be determined by the location of land use change (i.e. land use change-based emissions are based on spatially explicit estimates of above and below ground carbon, soil organic carbon, or peatland loss). From an emissions perspective, a unit of land use change in one area is therefore not necessarily equivalent to a unit of conversion in another area. Factors are fixed over time for each land use type.

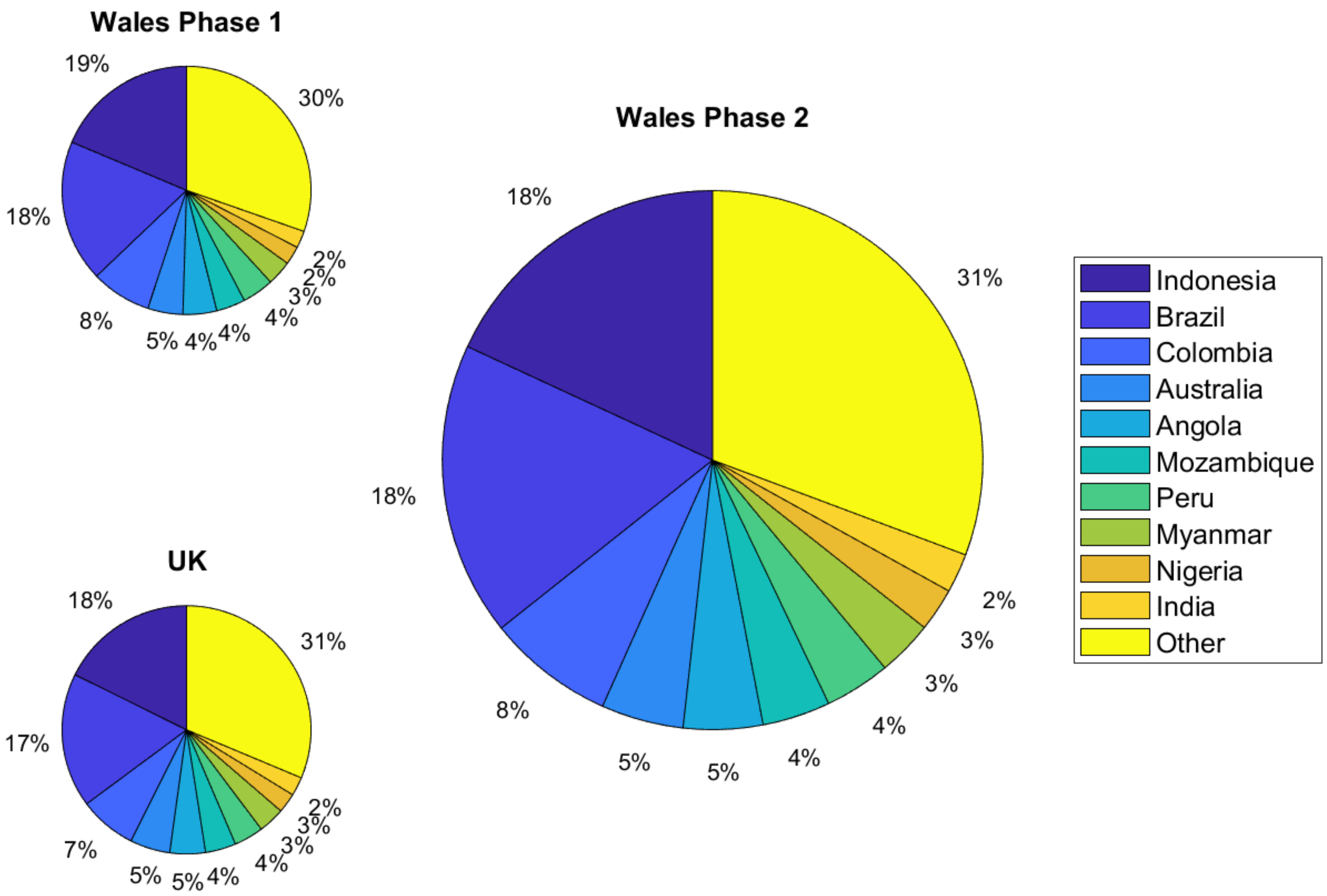


**Figure 23.** Pie charts representing the composition by country of deforestation risk (ha) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers the rest of the world; a more detailed breakdown of results to a wider range of countries can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with Indonesia as the biggest slice shown (top left) and India the smallest.

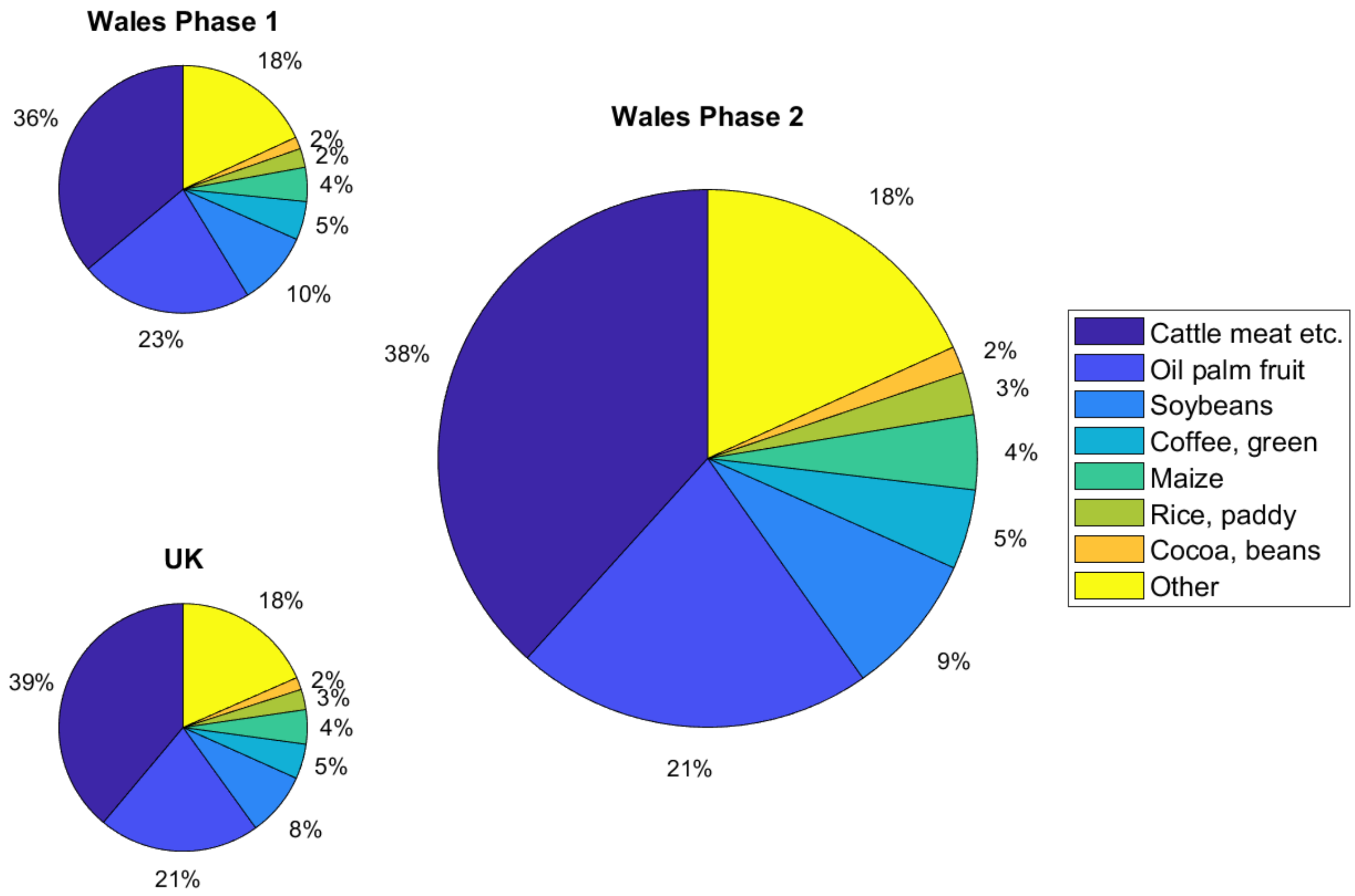


**Figure 24.** Pie charts representing the composition by commodity of deforestation risk (ha) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers all other agricultural crops, timber and cattle related products beyond those listed in the key; a more detailed breakdown of results to a wider range of commodities can be found in the accompanying datasheet. 'Cattle meat, etc' refers to cattle meat and associated co-products such as leather. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with cattle as the biggest slice shown (top left) and cocoa beans the smallest.

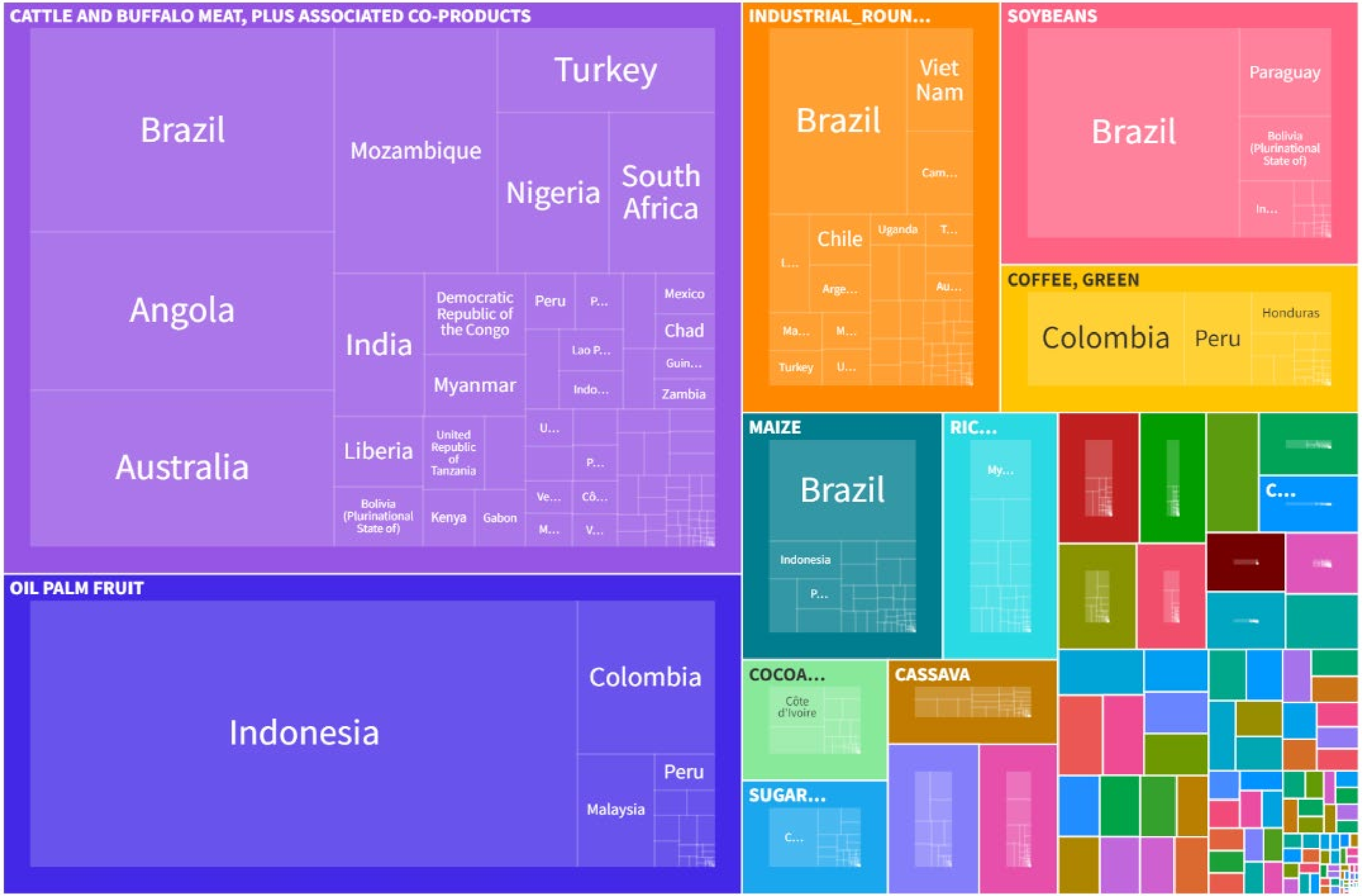


Figure 25. Treemap of deforestation risk (ha) embedded in Welsh consumption, arranged and coloured by commodity. The area of each rectangle is proportional to the deforestation risk. Note: Full details and numerical results can be found in the accompanying datasheet.

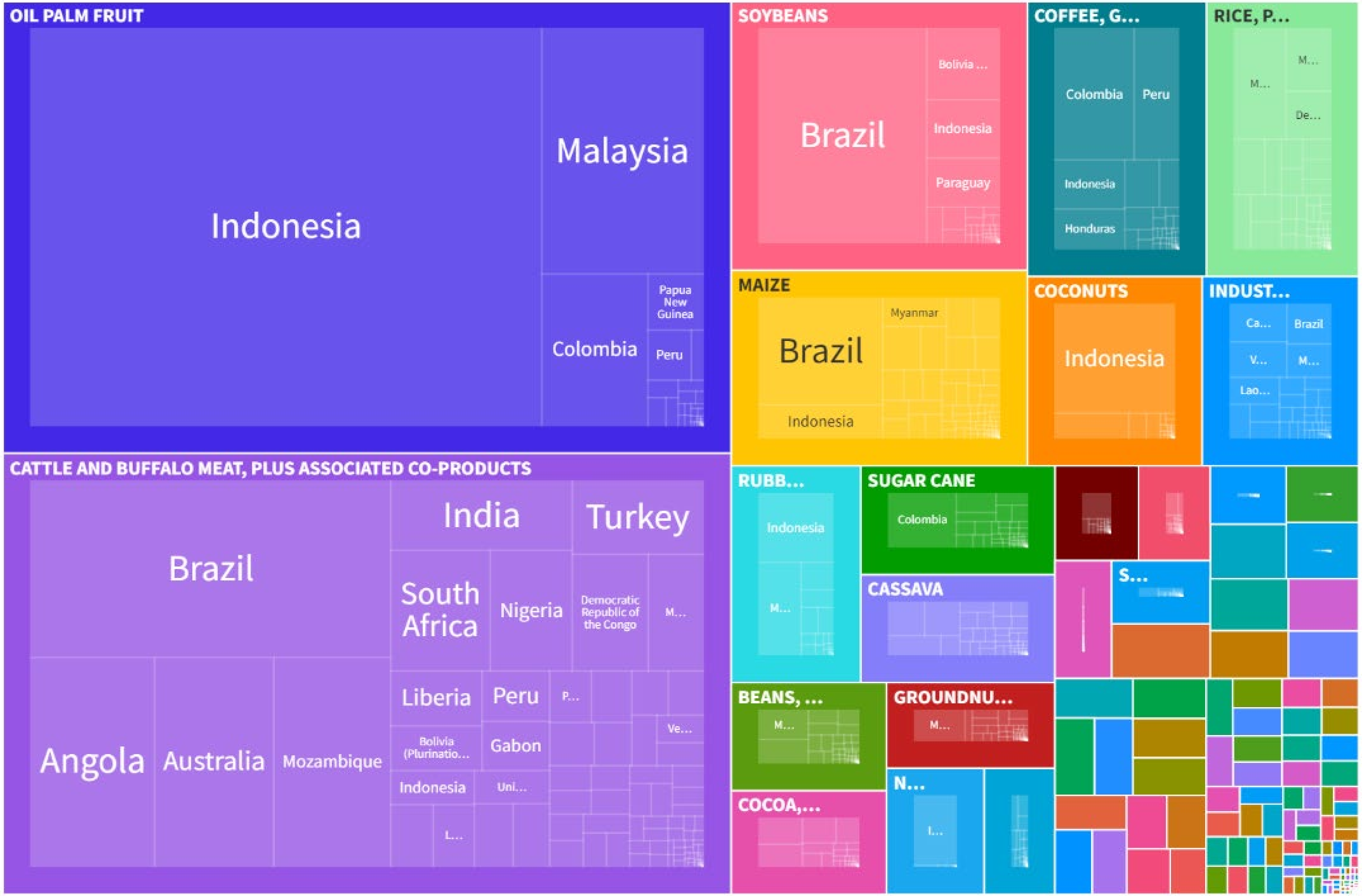


**Figure 26.** Treemap of $CO_2$ emissions (tonnes) - including emissions from peat - resulting from deforestation embedded in Welsh consumption, arranged and coloured by commodity. The area of each rectangle is proportional to emissions. Note: Full details and numerical results can be found in the accompanying datasheet

## 5.7 Biodiversity loss

Two biodiversity loss metrics are provided; the ‘regional species loss’ metric and the ‘species richness weighted crop area’. The ‘regional species loss’ measure is based on the countryside species-area relationship (cSAR) approach which can be used to estimate the number of species lost as a result of agricultural land use change and land occupation. Predicted species loss is defined as the number of species committed to extinction in the absence of restoration. The indicator is derived from the Chaudhary and Brooks (2016) dataset; see Croft *et al.* (2022) for details of implementation within the GEIC indicator framework. The ‘species richness weighted crop area’ uses MAPSPAM data (a modelled global dataset of which crops are grown where) alongside species richness information from the International Union for the Conservation of Nature (IUCN) and BirdLife International. This represents the hectares of crop production scaled by the number of species present in that hectare, and therefore where there is overlap between production and areas of biodiversity importance. Both indicators as currently applied cover crop commodities only, meaning that timber and cattle-related products are not covered by the metric (in contrast to the material and deforestation metrics, which do include these groups).

The total GEIC regional species loss footprint for Wales for 2018 is estimated at 1.58 species (Phase 1 results) or 1.20 species (Phase 2 results). In general, it appears that results associated with Welsh consumption obtained using Phase 1 and Phase 2 methods are very closely aligned in terms of their country and commodity composition (Figures 27 and 28). The higher estimated material dependency on UK-sourced supply from Wales compared to the UK average, however, is reflected in a higher relative UK-based biodiversity footprint. Whilst 1-2 species for the whole of Wales may seem relatively low, it should be noted that this metric only accounts for mammals, birds, fish and reptile species, so does not include taxa such as insects that may be more sensitive (but harder to get data on). In addition, the cumulative effects across geographies and timeframes should not be underestimated.

Figure 29 provides a treemap diagram of the breakdown of the Welsh regional species loss footprint (Phase 2 results shown, year 2018) by commodity and country. Alongside the UK-based biodiversity footprint associated with wheat, barley and rapeseed production, the footprints in Indonesia (associate with oil palm fruit), Viet Nam (associated with rice) and Brazil (coffee) and the Philippines (coconuts) are notable.

The total GEIC species richness weighted crop area footprint for Wales for 2018 is estimated at 144 million species-hectares (Phase 1 results) or 111 million species-hectares (Phase 2 results). The compositions suggested by the two methods are closely aligned to each other and to the UK average (Figures 30 and 31). As observed for the species loss metric, the results reflect the relative material dependency on UK-sourced supply from Wales. Compared to the regional species loss metric, Brazil is relatively more significant (2$^{nd}$ place) with other countries (e.g. Ukraine, Russia, China) also featuring but absent from the top 10 contributors with the regional species loss metric.

Figure 32 provides a treemap diagram of the breakdown of the Welsh species hectares footprint (Phase 2 results shown, year 2018) by commodity and country. In contrast to the regional species loss metric, maize and soybeans (key country Brazil) make a relatively more significant contribution.

The species loss metric depends on characterisation factors provided by Chaudhary and Kastner (2016). These are expressed in terms of the regional species loss per tonne of commodity production and are static. Therefore, with this metric, on-the ground changes over time in (e.g. species richness), or changing extents of production to produce the same amount of a commodity would not be reflected in modifications to the metric. However, it would be sensitive to all the same changes as the GEIC material footprint and (as with the deforestation metric) it would also be sensitive to changes in sourcing patterns between areas or sectors with high predicted impact and areas with low predicted impact (noting the risk of displacement effects).

In addition to the sensitivity described for the material footprint, the species hectares metric combines estimates of the spatial extent of crop production with species richness estimates (based on IUCN species ranges). Therefore, it would be sensitive to changes in estimates provided by these datasets, although they are not updated annually and are likely to remain relatively constant. It is also sensitive to changes in crop yield which would have the effect of changing productive output per unit area and therefore increasing/decreasing the species hectares metric accordingly.

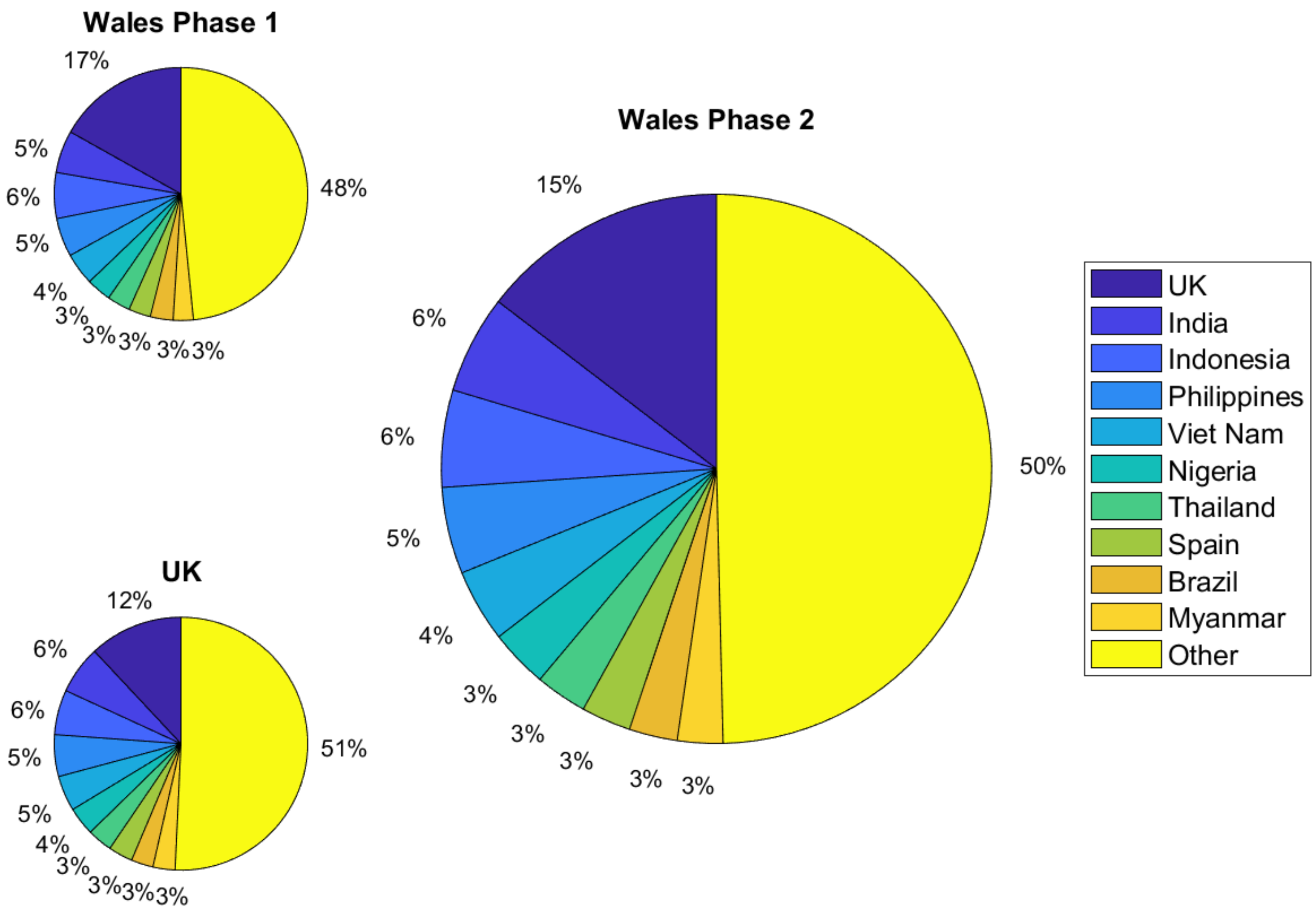


**Figure 27.** Pie charts representing the composition by country of regional species loss (number of species) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers the rest of the world; a more detailed breakdown of results to a wider range of countries can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with UK as the biggest slice shown (top left) and Myanmar the smallest.

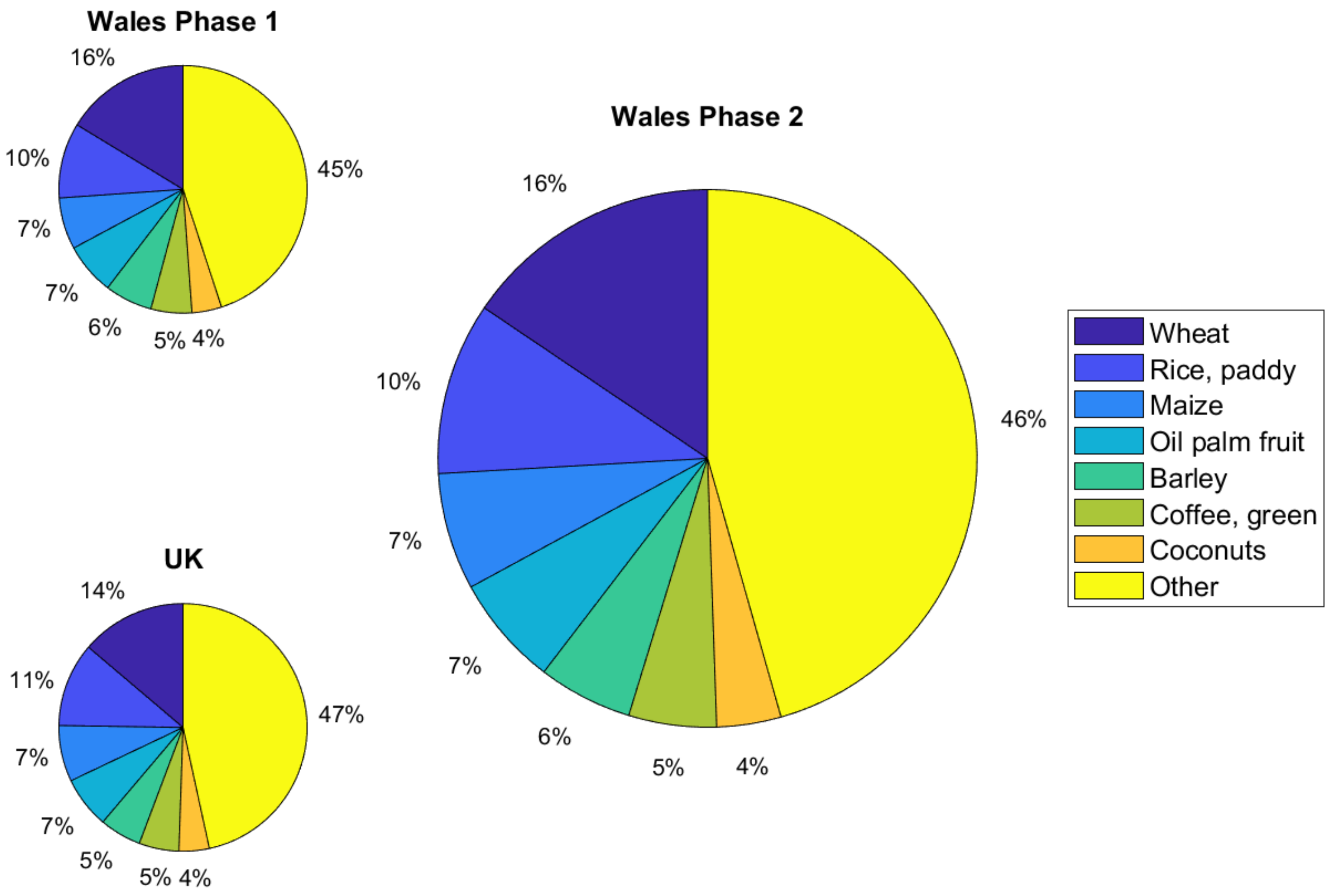


**Figure 28.** Pie charts representing the composition by commodity of regional species loss embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers all other agricultural crops, timber and cattle related products beyond those listed in the key; a more detailed breakdown of results to a wider range of commodities can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with wheat as the biggest slice shown (top left) and coconuts the smallest.


Figure 29. Treemap of species loss embedded in Welsh consumption, arranged, and coloured by commodity. The area of each rectangle is proportional to the associated species loss. Note: Full details and numerical results can be found in the accompanying dataset.

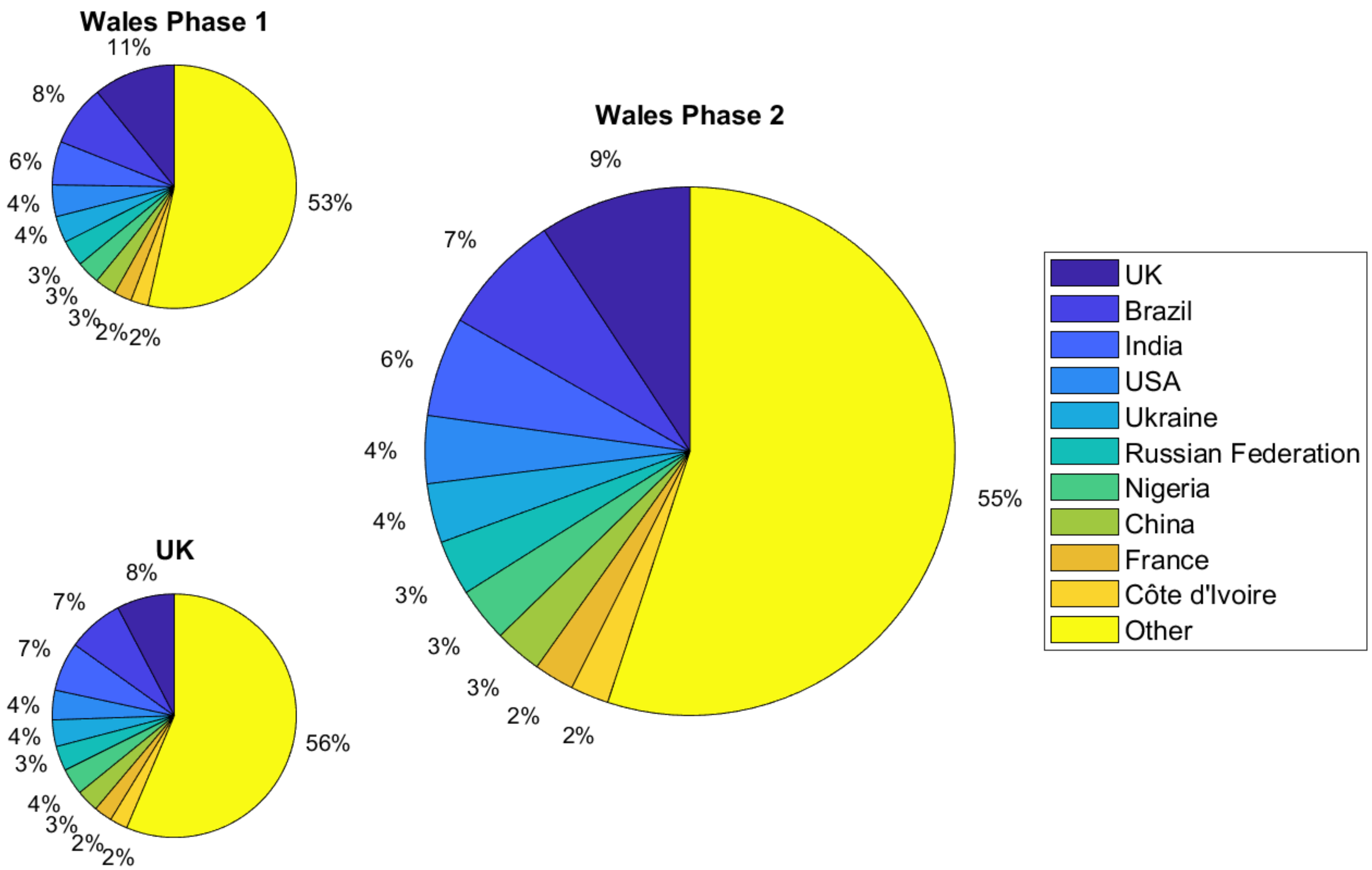


**Figure 30.** Pie charts representing the composition by country of 'species richness weighted crop area' (species hectares) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers the rest of the world; a more detailed breakdown of results to a wider range of countries can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with UK as the biggest slice shown (top left) and Côte d'Ivoire the smallest.

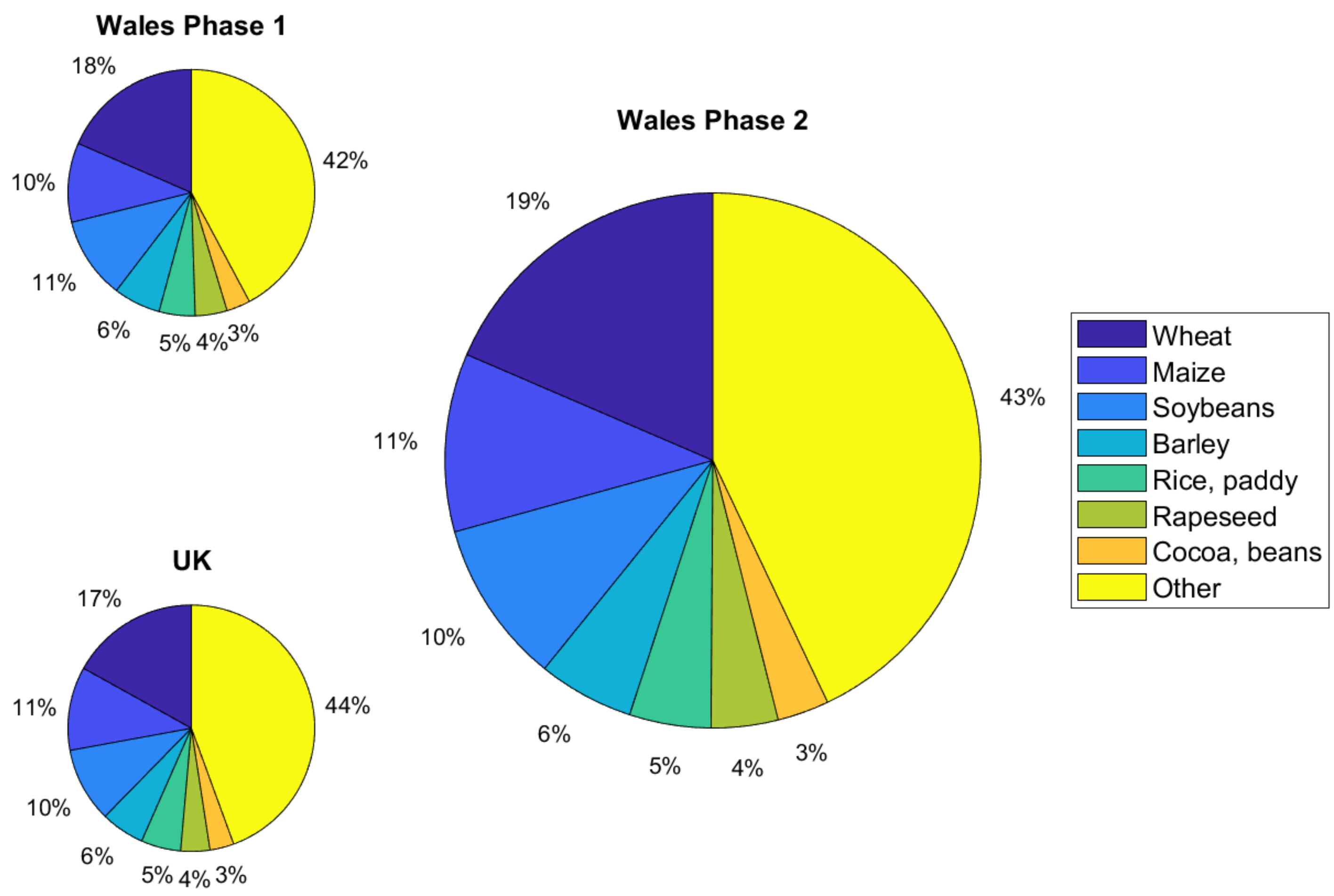


**Figure 31.** Pie charts representing the composition by commodity of 'species richness weighted crop area' (species hectares) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers all other agricultural crops, timber and cattle related products beyond those listed in the key; a more detailed breakdown of results to a wider range of commodities can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with wheat as the biggest slice shown (top left) and cocoa beans the smallest.


**Figure 32.** Treemap of species richness weighted crop area (ha) embedded in Welsh consumption, arranged and coloured by commodity. The area of each rectangle is proportional to the associated species richness weighted crop area. Note: Full details and numerical results can be found in the accompanying datasheet.

## 5.8 Water use

Three water use estimates are provided in the results; blue (irrigation) water consumption, green (rainwater) water consumption, and scarcity weighted blue water use (blue water consumption scaled by a measure of national 'water availability'). The blue and green water use metrics, are based on the well-established 'Water Footprint Network' crop-specific water footprint data which are extended to provide estimates of crop footprints that vary over time using a 'fast-track' method that takes into account changes in ratios of agricultural yields which impact on water consumption. The scarcity weighted water use metric further utilises a method to scale blue water consumption by national-scale characterisation factors from the AWARE (Available WAter REmaining) dataset which accounts for the amount of water remaining in an area after human and aquatic ecosystem demands have been met. Areas with low water availability have higher characterisation factors and therefore water consumption is scaled upwards in areas with low availability/high scarcity. See Croft *et al.* (2022) for details of implementation within the GEIC indicator framework. All three indicators as currently applied cover crop commodities only, meaning that timber and cattle-related products are not covered by the metric (in contrast to the material and deforestation metrics, which do include these groups).

The total GEIC green water footprint for Wales for 2018 is estimated at 1,766 million cubic metres (Phase 1 results) or 1,347 million cubic metres (Phase 2 results). Comparisons of proportional contribution of countries and commodities (Figures 33 and 34) again illustrate a higher proportional footprint contribution from the UK and Wheat compared to the UK average. A similar observation holds for results on blue water and scarcity weighted blue water (not shown). The total GEIC blue water footprint for Wales for 2018 is estimated at 180 million cubic metres (Phase 1 results) or 139 million cubic metres (Phase 2 results). The total GEIC scarcity weighted blue water footprint for Wales for 2018 is estimated at 8,949 million cubic metres (Phase 1 results) or 6,858 million cubic metres (Phase 2 results).

Figure 35 provides a treemap diagram of the breakdown of the Welsh green water footprint (Phase 2 results shown, year 2018) by commodity and country. In addition to the footprint associated with wheat (as the largest contributor, with the UK footprint largest), the footprints of soybean (US, Brazil, Argentina), maize (Brazil, Ukraine), barley (UK) and oil palm fruit (Indonesia, Malaysia, Nigeria) are prominent.

Figure 36 provides a treemap diagram of the breakdown of the Welsh blue water footprint (Phase 2 results shown, year 2018) by commodity and country. Whilst wheat still features as the largest contributor, the countries associated with this footprint (i.e. those requiring irrigation-based production) are notably different to those in the green water footprint, including Pakistan, India, Iran, China and Egypt. Additionally, several commodities are relatively more significant such as rice (Pakistan, China, Thailand, India), cotton (Pakistan, Uzbekistan, India) and sugarcane (India, Pakistan).

Figure 37 provides a treemap diagram of the breakdown of the Welsh scarcity weighted blue water footprint (Phase 2 results shown, year 2018) by commodity and country. For wheat, key countries are somewhat similar to the non-scarcity weighted blue water footprint, but for other commodities there are striking changes. For example, for rice and sugar cane Egypt appears relatively more prominently. Olives also appear more prominently as a commodity (associated with Spain's production in particular).

In addition to the attributes described above for the GEIC material footprint, which are also relevant to this metric, the blue and green water metrics will also be sensitive to:

- Changes in reported crop yields which — has captured with the methods to annualise water consumption — will have the effect of increasing or decreasing water consumption per tonne of output.
- Changes in sourcing location to different countries of production which will interact with baseline estimates of blue and green water consumption per crop.
- In addition, the scarcity-weighted blue water measure will also be sensitive to changes in sourcing location which will interact with nationally specific estimates of available water remaining.
- Longer term shifts in climate. The underlying data source is planned to be updated periodically, so while it will not be possible for the data to, for example, respond to a specific drought, it will soon be sensitive to longer term climatic changes.

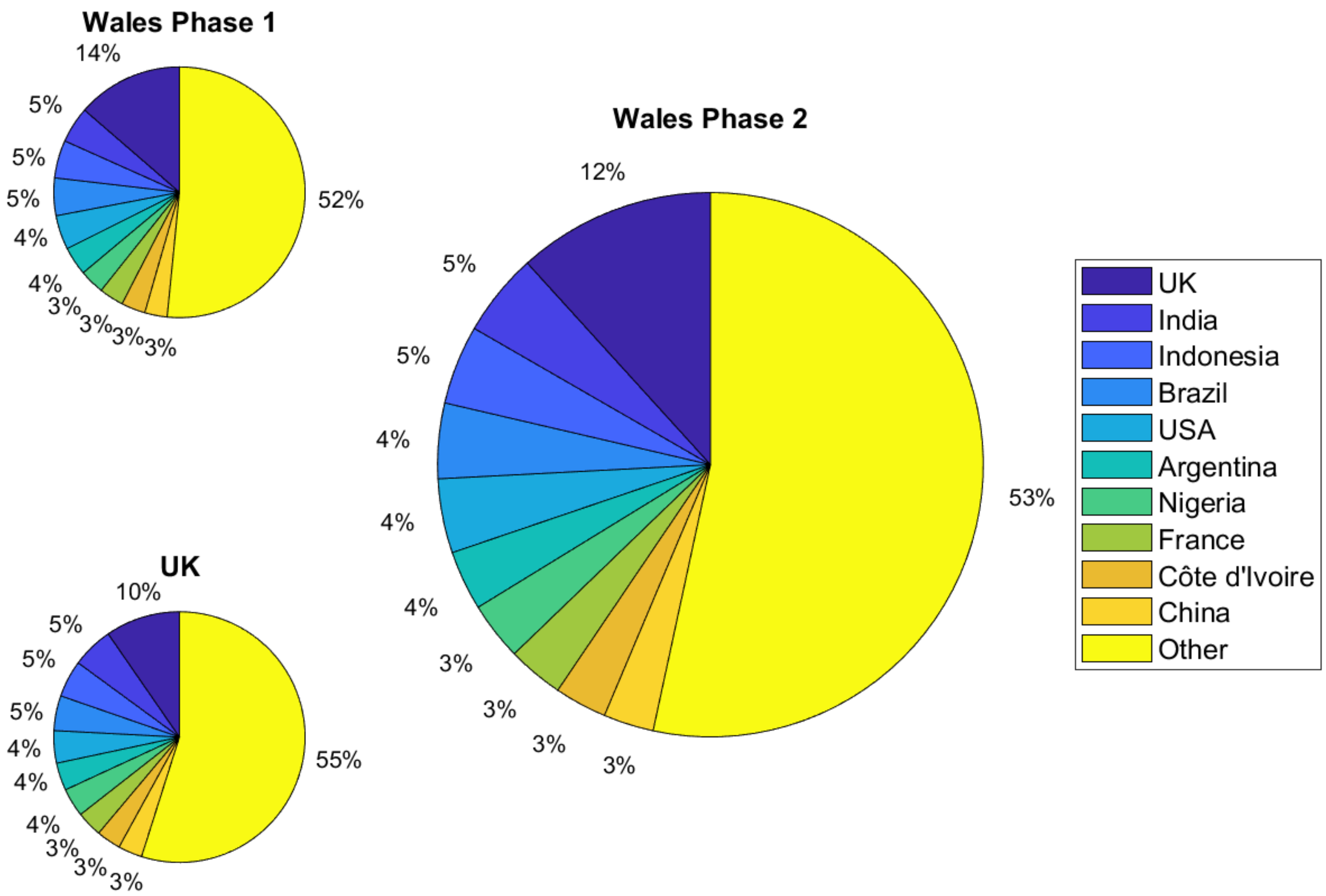


**Figure 33.** Pie charts representing the composition by country of green water (cubic metres) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers the rest of the world; a more detailed breakdown of results to a wider range of countries can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with UK as the biggest slice shown (top left) and China the smallest.

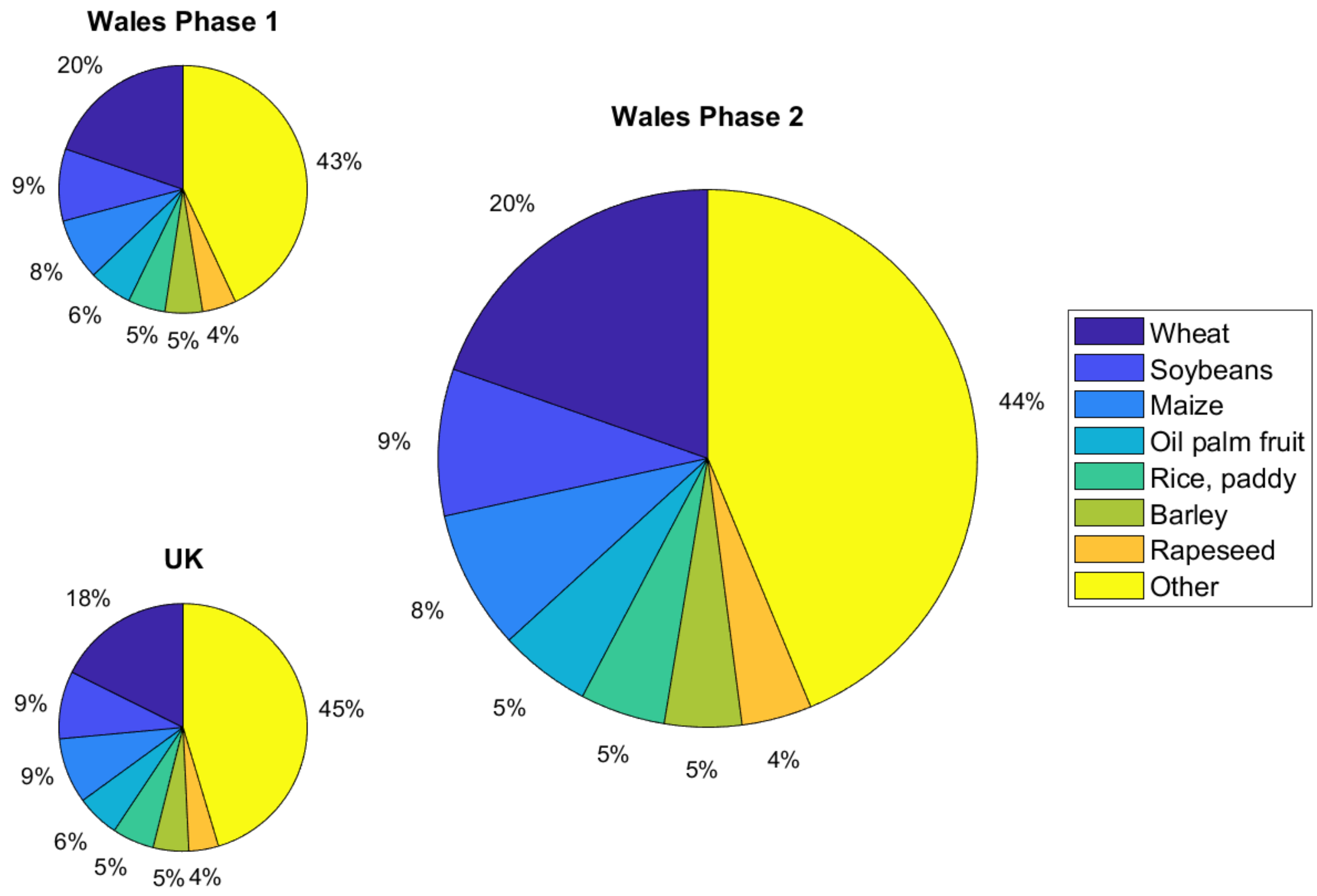


**Figure 34.** Pie charts representing the composition by commodity of green water (cubic metres) embedded in consumption by: Wales according to Phase 1 methods; Wales according to Phase 2 methods; the UK. 'Other' covers all other agricultural crops, timber and cattle related products beyond those listed in the key; a more detailed breakdown of results to a wider range of commodities can be found in the accompanying datasheet. In all three charts, the largest pie chart section is "Other." Apart from this, the key is listed in descending order, with wheat as the biggest slice shown (top left) and rapeseed the smallest.


**Figure 35.** Treemap of green water use (metres cubed) embedded in Welsh consumption, arranged and coloured by commodity. The area of each rectangle is proportional to the associated green water use. Note: Full details and numerical results can be found in the accompanying datasheet.

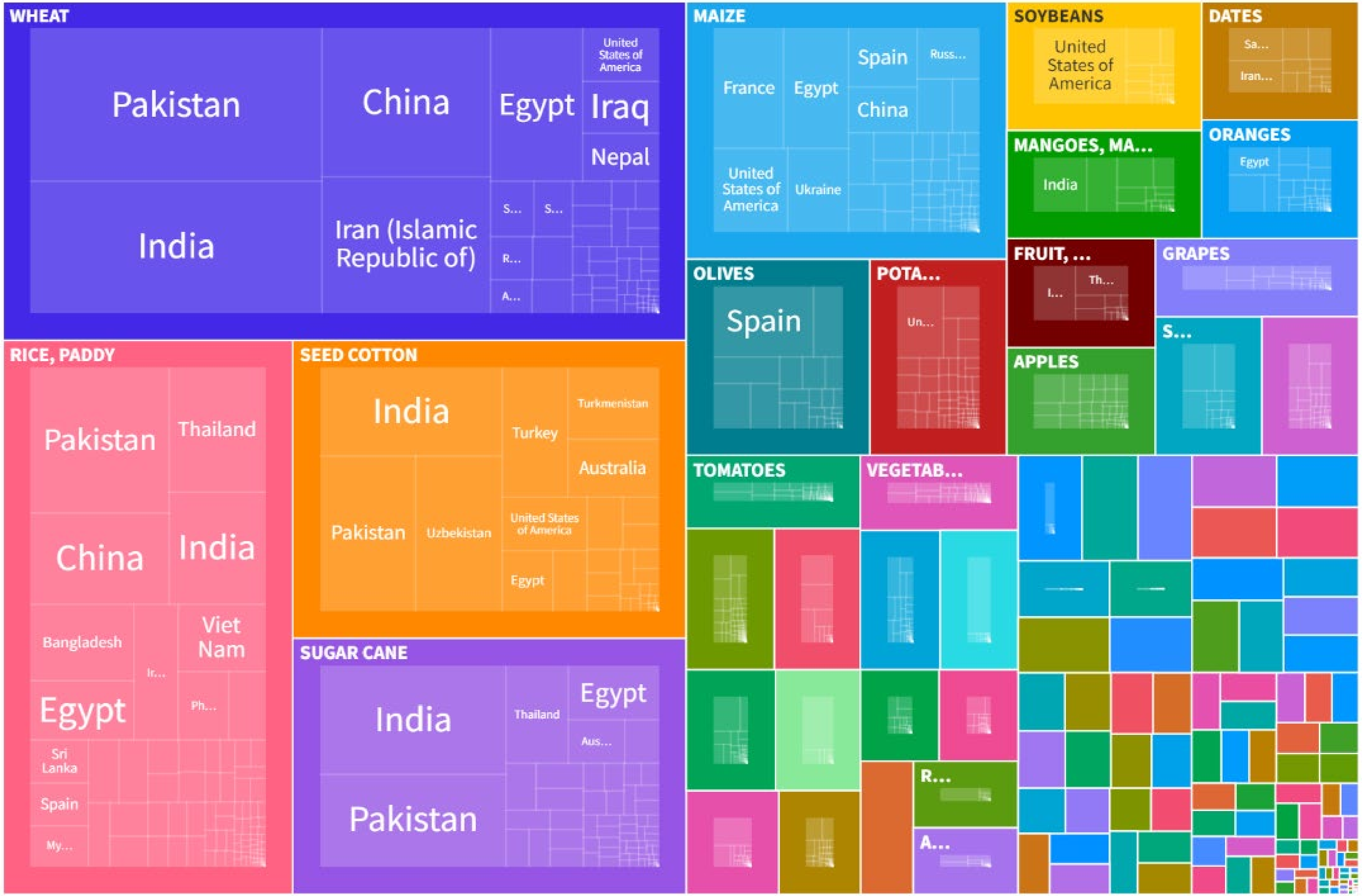


**Figure 36.** Treemap of blue water use (metres cubed) embedded in Welsh consumption, arranged and coloured by commodity. The area of each rectangle is proportional to the associated blue water use. Note: Full details and numerical results can be found in the accompanying datasheet.

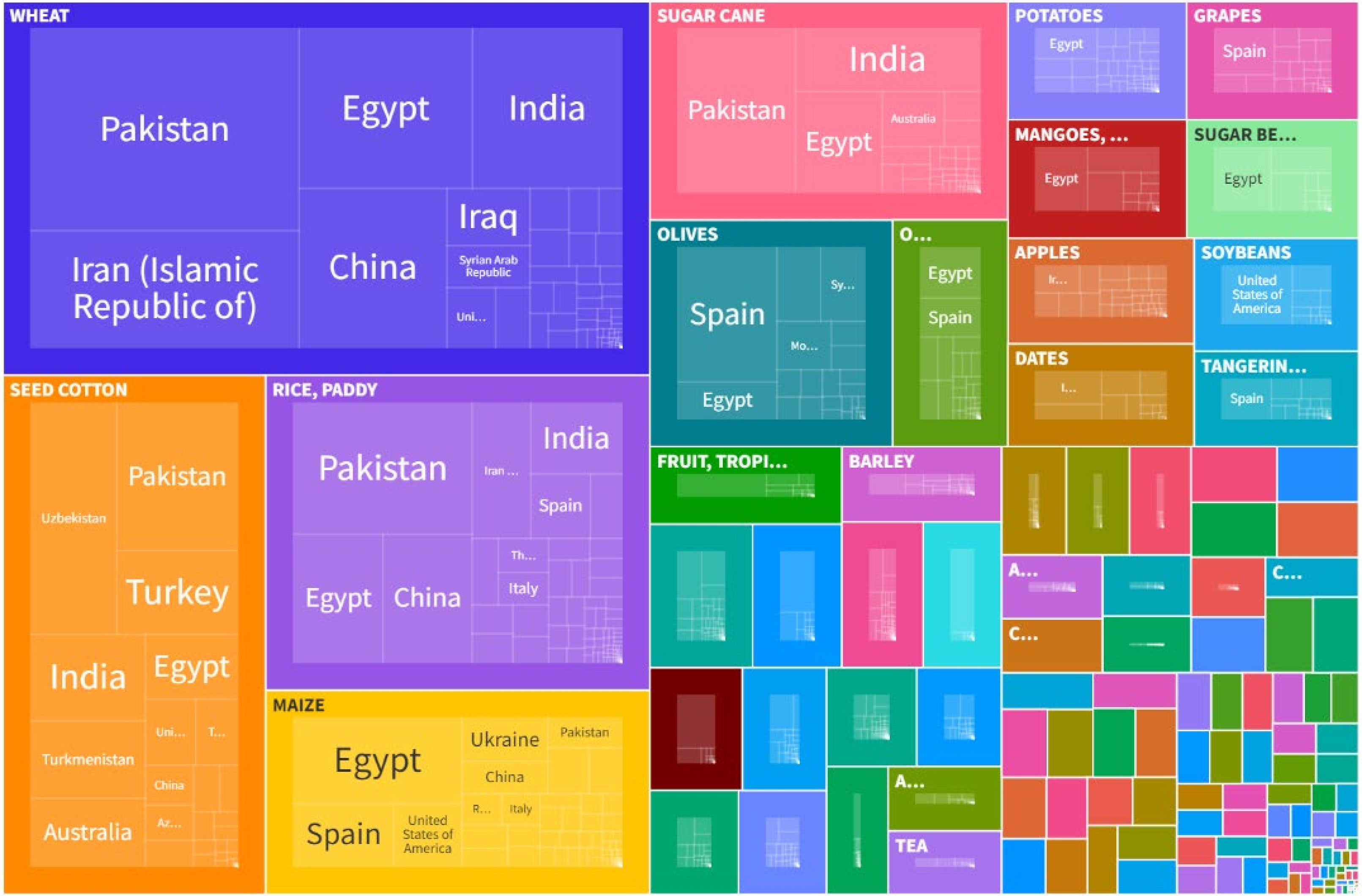


**Figure 37.** Treemap of scarcity weighted blue water use (metres cubed) embedded in Welsh consumption, arranged, and coloured by commodity. The area of each rectangle is proportional to the associated scarcity weighted blue water use. Note: Full details and numerical results can be found in the accompanying datasheet.

## 5.9 Discussion

The results are provided from a first attempt to downscale the ‘Global Environmental Impacts of Consumption’ (GEIC) indicator to a nation within the UK. The utility of the method that underpins the GEIC indicator is the commodity-specificity of the consumption-based footprint that it provides. Combining this with the innovation of utilising Welsh-specific data, in sum, results in a more thorough understanding of Wales’ specific commodity-dependencies than is provided by a UK-level analysis. Given that there is general awareness that certain commodity-production systems are associated with more acute environmental problems (e.g. palm oil or soybean with deforestation), that corporate decision making often focuses efforts on the sustainability of particular product lines, and that policy in the UK will affect Wales (e.g. the UK Environment Act 2021 and associated Due Diligence legislation linked to deforestation-risk commodities), such granularity can be helpful in guiding assessments of where Wales might be exposed to more or less risk and, consequently, should prioritise areas of focus.

Overall, the GEIC indicators suggest that, whilst Wales has a wide range of important commodity specific dependencies which may lead to negative environmental impacts, its overall contribution to the UK footprint as a whole is relatively modest. Indeed, impacts can be seen as relatively marginal in international terms, with – for example – the higher estimate of Wales’ annualised tropical and subtropical deforestation footprint of 884 hectares in 2018 representing less than 2.5% of the UK total, and only around 0.2% of the associated deforestation footprint of China (according to GEIC, China in 2018 had a deforestation footprint of over 484k ha. Source: commodityfootprints.earth). Much of this, however, is explained by the modest size of the Welsh population and smaller economy, and therefore this should not detract from the responsibilities Wales has in avoiding deforestation, biodiversity loss or other negative environmental impacts in sum.

It is perhaps more useful to use the information provided by GEIC to target for further attention particular priority commodities and source countries where there are dependencies and higher associated environmental impacts. For example, for biodiversity loss, aside from concentrations associated with UK production, Welsh impacts are primarily associated with Indonesian palm oil, Vietnamese rice, and coconuts in the Philippines. For carbon emissions resulting from deforestation, impacts are notable again for Indonesia, Malaysia and Colombia for palm oil, and Brazil, Angola, Mozambique, and Australia for cattle meat.

Whilst the results of the Welsh GEIC indicator provide insights of this kind, it should also be recognised that their absolute values remain experimental and subject to a high degree of uncertainty. In part, this is true even for the non-downscaled GEIC indicator-; environmental footprinting using MRIOs is inherently uncertain given the assumptions involved in the compilation of accounts and should therefore be treated mainly as a ‘hotspotting’ assessment. However, for this Welsh version, in addition there are further uncertainties introduced via the integration of imperfect Welsh-specific information. The Welsh IO data provided, and Welsh-specific industry and demand information used to downscale the model do not align well with the EXIOBASE MRIO structure used in the GEIC indicator. Whilst best efforts have been made to make alignments in this work, the fact remains that the data-landscape for downscaled MRIO-based models within the UK is severely hampered by a lack of consistent country-specific IO tables and require significant assumptions (which have consequences for accuracy, but also alternative parameterisations will likely modify results). Similarly, there is low confidence in some of the data sources such as the Household Expenditure Survey when interpreted at a regional scale. A key recommendation from this work, therefore, is for the Welsh Assembly Government to seek both to improve its own IO accounts and to encourage other devolved governments, and the ONS, to provide a set of consolidated national IO accounts across the entire UK. Similar improvements to other data sources, such as increasing the sample size of the Household Expenditure Survey to help it better provide regional level data, would also be useful. This report also provides just a snapshot (for 2018); further attention here (including a future release of 2019 Welsh IO data) would also allow the Welsh GEIC results to be repeated in the future to allow the monitoring of commodity-specific impacts and trends over time.

# 6 Case studies for a set of selected commodities

## 6.1 Commodity selection

A series of three small case studies are included which provide additional information on Wales' potential consumption-based impacts linked to tropical deforestation. These case studies were chosen as illustrative examples of the ways in which Welsh consumption activities and/or industry interact with overseas forest loss. The three examples were chosen to encompass coverage of three commodities particularly linked to forest loss: soy, industrial roundwood and palm oil. However, the specific context of the case studies varies. For inclusion of soy deforestation, we selected the Welsh livestock industry case study (Section 6.2), given the fact that the industry in Wales - by virtue of its upland nature - is distinct from that operating throughout the rest of the UK, with important implications on animal feed use which is closely linked to soy-deforestation. For industrial roundwood deforestation (Section 6.3), we focused attention on Welsh timber consumption and the Welsh timber industry, given the potential that extensive forest landscape in Wales may help to reduce overseas impacts either now or in the future. Finally, for palm oil deforestation (Section 6.4), we did not expect *a priori* for there to be extensive *direct* dependencies within Wales on palm oil materials and were thus interested in understanding the degree to which Wales is exposed to palm oil deforestation impacts via its connection to the UK palm oil economy.

For each case study, publicly available datasets were screened to provide additional detail and context on the Welsh (and UK) supply chains. These are presented alongside results from the Welsh-downscaled IOTA modelling framework to derive insights into the deforestation impact associated with these supply chains. It is important to note that in all cases the data landscape is relatively sparse, meaning that making concrete connections between Welsh consumption and/or industry and specific supply chain dependencies linked to deforestation is challenging. Additional work with industry is likely needed to provide more specificity for high-impact supply chains.

## 6.2 The Welsh livestock sector

### 6.2.1 Introduction

The Welsh livestock sector has been investigated as a case study given the relatively important role that livestock plays in Welsh land use and food production, and the expectation that the profile of the industry - given differences to the rest of the UK - may have implications for Wales' connection to deforestation risk, via the use of animal feed.

A large proportion of land area in Wales is used for farming, with an estimated 90% being used for agriculture (Welsh Government 2022b). Compared to England, this extent is considerably higher, with agricultural land in England only covering 69% of the total area (Defra 2022a). A key reason for this is the nature of the land, with the majority in Wales being used for sheep farming, especially in upland areas of Wales where there are less viable alternative business opportunities. About 80% of land in Wales is categorised as a 'Less Favourable Area' (LFA) for farming (Welsh Government 2019a) which is defined by the EU as 'Land that is designated as being of lower potential than the national average.' This is similar to Scotland which has 84% of its land designated as LFA, whereas England has significantly lower at 16% (but noting that the picture is more complex when taking into account the different sub-categories within LFA land). Only 6% of agricultural land in Wales is arable compared to over 40% in England (Defra 2022a). Cattle and sheep holdings are the most common, with pigs, poultry, cereals and horticulture together representing only 3% of all active holdings (Welsh Government 2022b). Compared to UK total livestock numbers, the number of sheep in Wales is particularly notable, with almost a third of all sheep in the UK being located in Wales (Table 2).

**Table 2.** Livestock numbers in Wales from 2022 Survey of Agriculture and Horticulture compared to UK 2022 totals. Sources: Welsh Government (2022b)/Defra (2022a).

| 2022 Livestock numbers (millions) | Wales | Rest of UK | UK total | % of UK |
|---|---|---|---|---|
| **Sheep** | 9.4 | 23.6 | 33 | 28.5 |
| **Cattle** | 1.1 | 8.5 | 9.6 | 11.5 |
| **Pigs** | 0.027 | 4.93 | 5.2 | 0.5 |
| **Chickens** | 9.9 | 178.1 | 188 | 5.3 |

Ratios of livestock numbers (Table 3) further demonstrate how different the livestock industry is in Wales compared with the rest of the UK. For example, total numbers of sheep and chickens are similar in Wales whilst UK ratios show chickens to vastly outnumber sheep. Figure 38 provides the total number of animals in each livestock category across each of the countries of the UK.

**Table 3.** Approximate ratios of sheep to other livestock for Wales and compared to the UK average. Source: Welsh Government (2022b)/Defra (2022a).

| Ratio of sheep to: | Wales | UK |
|---|---|---|
| **Cattle** | 9:1 | 3:1 |
| **Pigs** | 45:1 | 6:1 |
| **Chickens** | 1:1.1 | 1:56 |

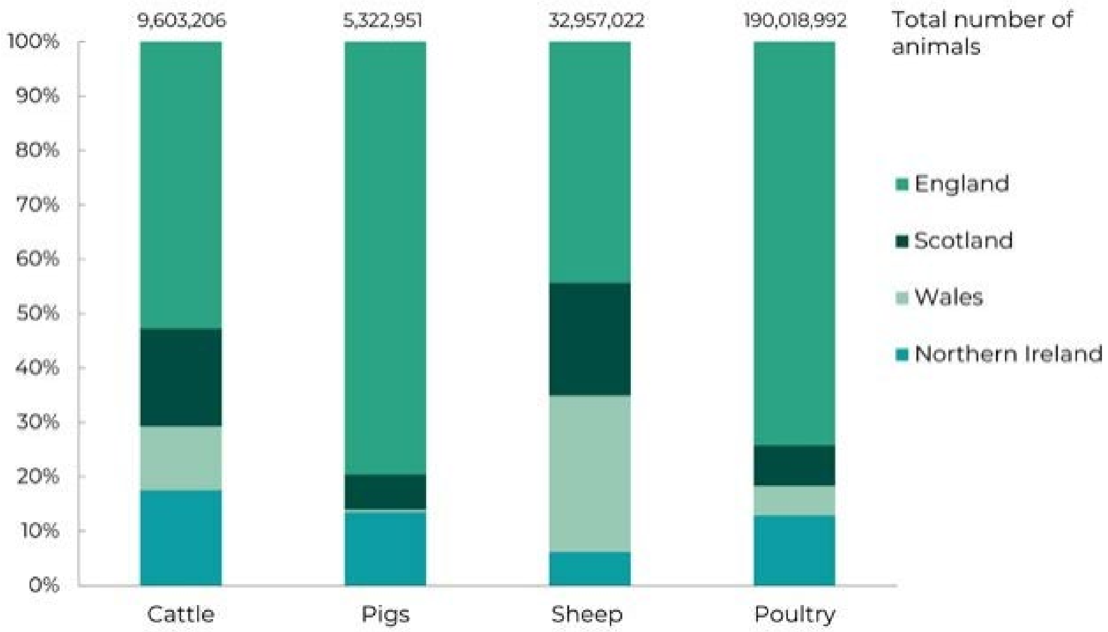


**Figure 38.** UK country shares of total UK livestock 2022. Source: Welsh Parliament (2022), reproduced with permission.

### 6.2.2 Feed dependencies

Whilst it is not the only impact that the livestock industry has on the environment (emissions from enteric fermentation, local soil erosion, and water pollution constitute other non-exhaustive examples; Business Wales 2020), the primary driver of overseas deforestation linked to the UK animal industry is the production of agricultural materials used for animal feed. This is particularly true for soy - which is produced mainly as an input to the global animal feed industry - but other feed components such as maize may also be important. According to the Agriculture and Horticulture Development Board (AHDB) the most important materials used in the UK for livestock feed are wheat, soy and barley (AHDB 2023). Maize is also utilised, but with lower quantities overall. Wheat and barley are predominantly produced domestically, whereas the majority of soy is imported from South America, primarily from Argentina, Brazil and Paraguay (see also below). Some maize is also imported, however there is a lack of data about the sourcing of this commodity for UK animal feed in the literature (WWF 2022b).

Table 4 shows statistics from 2022 on the production of animal feed and the raw materials used in the production process. The table highlights that only a relatively small proportion of total feed produced in the UK is given to sheep. Cattle, followed by poultry and pig industries consume the most feed. Given that the livestock system in Wales is dominated by sheep, this suggests that Wales is likely to be less reliant overall on animal feed compared to the rest of the UK. It should be noted that that this reliance is relative and therefore should not undermine a case for action around addressing impacts such as deforestation associated with the Welsh feed sector.

**Table 4.** Volume of animal feed produced by manufacturers in the UK and raw materials used in the process, showing the latest monthly statistics (November 2022), statistics for the total crop year (provided from July onwards) and the percentage change relating to the same period in the previous year. Source: AHDB (2023).

| Thousand tonnes | Nov 22 (monthly statistic) | % change from same time period in the previous year | Jul 22 to Nov 22 (statistics for the total crop year) | % change from the previous total crop year |
|---|---|---|---|---|
| **Usage** | 907.3 | -6.4% | 4530.0 | -5.5% |
| **Wheat** | 260.3 | -11.6% | 1354.8 | -4.2% |
| **Barley** | 94.6 | -17.7% | 460.6 | -25.8% |
| **Oats** | 7.0 | -47.4% | 32.4 | -34.8% |
| **Whole and flaked maize** | 30.5 | 21.0% | 168.4 | 19.5% |
| **Oilseed rape cake and meal** | 61.5 | -0.2% | 273.6 | -2.7% |
| **Soya cake and meal** | 97.9 | -8.7% | 522.7 | -6.6% |
| **Sunflower cake and meal** | 29.8 | 19.7% | 124.4 | 16.5% |
| **Other oilseed cake and meal** | 36.2 | 27.9% | 158.2 | 6.2% |
| **Other usage** | 289.5 | -3.4% | 1434.9 | -2.6% |

| Thousand tonnes | Nov 22 (monthly statistic) | % change from same time period in the previous year | Jul 22 to Nov 22 (statistics for the total crop year) | % change from the previous total crop year |
|---|---|---|---|---|
| **Production** | 909.2 | -7.1% | 4567.2 | -5.4% |
| **Cattle and calf feed** | 347.8 | -1.5% | 1596.0 | -1.8% |
| **Compounds for dairy cows** | 182.6 | 3.1% | 876.6 | 1.3% |
| **Blends for dairy cows** | 71.5 | 4.1% | 304.7 | -0.5% |
| **Pig feed** | 154.9 | -15.4% | 813.9 | -8.9% |
| **Pig growing compounds** | 24.5 | -13.1% | 132.6 | -10.5% |
| **Pig finishing compounds** | 85.6 | -18.2% | 454.5 | -6.8% |
| **Pig breeding compounds** | 32.1 | -12.1% | 162.4 | -12.1% |
| **Poultry feed** | 295.8 | -10.5% | 1634.2 | -8.9% |
| **Layers compounds** | 81.0 | -12.7% | 438.3 | -9.6% |
| **Broiler compounds** | 162.3 | -1.6% | 854.5 | -4.8% |
| **Sheep feed** | 51.0 | -4.9% | 215.4 | 4.8% |
| **Compounds for breeding sheep** | 6.0 | -18.9% | 21.4 | 10.3% |
| **Compounds for growing and finishing** | 36.9 | -3.1% | 155.2 | 4.3% |
| **Other feed** | 59.7 | 1.5% | 307.7 | -0.9% |

Furthermore, given differences across landscapes in terms of terrain and climate (e.g. with the western side being wetter but milder and the eastern side dryer but with more extremes of hot and cold; and with upland and lowland areas providing pasture of differing quality), the UK uses a unique stratified system for sheep which entails the use of specific breeds and crosses that are best suited to different areas and production systems (Hybu Cig Cymru 2004). Three tiers, characterised by differences in altitude and grazing, are hill, upland, and lowland. Given the topography and climate of Wales (western and largely upland), the majority of breeds are those that have adapted to living in hard hill conditions, with the Welsh breed survey (Hybu Cig Cymru 2004) indicating 62% of sheep to be Welsh Mountain. Breeds of sheep in hill and upland areas are more likely to be lambed outdoors and often require little additional feed. Given the breeds of sheep utilised, there is therefore likely to be a significant difference between Wales and the rest of the UK in terms of feedstock given to flocks (i.e. lower feed use compared to UK-average sheep). However, we have not been able to source breed-specific statistics on animal feed for Wales.

### 6.2.3 Soy and maize use and implications for the deforestation footprint of Wales

According to a study by WWF, Wales imports a relatively high amount of soy, compared to its share of UK GDP and population (WWF 2021). Wales' comparatively large livestock sector explains why - according to the WWF study - Welsh imports of soy account for 6% of the UK's total soy imports. WWF estimates that Welsh soy use equates to an estimated 190,000 tonnes, of which 80% is fed to livestock. If basing results on UK-wide livestock soy consumption and farm management data, this would mainly be consumed by the poultry industry (48%) followed by dairy (20%) and sheep (19%). The majority of soy imported to the UK for animal feed is fed to poultry, followed by pigs (Figure 39), with soymeal often the primary protein used in their feed. Relatively little, in comparison, is fed to other livestock.

However, it is important to note that (as described above) the structure of the agricultural sector in Wales is substantially different to the rest of the UK. The methods provided in the WWF report state the use of UK-wide livestock soy consumption and farm management data to estimate the Welsh share of UK soy imports However, given that Wales rears only 5.3% of the UK's chickens and 0.5% of the UK's pigs (Table 5), it is likely to contribute a relatively small component of the UK's total soy-feed-linked deforestation footprint. For Welsh breed sheep, which require lower feed inputs in general compared to both other sheep breeds and other livestock species, there is also likely to be lower dependency per tonne/head of livestock production on commodities such as soy and maize, compared to the UK's sheep as a whole. An important point, however, is that where any feed is used it is still potentially exposed to deforestation impacts given its potential reliance on soy and maize as component ingredients.

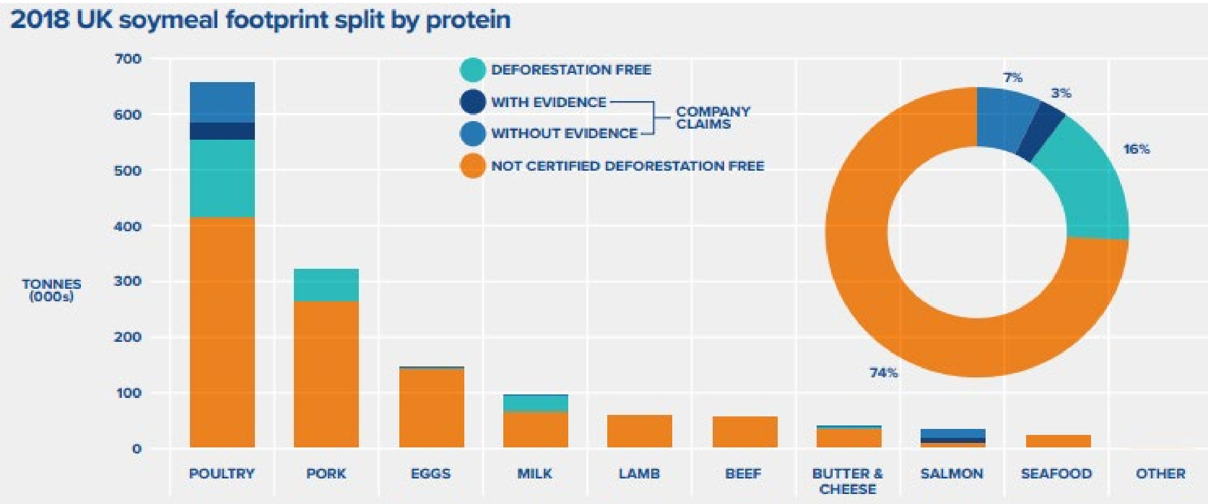


**Figure 39.** UK soymeal footprint 2018 for companies surveyed. Source: 3Keel (2019), reproduced with permission.

Using the Roundtable on Responsible Soy calculator (RTRS, 2023), we can estimate — based on the AHDB feed statistics (Figures shown in Table 5 have been multiplied by two to represent the annual volume of animal feed) and livestock numbers (these numbers will differ from Table 3 due to male cattle under 2 being excluded as they are not designated as beef or dairy and breeding flocks/other birds apart from chickens for poultry also not being included) for Wales — how much soy and maize is needed to produce the amount of animal feed used for various livestock types. Estimates are based on global-average conversion factors provided by the RTRS calculator, not Wales or even UK specific and calculations are based on the 'economic' allocations of materials to feed uses, which considers that multiple products can originate from a crop. There is not however a section in the RTRS calculator for sheep feed, which reflects the fact that soy and maize use in sheep feed is not of primary concern to soy footprint calculations. We compare results for Wales to the rest of the UK.

According to the results, there is likely to be higher proportional use of soy used to feed cattle in Wales compared to the rest of the UK. This is due to a higher proportion of cattle in Wales being dairy, which have higher soy requirements on average compared to beef cattle. For the rest of the UK, the largest amount of soy is used in feed for meat poultry, followed by dairy and pigs, whilst for Wales, pigs have the smallest allocation (Table 5). This is also the case for maize, with the largest allocation in Wales being the same as for soy; dairy cattle. The use for maize in the rest of the UK is highest for meat poultry, followed very closely by pigs. Meat poultry has the highest maize use in the rest of the UK whilst beef cattle has the lowest for both crops. Although the contributions are different for Wales, meat poultry still has the second largest allocation for both crops.

**Table 5.** RTRS calculator results showing economic allocations for soy and maize for each livestock type in tonnes based on feed statistics and livestock numbers. Note that estimates depart substantially from estimates of soy dependencies in the WWF report, which is likely explained by underlying methodological differences and reliance on different statistics. It is beyond the scope of this case study to investigate differences between estimates. Note also that where livestock are not assigned in Welsh statistics to categories they are not included in the estimations within this Table. For cattle, males under two are not assigned to meat or dairy, therefore have been excluded from the figures provided. This equates to a total of 2,596,278 cattle in the UK, 269,375 of which are in Wales. To provide a crude estimate of the footprints associated with these animals, if one assumes that males would be used for beef, this will equate to an additional soy footprint of 1,787 tonnes for Wales and 15,438 tonnes for the rest of the UK, and an additional maize footprint of 9,636 tonnes for Wales and 83,235 tonnes for the rest of the UK. For poultry, data table chickens (broilers) and laying fowl have been used within Table 5. Other poultry, including turkey, geese, and ducks, were not included in the Table, and with additional chicken breeding flocks, this amounts to 21,888,966 birds in the UK, 648,982 of which are located in Wales. As a crude estimate, assuming the conversion factors for ‘poultry-meat’, this would approximate an additional soy footprint of 4,898 tonnes for Wales and 160,301 tonnes for the rest of the UK, and an additional maize footprint of 12,065 tonnes for Wales and 394,880 tonnes for the rest of the UK.

| | **Soy** | | **Maize** | |
|---|---|---|---|---|
| | **Wales** | **Rest of UK** | **Wales** | **Rest of UK** |
| Cattle-beef | 7,480 | 42,879 | 40,329 | 231,188 |
| Cattle-dairy | 48,447 | 230,533 | 108,471 | 516,156 |
| Poultry-eggs | 9,664 | 103,497 | 40,626 | 435,101 |
| Poultry-meat | 20,128 | 413,545 | 49,584 | 1,018,713 |
| Pigs | 765 | 146,778 | 5,137 | 986,229 |
| **Total** | **86,483** | **937,232** | **244,147** | **3,187,388** |

The RTRS calculator does not provide any detail on the potential sources of soy or maize, and we have been unable to find any Welsh-specific detail on the sources. Therefore, the downscaled version of IOTA, prepared for this project, provides us with the ability to approximate the origin of soy and maize materials. Table 6 provides the total soy and maize masses demanded by the Welsh ‘livestock’ sector’ according to IOTA, and the associated deforestation risk.

Table 6. Soy and maize masses embedded in outputs by the Welsh livestock sector and the associated deforestation risk.

| Commodity | Producing country | Total material footprint (tonnes) | Total associated deforestation risk (ha) |
|---|---|---|---|
| **Soybeans** | All | 3,814 | 2.23 |
| | Brazil | 596 | 1.13 |
| | Paraguay | 277 | 0.50 |
| | Bolivia | 82 | 0.39 |
| **Maize** | All | 7,561 | 1.25 |
| | Brazil | 416 | 0.45 |
| | Indonesia | 51 | 0.15 |
| | Paraguay | 45 | 0.09 |
| **Total** | All | 11,375 | 3.48 |

Overall, the Welsh GEIC data indicate that the livestock sector (which combines cattle farming, pig farming, poultry farming and 'meat animals nec' sectors) in Wales is responsible for the production of 3,814 tonnes of soy and 7,561 tonnes of maize which in turn are associated with 2.23 ha and 1.25 ha of deforestation risk. Sourcing from Brazil accounts for just over 50% of deforestation risk associated with soy, with 22% associated with Paraguay, and 17% with Bolivia, leaving 9% split across other countries. The deforestation risk associated with the sourcing of maize is less concentrated, with the main contributions coming from Brazil (36%), Indonesia (11%), and Paraguay (7%). It is notable that the estimates provided by the Welsh GEIC data are significantly lower than those estimated via the RTRS soy and maize calculator above.

Ultimately, additional information on feed-dependencies, and associated sourcing patterns by feed providers in Wales, would be necessary to build a more accurate picture of soy and maize usage and the risks associated with sourcing locations. Data that would be helpful include, for example, further detail on Welsh-specific ingredient mixes per breed. At present there is limited information on how different breeds of livestock are fed apart from suggestions that sheep in different tiers of the national stratification system could be left longer to graze outside as opposed to being brought inside for lambing season. Via the use of trade statistics, and via industry platforms such as the UK Roundtable on Responsible Soy (Efeca 2022), there is some information on sourcing of soy and maize for the UK, however there is no commodity-specific import and export data available specific to Wales. Engagement with the livestock and feed industry in Wales, to 'track' materials used to origin via the supply chain, would help understand key sources in more detail. This process may also help to understand how much organically produced and/or certified deforestation free soy and maize is used within particular farming systems in the Welsh livestock industry, which would reduce potential exposure to deforestation in the supply chain.

## 6.3 Welsh consumption of timber

### 6.3.1 Introduction

Welsh consumption of timber has been investigated as a case study given the presence of an extensive forest landscape in Wales that may help to reduce overseas dependencies, and therefore deforestation impact, linked to timber either now or in the future.

The Welsh Forest Sector is worth over £450 million, employing over 11,000 people (Natural Resources Wales 2023). Welsh woodland cover sits at 15%, slightly above the UK as a whole at 13%, and second highest in the UK below Scotland (19%) (Forest Research, 2022). Welsh timber production is significantly lower than for Scotland. The relatively small scale of the Welsh forestry industry, when compared to leading European producers such as Finland, Sweden, and Austria, places it a distinct disadvantage when considered purely in terms of supply and primary processing (Bryans 2011).

In the context of historically low and declining forest planting (Figure 40), the Welsh Government recently recognised the need for a refocus on woodlands and tree planting. A task force was assembled under Lee Waters MS in 2021, which called for the development of a Timber Industrial Strategy, increased tree planting, increased use of timber in construction to aid net-zero targets, and increased funding for woodlands and community planting (Welsh Assembly Government 2022).

Below, we first describe the Welsh timber industry, with Welsh sawmills revealed to be dependent primarily on locally sourced timber materials rather than on imports. However, timber output from Welsh mills represents only a relatively small proportion of the consumption of timber products as a whole, which is revealed to be highly import-dependent. We finish this case study with a discussion of what this means, in sum, for the link between Welsh timber consumption and tropical deforestation.

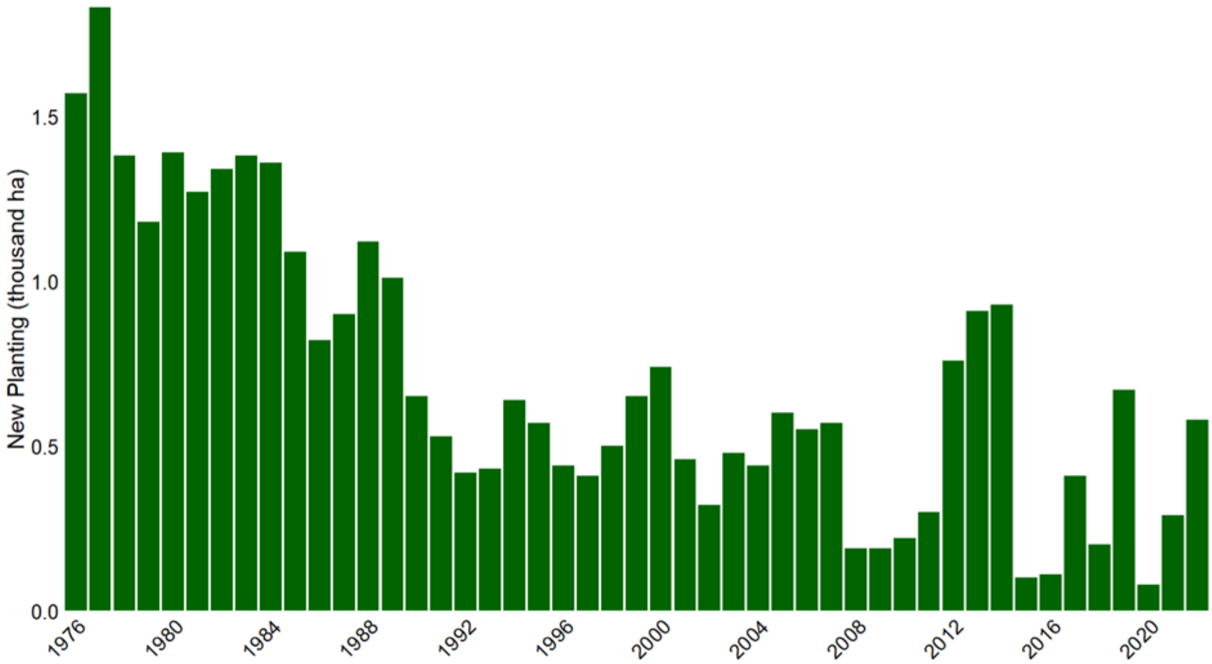


Figure 40. New planting in Wales over time (Graph produced using data from Forest Research, 2022).

### 6.3.2 The timber industry

The UK timber industry produces a range of products including sawn timber, pallets, fencing, biomass, sheet material, furniture, and craft products (Bryans 2011). A typical supply chain for timber includes initial harvesting or felling, then primary processing into sawn timber, then secondary processing into co-products. The supply chain can be complex, as products can be sold to third parties at each processing stage, as well as being further processed, or re-processed, into downstream products (CTI 2020). Bryans (2011) reports that the key strength of the Welsh timber industry is the breadth of expertise, suppliers, and manufacturers that it encompasses.

Our review for this case study has not identified a large amount of Welsh-specific information on the timber supply chain, or its relative levels of dependency on non-Welsh (i.e. rest-of-UK or overseas production). Therefore, in this case study we primarily provide statistics based on UK-wide resources but pull-out Welsh-specific insights where these are available.

In 2021, according to Forest Research, 11.2 million tonnes of roundwood (softwood and hardwood) were produced in the UK, with 6.3 million tonnes going to sawmills, 1.5 million tonnes to wood-based panels, 0.4 million tonnes to integrated pulp and paper mills, and 3.0 million tonnes to other uses including round fencing, wood fuel, shavings and exports of roundwood (Forest Research 2022). Production of wood products in the UK included 3.6 million $m^3$ of sawn wood, 3.5 million $m^3$ of wood-based panels, 3.6 million tonnes of paper and paperboard and 0.3 million tonnes of wood pellets and briquettes. Consumption of wood products in the UK included 11.5 million $m^3$ of sawn wood, 6.8 million $m^3$ of wood-based panels, 6.8 million tonnes of paper, and 9.4 million tonnes of wood pellets. Ultimately, then, the UK has a net-requirement for imported forest materials, as domestic production does not equal consumption. Estimates here are measured in green tonnes. The term ‘green tonnes’ describes the weight of freshly cut or unseasoned timber, including its moisture content. The timber will typically go to a sawmill or processing facility to be dried or seasoned to reduce its moisture content to improve the quality of the timber and make it more suitable for use in construction or other applications.

According to the data provided by Forest Research (Table 7), Wales produced 1.249 million green tonnes of softwood in 2021; ~12% of the UK total. Consumption of softwood by mills in Wales was 627 thousand tonnes; ~9.5% of the UK total. Production of sawn softwood was 293 thousand tonnes; ~8.2% of the UK total.

**Table 7.** Metrics of wood production, and sawmill production and consumption, with country breakdown, 2021. (Source: Forest Research 2022).

| Metric | Wales | Rest of UK | Total |
|---|---|---|---|
| **Softwood production (private and public), thousand green tonnes** | 581 (private), 668 (public)<br>1,249 (total) | 5,826 (private), 3,341 (public)<br>9,167 (total) | 6,407 (private), 4,009 (public), 10,416 (total) |
| **Hardwood production (private and public), thousand green tonnes** | Not Available | Not Available | 727 (private), 96 (public)<br>823 (total) |
| **Consumption of softwood by mills, thousand green tonnes** | 627 | 5,963 | 6,590 |
| **Production of sawn softwood by mills by country, thousand $m^3$** | 293 | 3,280 | 3,574 |

Wales has two large sawmills that consumed 76% of all softwood consumed in Wales in 2021. Proportional consumption by large mills is therefore slightly lower than the rest of the UK, where large mills consumed 88% of all softwood consumed (Table 7 & 8). Wales’ larger mills sourced softwood logs entirely from within the UK, whereas large mills in the rest of the UK required a small quantity of imports to meet demand.

**Table 8.** Source of softwood, consumption, and production for larger mills by country, 2021. Source: Forest Research (2022). Columns show sawmill location, rows show where the wood used by sawmills in those locations was grown.

| **Source** | **Wales** | **Rest of UK** | **UK** |
|---|---|---|---|
| **England, thousand green tonnes** | 42 | 984 | 1,026 |
| **Wales, thousand green tonnes** | 367 | 352 | 719 |
| **Scotland, thousand green tonnes** | 70 | 3,270 | 3,340 |
| **Northern Ireland, thousand green tonnes** | 0 | 300 | 300 |
| **Total UK, thousand green tonnes** | 479 | 4,907 | 5,386 |
| **Other countries, thousand green tonnes** | 0 | 321 | 321 |
| **Total consumption, thousand green tonnes** | 479 | 5,228 | 5,707 |
| **Production of sawn softwood, thousand $m^3$** | 216 | 2,885 | 3,101 |

UK sawmill processing is dominated by softwood, with 6.6 million tonnes utilised in 2021 (Table 9). 95% of softwood processed by sawmills is UK grown, meaning that 321,000 tonnes of softwood used in UK sawmills are estimated to be imported. Hardwood utilisation is much lower, 72,000 tonnes was used in UK sawmills in 2021, but a larger proportion 17% (12,000 tonnes) is associated with imported materials (Table 9).

**Table 9.** Consumption of roundwood by sawmills for 2021, in thousand green tonnes. (Source: Forest Research 2022).

| | **Hardwood** | **Softwood** |
|---|---|---|
| **UK grown** | 60 (83%) | 6,268 (95%) |
| **Imported** | 12 (17%) | 321 (5%) |
| **Total** | 72 | 6,590 |

For UK wood-based panel mills, the vast majority of the 4.1 million tonnes of input material are softwood-based (Table 10) with only 3 thousand tonnes of hardwood used (all domestic). 33 thousand tonnes of softwood are imported (<1% of total inputs). Whilst Tables 7 to 10 show UK and Welsh timber production is not import dependent, this domestic production fulfils a small proportion of overall total UK demand for timber in its supply chains. This demand gap is met through importation (Tables – 12 to 14).

**Table 10.** Inputs to wood-based panel mills for 2021, in thousand green tonnes. (Source: Forest Research 2022).

| | Softwood | Hardwood |
|---|---|---|
| **UK roundwood** | 1,508 | 3 |
| **Sawmill products** | 1,516 | 0 |
| **Imports** | 33 | 0 |
| **Recycled wood fibre** | 1,085 | |
| **Total** | 4,145 | |

Historically, the majority of Welsh softwood timber has been derived from Sitka spruce, which is fast growing and produces lower density material, resulting in the sector orienting towards products such packaging, whereas the UK as a whole sends relatively more sawn softwood to construction (Table 11, Bryans 2011).

**Table 11.** Sawn softwood product markets for larger mills, % of total softwood product markets, 2021 (Forest Research 2022).

| Product market | Wales | UK average |
|---|---|---|
| **Construction** | 9 | 27 |
| **Fencing** | 33 | 40 |
| **Packaging / pallets** | 40 | 25 |
| **Other** | 18 | 9 |
| **Total** | 100 | 100 |

### 6.3.3 Further details on trade dependencies

Forest Research provides details of ‘apparent consumption’; estimates of the amount of timber used as wood and wood products by people and industries in the UK, which is calculated as total domestic production, plus imports, minus exports. Table 12 provides estimates of apparent consumption (in $m^3$). These figures indicate that — whilst dependence on imported materials for UK-based sawmills specifically is relatively low (see above) — imported wood makes up a very significant component of total demand in the UK. In other words, as domestic production meets only a small proportion of total UK timber demand, demand for wood products overall is met through importation (see below).

**Table 12.** Apparent consumption of wood, 2021. (Source: Forest Research 2022).

| Metric | UK production | Imports | Exports | Apparent consumption |
|---|---|---|---|---|
| **Apparent consumption of wood, million $m^3$** | 10.9 | 46.9 | 4.7 | 53.1 |

The statistics reveal (Table 13) relatively high import dependencies for both coniferous (softwood) sawn wood, and particularly for non-coniferous (hardwood) sawn wood where a very large proportion is imported. The UK is also fully import-dependent for plywood. Table 14 shows the UK is highly reliant on imports of wood pellets.

EU countries are major UK import partners for sawn softwood & hardwood, particle board, fibre board and paper and paperboard (Table 15). Non-EU countries are important UK import partners for sawn hardwood (USA, Cameroon), plywood (China, Brazil), pellets (USA, Canada), and wood pulp (Brazil, Norway) (Table 16).

**Table 13.** Breakdown of apparent consumption for selected wood products, 2021, thousands of $m^3$**.** **(**Source: Forest Research 2022).

| Product | UK production | Imports | Exports | Apparent Consumption |
|---|---|---|---|---|
| **Coniferous sawn wood** | 3,574 | 7,623 | 237 | 10,960 |
| **Non-coniferous sawn wood** | 37 | 536 | 39 | 534 |
| **Total sawn wood** | **3,611** | **8,159** | **277** | **11,493** |
| **Veneer sheets** | 0 | 14 | 0 | 14 |
| **Plywood** | 0 | 1,541 | 55 | 1,486 |
| **Particleboard** | 2,688 | 1,159 | 195 | 3,652 |
| **Fibreboard** | 798 | 1,080 | 71 | 1,807 |
| **Total wood-based panels** | **3,486** | **3,794** | **321** | **6,959** |

**Table 14.** Breakdown of apparent consumption for selected wood products, 2021, thousands of tonnes. (Source: Forest Research 2022).

| Product | UK production | Imports | Exports | Apparent Consumption |
|---|---|---|---|---|
| **Sanitary & household papers** | 689 | 486 | 101 | 1,074 |
| **Packaging materials** | 1,898 | 1,929 | 456 | 3,371 |
| **Other paper & paperboard** | 1,053 | 1,791 | 490 | 2,354 |
| **Total paper & paperboard** | 3,640 | 4,206 | 1,048 | 6,798 |
| **Wood pellets/ thousands of tonnes** | 304 | 9,128 | 2 | 9,432 |

**Table 15.** Country of origin of wood imports to the UK (EU-only), 2021, **%** of total UK import volumes. Top five individual countries of import shown, plus 'other EU'. (Source: Forest Research 2022).

| Country | Sawn soft-wood | Sawn hard-wood | Ply-wood | Particle-board | Fibre-board | Pellets | Wood pulp | Paper and paper board |
|---|---|---|---|---|---|---|---|---|
| **Sweden** | 35 | 1 | 0 | 0 | 0 | 0 | 22 | 17 |
| **Germany** | 11 | 3 | 0 | 20 | 19 | 0 | 1 | 16 |
| **Finland** | 13 | 0 | 8 | 0 | 1 | 0 | 7 | 15 |
| **Latvia** | 21 | 14 | 2 | 10 | 3 | 12 | 0 | 0 |
| **Ireland** | 4 | 2 | 0 | 11 | 35 | 0 | 1 | 0 |
| **Other EU** | 7 | 33 | 5 | 43 | 28 | 6 | 8 | 30 |
| **Total EU** | 92 | 53 | 16 | 85 | 85 | 18 | 39 | 78 |

**Table 16.** Country of origin of wood imports to the UK (non-EU-only), 2021, **%** of total UK import volumes. (Source: Forest Research 2022).

| Country | Sawn softwood | Sawn hardwood | Plywood | Particle board | Fibreboard | Pellets | Wood pulp | Paper and paperboard |
|---|---|---|---|---|---|---|---|---|
| **USA** | 0 | 19 | 0 | 0 | 0 | 60 | 2 | 4 |
| **Canada** | 1 | 4 | 1 | 0 | 0 | 16 | 0 | 2 |
| **Brazil** | 0 | 1 | 20 | 0 | 0 | 2 | 24 | 2 |
| **China** | 0 | 0 | 40 | 1 | 4 | 0 | 0 | 1 |
| **Russia** | 5 | 2 | 7 | 4 | 3 | 4 | 0 | 1 |
| **Norway** | 2 | 3 | 0 | 0 | 0 | 0 | 28 | 4 |
| **Indonesia** | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 |
| **Chile** | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 |
| **Malaysia** | 0 | 2 | 5 | 0 | 0 | 0 | 0 | 0 |
| **Cameroon** | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Other non-EU** | 0 | 6 | 4 | 9 | 7 | 0 | 6 | 6 |
| **Total non-EU** | **8** | **47** | **84** | **15** | **15** | **82** | **61** | **22** |

### 6.3.4 Implications for Welsh deforestation impact

The data above suggests that there is significant potential for Welsh *sawmills* to become ‘self-sufficient’ with domestic timber production. Table 8 suggests high softwood self-sufficiency already for Wales’ two larger mills, but some use of Scottish and English production and none from overseas. Specific hardwood dependencies for Welsh mills are not available from Forest Research. However, Table 9 shows most hardwood consumed by UK sawmills is sourced domestically and Table 10 shows wood-based panel mills do not depend on hardwood imports. Overall, much of the material used in Welsh mills is, or could likely be, sourced domestically in Wales. Wales has a relatively high proportion of area covered in forest, but productive output, roundwood consumption and number of mills appears to be relatively low compared to Scotland, which makes up the bulk of UK production, suggesting potential for expansion of production (Bryans 2011). An interesting point of note is that Welsh-production appears to have lower-than-average utilisation in the construction sector (Table 11), which suggests an opportunity to focus on this sector, as per the recommendations of Lee Waters' MS taskforce (Welsh Government 2022c).

However, Table 12 reveals that apparent UK consumption of all non-coniferous (hardwood) sawn wood is mostly supported by imports. Imports of sawn hardwood are sourced from both EU countries (53%) and non-EU countries such as the USA (19%) and Cameroon (10%), potentially exposing UK hardwood processing to overseas impacts.

Forest Research's estimates of 'apparent consumption' across industry and individuals provides a very different perspective; that the UK is highly import dependent. In relative terms (overall import quantities are lower) import dependencies for hardwood are particularly high (Table 13). In the absence of any third-party Welsh-specific data on the sources of wood consumption overall, the assumption must ultimately be made that consumers in Wales are likely to source from regions which approximate the UK average. Whilst the bulk of imported material comes from the EU (Table 14) notably, in the list of countries of import specified by Forest Research, import sources include several in tropical areas including Brazil (which according to data used within the Welsh GEIC model has a deforestation rate associated with industrial roundwood production of 0.00199 ha per tonne), Indonesia (0.000718 ha per tonne), Chile (0.00110 ha per tonne), Malaysia (0.000881 ha per tonne) and Cameroon (0.000768 ha per tonne). This deforestation is an estimate of permanent natural tree cover loss; not the clearance of commercial forest that is compensated by replanting in managed systems. The data from the Welsh GEIC model (a 'consumption-based account' based on MRIO) does not provide statistics in a comparable manner to the Forest Research data ('apparent consumption' based on the difference between domestic production, imports, and exports). However, it has the advantage of providing Welsh-specific estimates of potential sources that might constitute Wales' overall dependencies and associated impacts. Table 15 details the Top 20 sources of supply to meet Welsh consumption, along with associated tropical deforestation impact in 2018. Table 18 details the Top 20 sources of tropical deforestation impact associated with Welsh consumption. According to Phase 1 methods, the total deforestation impact is estimated to be 91.40 ha to provide the 595,541 tonnes of 'industrial roundwood' material required to meet Welsh consumption. According to Phase 2 methods, the total deforestation impact is estimated to be 58.8 ha to provide the 343,673 tonnes of 'industrial roundwood' material required to meet Welsh consumption. The Welsh GEIC results from Phase 2 suggests that the timber sector, specifically, requires 32,232 tonnes of 'industrial roundwood', of which 17,522 is sourced from outside of the UK, with a deforestation footprint of 0.94 ha.

**Table 17.** Top 20 countries of supply to meet Welsh consumption and associated tropical deforestation risk in 2018.

| Country | Welsh consumption (tonnes), Phase 1 | Associated tropical deforestation (ha) | Welsh consumption (tonnes), Phase 2 | Associated tropical deforestation (ha) |
|---|---|---|---|---|
| **UK** | 142,413 | 0 | 87,442 | 0 |
| **Sweden** | 69,010 | 0 | 33,698 | 0 |
| **United States of America** | 58,860 | 0 | 30,577 | 0 |
| **Finland** | 36,945 | 0 | 17,906 | 0 |
| **Canada** | 29,081 | 0 | 13,316 | 0 |
| **Poland** | 24,626 | 0 | 13,120 | 0 |
| **China** | 20,297 | 0 | 14,342 | 0 |
| **Latvia** | 19,637 | 0 | 12,059 | 0 |
| **Ireland** | 18,560 | 0 | 8,574 | 0 |
| **Russian Federation** | 17,924 | 0 | 13,778 | 0 |
| **Germany** | 16,422 | 0 | 9,042 | 0 |
| **Brazil** | 15,769 | 31.38 | 10,418 | 20.73 |
| **Portugal** | 8,010 | 0 | 4,313 | 0 |
| **Spain** | 7,459 | 0 | 5,020 | 0 |
| **Czechia** | 7,361 | 0 | 5,140 | 0 |
| **Estonia** | 6,998 | 0 | 3,285 | 0 |
| **Viet Nam** | 6,768 | 8.04 | 4,592 | 5.46 |
| **Norway** | 5,609 | 0 | 3,016 | 0 |
| **Turkey** | 5,609 | 2.07 | 3,989 | 1.47 |
| **New Zealand** | 5,036 | 0 | 3,417 | 0 |

**Table 18.** Top 20 source countries of tropical deforestation risk associated with Welsh consumption.

| Country | Associated Tropical deforestation (ha), Phase 1 | Associated Tropical deforestation (ha), Phase 2 |
|---|---|---|
| **Brazil** | 31.38 | 20.73 |
| **Viet Nam** | 8.04 | 5.46 |
| **Cambodia** | 6.52 | 4.42 |
| **Lao People's Democratic Republic** | 4.72 | 3.20 |
| **Chile** | 4.38 | 2.53 |
| **Argentina** | 4.10 | 2.37 |
| **Uruguay** | 2.45 | 1.41 |
| **Uganda** | 2.42 | 1.38 |
| **Malaysia** | 2.39 | 1.62 |
| **Venezuela (Bolivarian Republic of)** | 2.24 | 1.29 |
| **Myanmar** | 2.10 | 1.42 |
| **Turkey** | 2.07 | 1.47 |
| **Ghana** | 1.85 | 1.05 |
| **Thailand** | 1.75 | 1.19 |
| **India** | 1.69 | 1.22 |
| **Paraguay** | 1.62 | 0.93 |
| **Australia** | 1.40 | 1.03 |
| **Peru** | 1.24 | 0.71 |
| **Dominican Republic** | 1.12 | 0.65 |
| **Ethiopia** | 0.80 | 0.46 |

Overall, it appears that Welsh consumers are exposed to a significant deforestation risk linked to dependency on overseas timber, whereas the Welsh timber industry itself is not highly exposed. There is potential to reduce exposure via further domestic production. Further detail on the sources of wood-based materials sold in Wales (e.g. the origin of sawn wood and processed wood-based materials such as plywood etc.) would provide a greater understanding of whether these are explicitly linked to international sources associated with tropical deforestation. Although it does not provide a breakdown of the different types of timber consumed in Wales, the Welsh GEIC indicator provides a 'best estimate' at the current time of the impacts of timber production overall.

## 6.4 Welsh consumption of palm oil

### 6.4.1 Introduction

Palm oil contributes to approximately 19% (6.88k hectares) of the UK's tropical deforestation footprint (2018 data; SEI/JNCC 2022) and is used as an ingredient within many processed foods and cosmetics. Due to its embedded nature, Welsh dependency on palm oil is likely highly entangled with the wider UK sourcing footprint. Because of this highly interlinked supply chain, a downscaled IOTA model for Wales should be an effective tool for assessing which Welsh sectors are most closely connected to palm oil-linked deforestation. This could then act as a jumping off point for further engagement with Welsh companies and palm oil users.

Results from the Welsh GEIC model using Phase 1 methods suggest that 107,679 tonnes of Oil Palm Fruit are required to meet Welsh consumption, with 178.9 hectares of associated tropical deforestation. The Phase 2 estimate is lower at 80,255 tonnes with an associated tropical deforestation of 130.9 hectares. The compositions by country of the associated tropical deforestation estimated by both Phase 1 and Phase 2 methods are closely aligned: over 80%, 11% and 5% is due to production in Indonesia, Colombia, and Malaysia, respectively.

To confirm this approach, this case study interrogates the hypothesis that Welsh palm oil dependency is highly interlinked with and comparable to the wider UK footprint. To analyse this, the case study explores to what extent there is a significant palm oil processing industry in Wales, and whether there are any Welsh-specific connections with significant palm oil risk, (e.g. via the direct imports of palm oil related materials). The case study summarises available data on the broader UK palm oil industry, where material is being processed and where it ends up, including what activity is ongoing in the UK to reduce the industry's exposure to deforestation risk.

### 6.4.2 Industry-linked Statistics

In 2021 WWF-Cymru produced a "Wales & Global Responsibility Report" that uses UN Comtrade data (UK-wide) to ascertain import volumes of palm oil products and provenance information, and calculates Wales' share of these imports to extrapolate Wales' estimated share of overseas environmental impacts. This is done by analysing Welsh and UK data on consumption (such as DEFRA Family Food Survey data), livestock numbers (for commodity imports used as livestock feed), and GDP (which is used where there is no other reliable and complete dataset for allocating imports). The WWF report allocates between 3 to 6% of the UK's relevant commodity imports to Wales. It is important to note that these methods are not readily comparable with the Welsh GEIC data which offers a full 'consumption-based' account of palm oil fruit dependencies associated with all goods and services utilised in the Welsh economy, as opposed to an assessment of palm oil product imports. The WWF-Cymru report offers more product-specificity, therefore, at the expense of a fully holistic overview of dependencies.

The WWF Report finds that palm oil is mostly brought into Wales in the form of palm kernel expeller (PKE) and palm oil cake (53% of total), which are used mainly as an ingredient in animal feed for the ruminant cattle sector, particularly the dairy sector. These are produced from the high-fibre husk of the palm oil kernel and are therefore seen as a by-product of the palm oil industry. A further 27% of imports are crude palm oil, which is used in many processed foods, such as biscuits, cakes and confectionery, as well as personal hygiene products (e.g. soap). According to the report, 85% of the palm import land footprint falls in countries that are at high or very high risk for deforestation and/or social issues, including Indonesia, Malaysia, and Papua New Guinea. Because of where the palm oil comes from, WWF's assessment is that this makes palm the highest risk commodity that Wales imports.

At the UK level, industry data are available. According to the UK Roundtable on Sourcing Sustainable Palm Oil (UKRSSPO), in 2020, the UK imported 436,000 tonnes of crude palm oil (PO) and 29,000 tonnes of Palm Kernel Oil (PKO), amounting to a total of 465,000 tonnes. The UK used around 0.5% of the total global volumes of crude palm oil and palm kernel oil. In 2020, the UK imported 364,000 tonnes of PKE (this was a significant drop from a 2019 import volume of over 500,000 tonnes) (UKRTSSO 2021). Palm kernel expeller (PKE) or ‘oilcake’ is high in protein and fat and is mainly used as one of the components for feed meal formulation for the ruminant industry. These data are not available at a Welsh scale, so considering UK data is the best proxy.

In contrast to the UK Roundtable data, the total volumes expressed in the Commodity Footprints Dashboard/UK GEIC indicator are expressed in terms of ‘palm oil fruit equivalents’ which is the total estimated mass of the oil palm fruit, not the mass of derived palm products and accounts for the fact that three-quarters of the fruit is not utilised. The conversion factor is 4 palm oil fruit equivalents: 1 tonne of palm oil (or other derivatives from oil palm fruit). The GEIC indicator estimates a total of 4.26 million tonnes of palm oil fruit are linked to total UK consumption activities.

In addition to these palm oil product imports, the UK imports a significant amount of embedded palm oil in products such as soap, margarine, biscuits, chocolate, etc. According to the Riskier Business Report, on average, 1.2 million tonnes of palm oil was imported into the UK every year between 2016 and 2018. In 2018, around 323,688 tonnes, or 77% of the crude and refined palm oil entering the UK, was certified as sustainable by the RSPO (WWF & RSPB 2020). However, this figure excludes palm kernel oil (PKO), RSPO credits, derivatives and finished goods and so only applies to 36% of the total palm oil that is imported to the UK. Figure 41 below illustrates in which products embedded palm oil fractions can most often be found. These data are not available at a Welsh scale, so considering UK data is the best proxy.

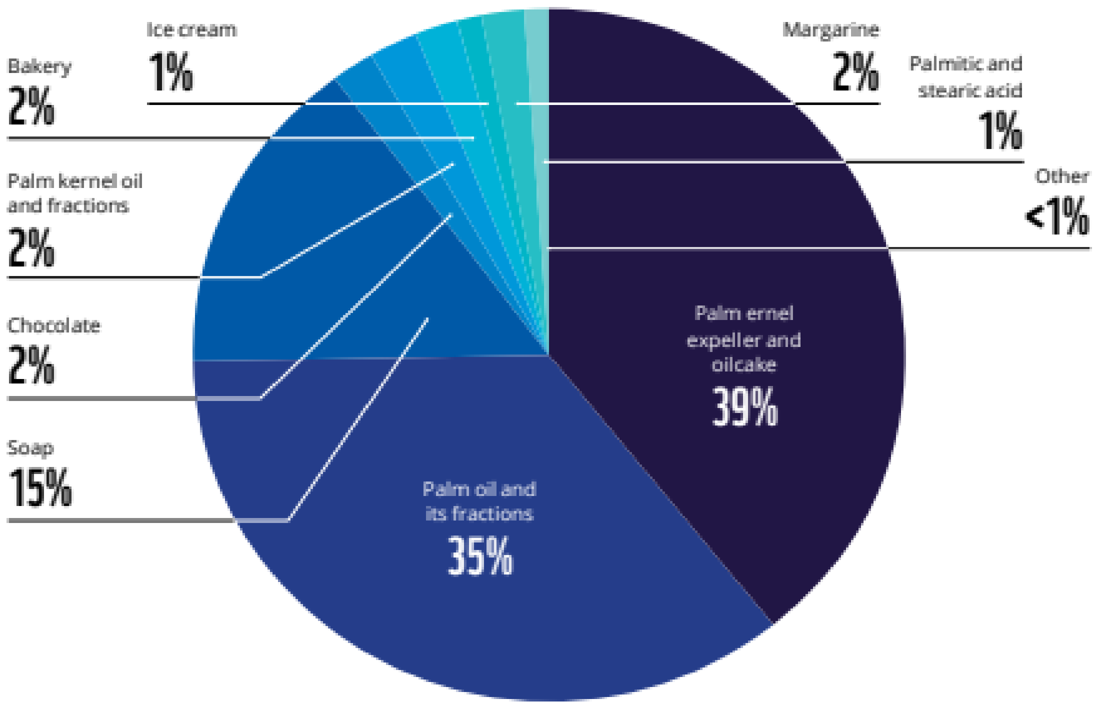


Figure 41. Estimated Proportion of Palm Oil Imported into the UK, by product (Average 2016-18) (WWF, RSPB Riskier Business Report 2020, © 2020 WWF-UK and RSPB. All rights reserved.).

According to the UK Roundtable figures, the UK received the majority (around two thirds) of its oil palm products directly from countries of origin in 2020 (Figure 42). Papua New Guinea was the largest producer country exporting to the UK in 2020, accounting for 28% of UK imports of crude oil. A considerable proportion is imported from Europe – the Netherlands accounted for 29% of UK imports in 2020, likely sourced and re-exported from palm oil production landscapes in Southeast Asia. Of the palm oil imported to the UK between 2016 and 2018, 89% came from risky countries (Indonesia, Malaysia, and Papua New Guinea) (WWF Riskier Business 2020).

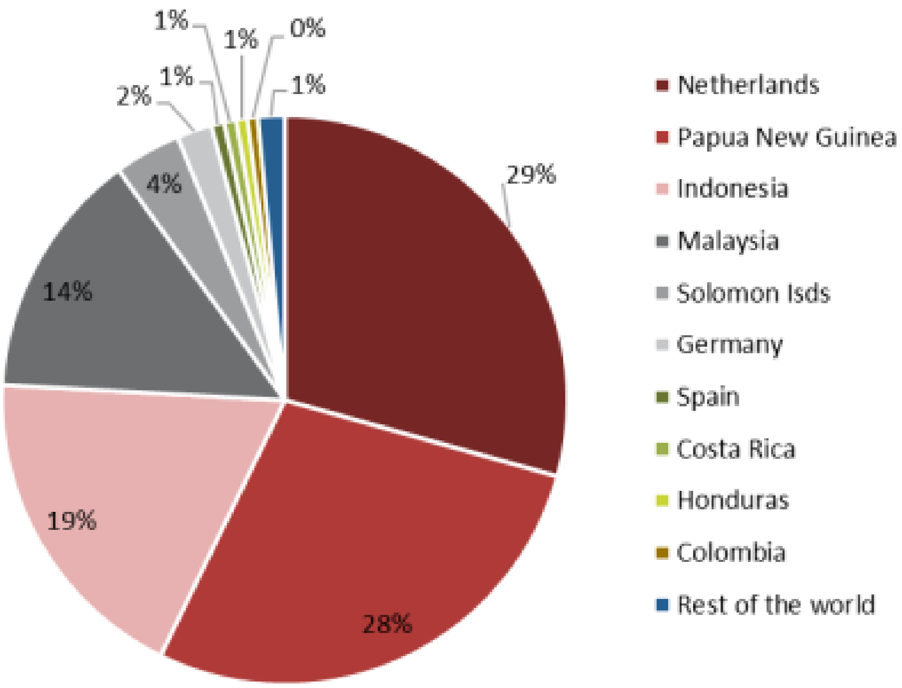


**Figure 42.** 2020 UK Imports of PO and PKO from different countries (Efeca 2021; reproduced with permission from Efeca).

### 6.4.3 Where, and via whom, does palm oil come into Wales and the UK?

UK Trade Info lists 133 importers of palm oil to UK in 2022.

Four major agricultural commodity traders source the majority of the UK's crude palm oil; AAK, ADM, Olam and Sime Darby. These companies report their trading volumes to the UK Roundtable on Sourcing Sustainable Palm Oil on an annual basis, which then forms the basis of their annual reporting figures, cited in Figure 42 (Efeca 2021).

Each of these major traders currently own and operate the only four palm oil refineries in the UK. AAK has a refinery based in Hull, ADM in Erith/Purfleet near London, Sime Darby in Liverpool, and Olam in Goole/Hull.

The schematic below from the UK Roundtable illustrates flow of palm oil in the UK beyond these major traders (Figure 43).

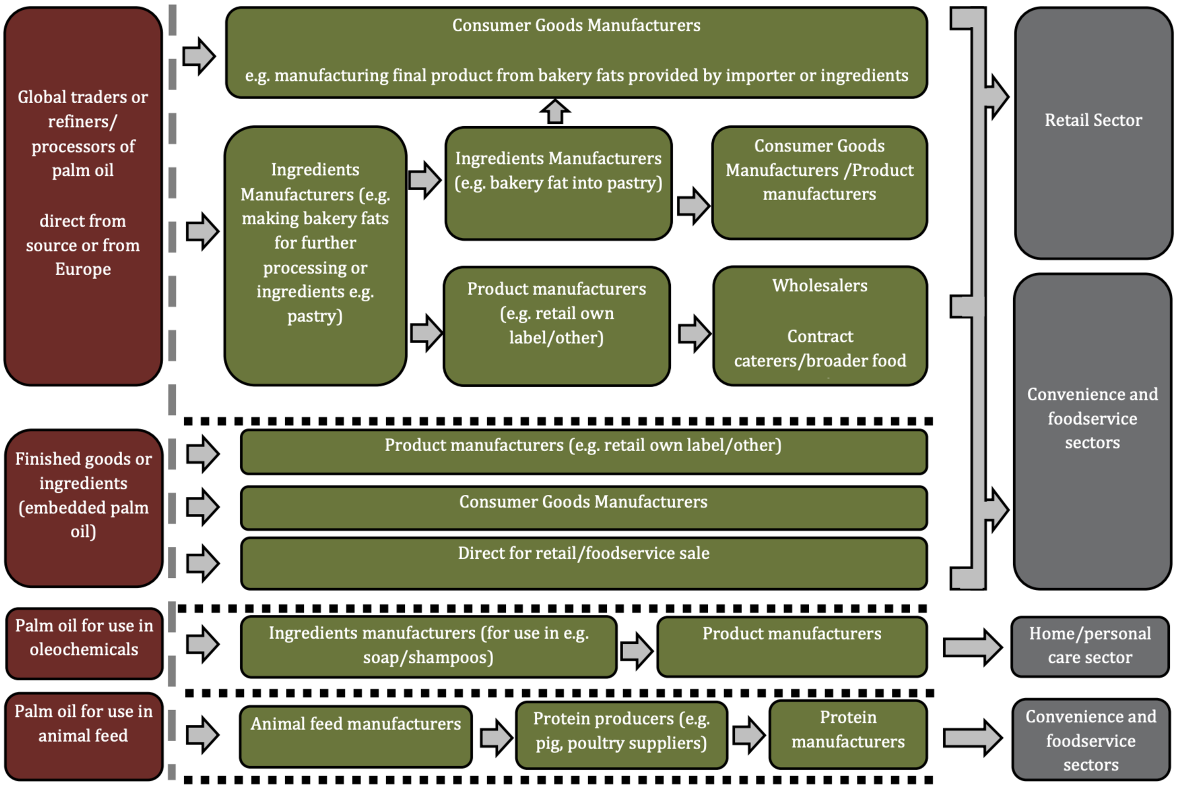


Figure 43. A schematic of the UK Palm Oil Supply Chain (UKRTSSPO 2021; reproduced with permission from Efeca).

As the schematic above shows, in addition to crude palm oil imports, palm oil is also imported into the UK already 'embedded' into finished goods. This palm oil is sometimes accounted for as "palm oil fractions." It is likely that Wales' consumption of embedded palm oil is aligned with wider UK consumption due to the UK's consistent spread of supermarkets and food service sector offerings.

In order to check whether Wales might have any specific large companies or industries using palm oil in manufacturing that differed from an 'average' UK mix dependent on sources (e.g. from the four major importing processors), a scan was conducted of UK Trade Info data and the UK Roundtable participants of Wales-based companies importing palm oil from abroad. Only three companies appear to be importing palm oil products directly, as summarised in the table below. Research appears to indicate that each of these companies are covering their palm oil imports with RSPO certification (Table 19).

**Table 19.** The companies listed as importing 'palm oil' commodities in 2022 with registered addresses in Wales, with a description of their activities and evidence of RSPO certification (UK Trade Info).

| **Company name** | **Company description** (sourced from website) | **Evidence of RSPO** |
|---|---|---|
| Eurocaps Ltd | EuroCaps is a Soft Gelatin Capsule Contract Manufacturer, supplying the nutritional supplement and OTC markets across Europe and worldwide. | Yes- member of RSPO- but unsure on specific certification |
| Nimbus Foods Ltd | Nimbus Foods, one of Europe's leading innovators and manufacturers of high-quality decorations, toppings and inclusions for the food industry. Our extensive range of specialist bakery, confectionery, ice-cream, dessert, cereal and snacking products are already in use by the world's best-known brands of ambient, chilled and frozen foods. | Yes - RSPO certificate |
| O P Chocolate Ltd | OP Chocolate, a quality manufacturer and supplier of luxury chocolate wafers, chocolate bars and traditional family favourites such as Pink and White wafers. In 1991, OP was purchased by Groupe Cémoi. Cémoi are a major force in the European Confectionery industry, supplying both UK and European markets with an extensive range of goods | Yes - Parent company Cémoi's group says '100% RSPO certified' |

There are likely many other Wales-based companies buying palm oil or products containing palm oil from the major UK processors and manufacturers (AAK, ADM, Sime Darby, Olam) once it has already been imported and processed in the UK. Further analysis via direct engagement with (major) Welsh companies could investigate the sourcing/usage patterns of these Wales-based actors further, and to what extent they are covered by certification. However, given the concentration of the UK-based palm oil market to these four companies, it is likely that provenance data and sustainability certification coverage can be linked to these companies for much of the Welsh supply chain.

For embedded products, palm oil use in animal feed, and other uses, Welsh-specific sourcing data were not identified within the time constraints of this project.

### 6.4.4 What do we know about the deforestation risk of flows into Wales and the UK?

Based on the results from the application of the IOTA tool to Wales, Welsh consumption-based exposure to palm oil linked tropical deforestation is estimated at 179 hectares. However, while this captures Wales' exposure to deforestation risk, it does not capture action within the supply chain taken to reduce deforestation risk.

The UK palm oil-dependent sector has been taking action to reduce deforestation impacts for the past several years. To date, efforts have been focused on scaling up the uptake of the RSPO certification, primarily led by major UK supermarkets and consumer goods brands, facilitated by the UK Roundtable on Sourcing Sustainable Palm Oil.

The industry-led UK Roundtable on Sourcing Sustainable Palm Oil is part of the Government-funded UK Sustainable Palm Oil Initiative, which is facilitated by Efeca. It brings together procurers of palm oil working towards the shared goal of sustainable, resilient supply chains, and is supported by a network of civil society partners. Set up in 2012 by the UK Government, the UKRTSSPO worked towards the Government's goal of sourcing 100% Certified Sustainable Palm Oil. Membership has since expanded to encompass the breadth of the UK palm oil supply chain, including retailers, public sector, small palm oil growers, wholesalers, finance, the food service sector and manufacturers.

In 2020, for imports of palm and palm kernel oil only, the UK Roundtable reported that 71% could be classified as certified sustainable (RSPO or equivalent certification). Both the total and certified sustainable import volumes represent a continuation in the static trend of about 70% certification observed over recent years.

While encouraging, these figures do not include analysis of coverage of embedded palm oil or palm oil used in animal feed (PKE, oil cake, etc). There are very little data on traceability and certification/standards associated with these other sources of palm oil into the UK, but it is likely that this number is significantly lower than the 70% certification coverage for crude palm oil and palm kernel oil. In their Riskier Business Report, WWF estimates that certified coverage across all UK palm oil imports could be closer to 36% (Riskier Business 2020). These proportions are likely to be similar for Wales, given the analysis above.

However, progress has been made by industry in other areas beyond the purchasing of certified material. A further 12% of the total volume was imported under a "No-Deforestation, No-Peat, No-Exploitation" (NDPE) policy, which is an important volume to give recognition to due to the growing prominence of NDPE policies and their verification tools (UKRTSSPO 2021). This framework requires physical traceability to mill-level in high-risk sourcing areas. Several global industry groups have aligned with the NDPE framework, such as the Palm Oil Collaboration Group, the Consumer Goods Forum Forest Positive Coalition, and the Agricultural Commodity Trader's Roadmap Group.

In some cases, consumer brands have purchased additional RSPO 'credits' for products with palm oil ingredients, meaning they are not sure they have directly sourced deforestation-free palm oil, but they are funding the production of RSPO certified palm oil elsewhere. This means that assessing the deforestation risk of certain food, cosmetic and animal feed products requires additional scrutiny on a case-by-case basis.

The UK Government has specified in its Government Buying Standards for Public Procurement that "from the end of 2015 all palm oil (including palm kernel oil and products derived from palm oil) used for cooking and as an ingredient in food must be sustainably produced." However, uptake and enforcement of these standards has been patchy across the UK. Direct engagement is often needed with major food service providers to ensure compliance with this policy. More information on public procurement and the food service sector's efforts on palm oil can be found in Efeca's 2018 report.

The UK is introducing mandatory due diligence legislation for major importers of forest risk commodities to the UK as part of its Environment Act (Defra 2022b). The commodities have not yet been specified but it can be speculated that they are relatively likely to include palm oil given its widely accepted high forest risk status, and its high policy profile. This legislation has the potential to increase the transparency of the palm oil sector to allow for more granular analysis of the UK's progress in removing deforestation risk from its palm oil (and other commodity) supply chains.

In general, deforestation in Indonesia, Malaysia and Papua New Guinea fell to a four year low in 2020. A 2020 piece of research from Chain Reaction suggests that NDPE policies cover 83 percent of palm oil refining capacity in Indonesia and Malaysia. In November 2017, this percentage stood at 74 percent. This indicates that in general the supply of palm oil from production landscapes is increasingly certified or associated with the NDPE framework. However, the top ten palm oil companies associated with deforestation in the region are still not linked to the NDPE framework (Chain Reaction Research 2020, 2022).

The Welsh GEIC data suggests that Colombia is now an emerging source of palm oil and therefore deforestation risk for Wales. According to Chain Reaction Research, palm oil production in Latin America has increased by almost 60 percent since 2011/12, reaching a total of 4.6 million tonnes in 2020/21. Colombia ranked as the 4th largest global producer (2.1% of global production) and the top South American producer (UKRTSSPO 2021). A further production increase is forecasted, with export markets in the Latin American region as well as in Europe as important drivers. The direct link between deforestation and oil palm expansion is overall weaker than in Southeast Asia, but it still threatens valuable forest ecosystems. Oil palm may also displace other land uses in several countries, pushing cattle and crop production further into forested areas (Chain Reaction Research 2021).

### 6.4.5 Implications for Wales' exposure to palm oil-linked deforestation

Given the high rate of sustainability certification for direct palm oil imports into the UK, it is likely that much of directly sourced palm oil into Wales is certified sustainable. Only three Welsh companies are listed on UK Trade Info as importing palm oil products directly, and all three of these companies are linked to the RSPO and/or RSPO certification, although further follow up could confirm this (including whether it applies to all handled materials). Where other Welsh companies are buying crude palm oil products, the majority will likely be sourced from the major refineries based in the UK, which are associated with the UK Roundtable on Sourcing Sustainable Palm Oil and either RSPO or NDPE certification.

Wales may have some exposure to deforestation risk from palm oil expeller, or palm oil cake, which are products used in animal feed for the ruminant livestock sector. Given the slightly higher proportion of cattle livestock in Wales than in the UK overall, it could be that Wales has a slightly higher dependency on this ingredient. However, these products are often seen as a byproduct of the crude palm oil sector. Further analysis could be done in this area to test the economic demand for these types of palm oil byproducts in the Welsh livestock sector, and whether this material is largely being sourced domestically from refineries in the UK, or from abroad.

For embedded palm oil products coming into Wales and the wider UK, sustainability certification is still quite unclear. Given the interlinkages between the UK and Welsh processed food, cosmetics and consumer goods sectors, there is likely limited direct influence by Welsh specific supply chain actors on embedded palm oil deforestation risk. Further analysis could explore in more detail the sourcing profiles of the Wales-based downstream companies using palm oil material. However, given the embedded nature of many of the uncertified palm oil products in the UK, it might be most effective to focus on reform in the global food and cosmetics sectors.

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# Appendix 1: Method used to calculate the Ecological Footprint and biocapacity

## IO Approach

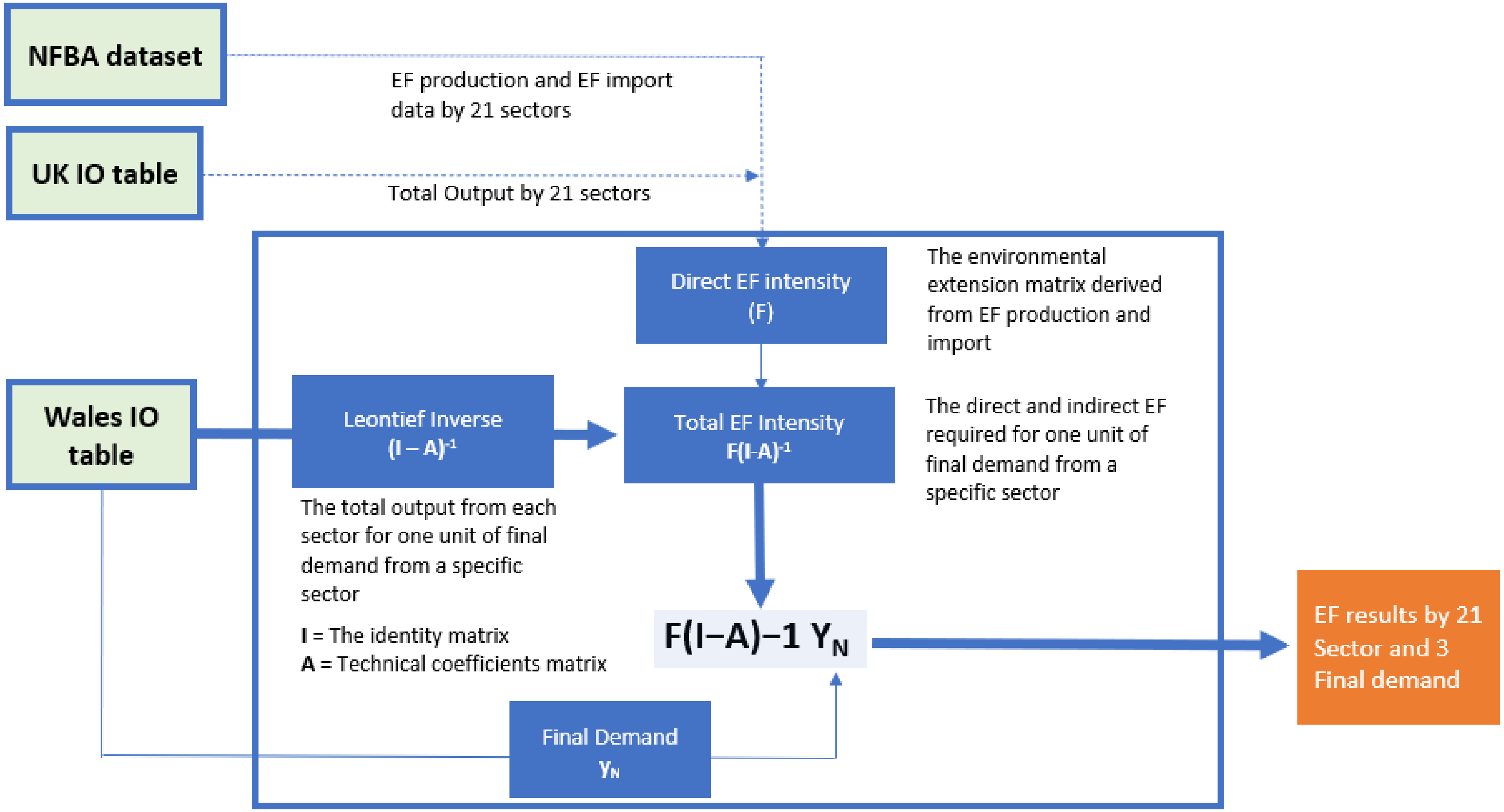


**Figure 44.** Method flowchart for calculating the Ecological Footprint for Wales using the IO approach.

The Ecological Footprint of Wales was calculated through an environmentally extended Input-Output (EEIO) analysis using the Ecological Footprint of the United Kingdom, Wales' Input-Output table, and the UK Input-Output table. The method consisted of three steps: 1) allocation of the Ecological Footprint data for the UK to the corresponding industrial sector, 2) development of an environmentally extended Input-Output table for the Ecological Footprint results for Wales, and 3) derivation of the Ecological Footprint of final demand according to economic sector. The extended input-output analysis is a well-established and widely applied method (Figure 44). Unless otherwise specified in this report, the term "Ecological Footprint" refers to the Ecological Footprint associated with consumption.

### 6.4.6 Step 1: Assigning Ecological Footprint Data for the United Kingdom to the Industrial Sectors (Direct EF Intensity)

In this step, the direct Ecological Footprint (EF) intensity is calculated using the Ecological Footprint data for the United Kingdom and the 2018 UK Input Output table. The Ecological Footprint of production and import for the year 2018 was obtained from the National Footprint and Biocapacity Account (NFBA). To ensure the consistency and comparability of the analytical framework used in this research, the 127 industrial sectors in the 2018 UK Input Output table were consolidated into 21 categories, as described in the waste study that is presented later in this paper. The Ecological Footprint of production and import data was then allocated to these 21 industrial categories and normalized by dividing each category's total output in the UK Input Output table. This normalization process facilitated the derivation of a direct Ecological Footprint (EF) Intensity vector for each industrial sector by each land type. This is a crucial analytical step in our investigation:

$$\text{Direct EF Intensity} = \mathbf{F}$$

### Step 2: Creation of an Environmental Extension Model by Allocating the Direct EF Intensity Vector to the 2019 Input-Output table for Wales and Determination of the Total Ecological Footprint Intensity

In this step, the Ecological Footprint associated with production and imports in United Kingdom is applied as an environmental extension to the Welsh input-output model.

The objective of this step is to break down the Ecological Footprint of Wales in relation to final demand by economic sector. The total EF Intensity is calculated using the following general formula:

$$\text{Total EF Intensity} = \mathbf{F}\,(\mathbf{I}\text{-}\mathbf{A})^{-1}$$

where $\mathbf{F}$ is the direct EF intensity calculated in Step 1; $\mathbf{I}$ is the identity matrix, a matrix of 21 columns and rows of zeros, with 1 on the diagonal; $\mathbf{A}$ is the technical coefficient matrix, $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ represents the Leontief inverse matrix, which reflects the monetary exchanges with other sectors required by each economic sector to produce one monetary unit of output. Finally, the total EF intensity is calculated by multiplying the direct EF intensity with $(\mathbf{I}\text{-}\mathbf{A})^{-1}$, considering the entire supply chain.

### Step 3: Calculation of Ecological Footprint of Final Demand by Economic Sectors

In this step, Ecological Footprint of final demand by economic sector is calculated. The Ecological Footprint is determined using the following equation:

$$\text{Ecological Footprint} = \mathbf{F}\,(\mathbf{I}\text{-}\mathbf{A})^{-1}\,\mathbf{Y}_{\mathbf{wales}}$$

where $\mathbf{Y}_{\mathbf{wales}}$ represents the total final demand in Wales, expressed in pounds (£). Final demand encompasses household consumption, government spending, and gross fixed capital formation. By multiplying the total Ecological Footprint intensity by the respective final demand, we can calculate the Ecological Footprint of final demand in Wales. Through the application of extended environmental input-output analysis, we can assess the industrial Ecological Footprint of Wales, which can inform environmental policy decisions and guide the development of Ecological Footprint reduction measures to promote regional sustainability.

## Top-down approach

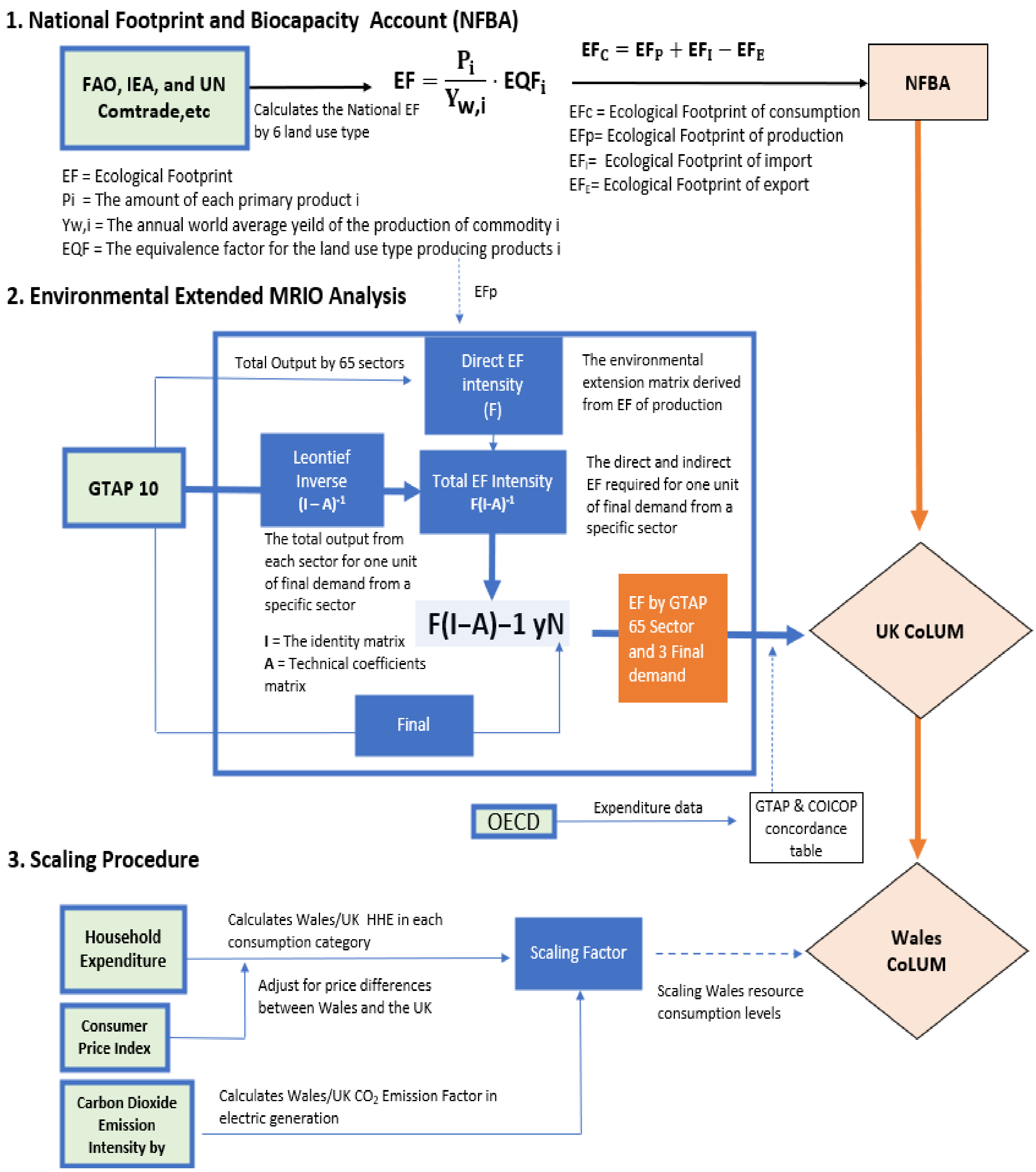


**Figure 45.** Method flowchart for calculating the top-down Ecological Footprint for Wales.

The second approach, which was used to calculate an alternative Ecological Footprint of Wales, used a top-down scaling method developed by Global Footprint Network (Isman *et al.* 2017; Baabou *et al.* 2018; Galli *et al.* 2020). This included MRIO analysis for the global trade analysis but did not rely on data from the Welsh specific IO table to downscale UK results to give Welsh data. The method includes three steps: 1) calculating the national level Ecological Footprint of Production ($EF_P$) for the UK, 2) developing an environmentally extended multi-regional input-output (EE-MRIO) with the national $EF_P$ results in order to derive the Ecological Footprint of final demand according to economic sector, and 3) scaling down Ecological Footprints to sub-national levels with household expenditure survey and other data sources (Figure 45).

The three steps outlined above are well established and widely applied methods, summarised below.

Ecological Footprint data for the UK was derived from the 2022 Edition of the National Footprint and Biocapacity Accounts, or NFBA (Global Footprint Network 2022). Ecological Footprints in the NFBA have six demand types: cropland, grazing land, fishing grounds, forest products, built-up land, and carbon footprints. Ecological Footprint and biocapacity are expressed in global hectares (gha), a unit representing a hectare with world-average bio-productivity (Kitzes *et al.* 2007). The general formula to derive the Ecological Footprint associated with each land type is:

$$EFf = \sum_{j=1}^{6} \sum_{i=1}^{n} \frac{Ti}{Yw,i} \cdot \times EQF_j$$

where i refers to the n-input needed to produce the flow f throughout its production chain; j refers to the six different types of ecological assets tracked by EFA; EQFj is the equivalence factor of the j-th asset/land type; EQFs capture the difference between the productivity of a given asset/land-type and the world-average productivity of all biologically productive assets/land-types (Galli 2015). Accounting methods and the underlying data sources are regularly revised and most recently documented by Borucke *et al.* (2013) and updated by Lin *et al.* (2018).

The UK's Ecological Footprint of production results from the NFBA were applied as an environmental extension to the multi-region input-output model (Leontief 1970). The Global Trade Analysis Project (GTAP) database version 10 (Aguiar *et al.* 2016) was used as the base MRIO model to develop a standard environmentally extended multi-region-input output model (EE-MRIO; Weinzettel *et al.* 2014; Kitzes 2013; Munoz & Steininger 2010; Wiedmann *et al.* 2006, Miller & Blair 2009) for the year 2014. The purpose of this step was to derive the Ecological Footprint for the UK associated with final demand and disaggregated by economic sector. Ecological Footprints are calculated via EE-MRIO using the following general formula:

$$EFc = F(I - A)^{-1}\, Y_N$$

where **F** is the environmental extension matrix (direct $EF_P$ of sectors normalized per unit of sector output, which is expressed in gha $\$^{-1}$) derived from the initial allocation of $EF_P$ for the 6 assets/land-types (crop-, grazing-, forest-, built-up and carbon-sequestration land as well fishing grounds) to each of the 65 producing economic sectors identified by GTAP 10 (Galli *et al.* 2017); $\mathbf{Y_N}$ is the country total final demand for goods, expressed in $; **I** is the identity matrix (a matrix of zeros for 65 columns and rows with diagonal consisting of one's); **A** is the technical coefficients matrix (representing the Leontief inverse), which reflects the monetary exchange between each sector to produce one currency unit worth of output from a specific sector of the economy.

The Ecological Footprint of final demand was calculated by multiplying the Ecological Footprint intensity by domestic final demand. The Ecological Footprint intensity is calculated by multiplying direct footprint intensity by the Leontief inverse (Leontief 1970) to consider the entire supply chain of final demand. The direct footprint intensity is calculated by dividing the Ecological Footprint production of each land type by the total output for each sector, including imports. The domestic final demand of the Ecological Footprints includes household consumption, government consumption, and gross fixed capital formation. Household consumption represents short-lived consumption by households (e.g. food, housing maintenance, goods and services paid for and consumed within a fiscal year); Government consumption represents short-lived consumption by governments (e.g. public services, schools, policing, defense, etc.); Gross fixed capital formation represents long-lived assets, purchased by households (e.g. new houses, white goods), firms (e.g. machinery), and governments (e.g. transport infrastructure). The Ecological Footprint of final demand is then translated to household consumption categories using a GTAP-COICOP (Classification of Individual Consumption According to Purpose, UN (2018)) concordance table. The concordance table describes all relationships between GTAP sectors and COICOP categories through many-to-many relationships, and the Ecological Footprint is allocated based on COICOP household expenditures. For each consumption category, we calculated the Ecological Footprint on six different land use types resulting from final purchases in each consumption category (Galli *et al.* 2017). The resulting dataset is called the COICOP Land Use Matrix (CoLUM).

Starting with the CoLUM of the UK, we then derived CoLUM datasets for Wales by following a scaling procedure based on sub-national household expenditures (Office for National Statistics (2022)), consumer price index (CPI, Office for National Statistics (2018)), and local $CO_2$ intensity of energy production (Ricardo Energy & Environment, ONS (2023)). Consumption expenditures were first adjusted using consumer price indices by COICOP category, and then scaling factors were calculated from the ratio of CPI-adjusted consumption between Wales' and the UK national average. Carbon dioxide emission per unit of electricity production (t-CO2/kWh, Office for National Statistics (2023)) were applied to further refine the carbon footprint in “Electricity, gas, other fuels” category in the CoLUM. Scaling factors for government and gross fixed capital formation categories were derived from capital and current government spending (cite: Country and Regional analysis dataset).

## Biocapacity

The biocapacity of Wales presented in this report was estimated using data from the NFBA on the average biocapacity per hectare of the United Kingdom. This assumes that the bioproductive land and sea areas of Wales are equivalent in biocapacity to the average bioproductive areas of the UK. Various methods exist to improve the biocapacity calculation. In general, because a global hectare is a standardised unit of bioproduction, the bioproduction potential of areas in Wales would need to be accurately converted by comparing it to an area of known bioproduction and known biocapacity. For natural or unmanaged areas, spatially explicit analysis, or existing data on actual or potential net primary production of Wales can be compared to the UK to derive the biocapacity of Wales. For managed areas, such as croplands, Agricultural yields can provide a more accurate indication of relative bioproductivity and using yield and equivalence factors from the NFBA, can be used to calculate the biocapacity of croplands.

## Differences to the previous method for calculating a Welsh Ecological Footprint

The methods and data used in this study and the methods used in the previous calculation of a Welsh Ecological Footprint differ. Therefore, the current results have recalculated historical data rather than used the previous calculation to create the time series. It would not be correct to directly compare the two; these methodological and data differences will mean there will be differences between the new and former data.

In this study, two approaches were applied to analyse different aspects of the Welsh Ecological Footprint. A top-down approach was used to calculate the Ecological Footprint based on final demand in the global supply chain. Conceptually, the top-down approach prioritizes understanding differences in final consumption, while the single IO approach prioritizes understanding the economic structure of Welsh industries as a producer of goods and services to meet Welsh Ecological Footprint demand.

In the previous report, "Ecological and Carbon Footprints of Wales Update to 2011" written by the Stockholm Environmental Institute (SEI) and GHD, the Welsh Ecological Footprint was calculated using the same approach as GFN's top-down approach, which started with the calculation of the UK Ecological Footprint using environmentally extended multi-regional input-output analysis and downscaling to Wales using Welsh expenditure data. The major difference between both top-down approaches came from input data: the previous study used the UK IO table and World Input-Output Databases for rest-of-world economic data, whereas this study uses the Global Trade Analysis Project (GTAP) version 10. Both studies utilize National Footprint and Biocapacity Account (NFBA) for Ecological Footprint of production data in initial allocation. The NFBA have undergone many methodological improvements since 2012 (Lin *et al.* 2018), with notable major improvements in average forest carbon sequestration (AFCS) value, allocation of fugitive $CO_2$ emissions, marginal crop-yield factors, and fishing grounds footprint embedded trade, which might affect some countries' Ecological Footprint value.

The single IO approach, using the Input-Output table for Wales (2019) is the biggest difference from the previous method. Advantages to this approach include: 1) detailed consideration of the industrial structure of Wales, and 2) consistency in the calculation procedure for the Ecological Footprint of waste and material footprint, which allows for the analysis of the relation between the three footprints. The single IO approach, however, has some limitations including lower sector resolution (21 sectors) and the method's inability to fully integrate country specific supply chain intensities for international trade partners as captured by MRIO-EF applied in the top-down methodology described above.

# Appendix 2: Method used to calculate the waste component of the Ecological Footprint

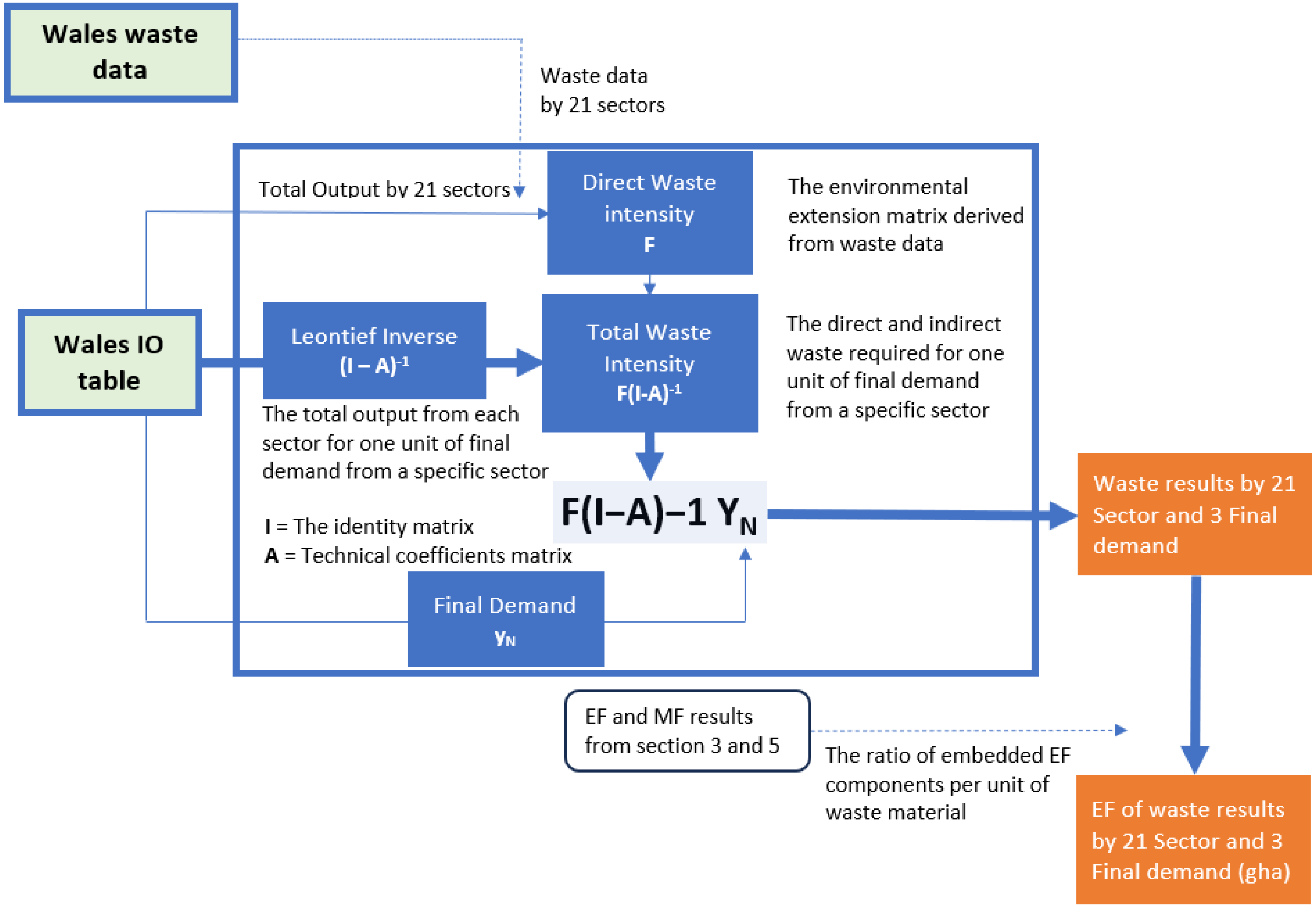


**Figure 46.** Method flowchart for calculating the waste component of the Ecological Footprint for Wales.

The waste component of the Ecological Footprint of Wales was estimated using an environmentally extended Input-Output (EEIO) analysis of waste, which involved utilising the Input-Output table for Wales, as well as the Ecological Footprint and Material Footprint results from sections 3 and 5 of this report. The method utilized in this study involved the following four steps:1) allocation of waste data for the Welsh region to their corresponding industrial sectors, 2) development of an environmentally extended Input-Output table (Waste-IO) using the waste results for Wales, 3) derivation of the waste flow of final demand based on the economic sector, and 4) conversion of the waste flow values to Ecological Footprint of Waste (Figure 46).

### Step 1: Assigning Waste Data for Wales to the Industrial Sectors (Direct Waste Intensity)

In this step, direct waste intensity is calculated using waste data for Wales and the 2019 Input-Output table for Wales. Summary waste generation data are reported in the Industrial and Commercial Waste Survey 2018 and Construction and Demolition Waste Survey 2019. The Input-Output table for Wales has 64 industry sectors. However, due to the lack of availability of high-resolution waste data, these industrial sectors were aggregated into 21 categories.

The waste data are assigned to the 21 industrial sectors in the Welsh region and divided by the total output of each of the 21 industrial categories in the Welsh Input-Output table to obtain a Direct Waste Intensity vector:

$$\text{Direct Waste Intensity} = \mathbf{F}$$

### Step 2: Apply the direct waste intensity vector to the Input-Output table for Wales to create an environmental extension model

In this step, the waste associated with production in Wales is applied as an environmental extension to the Welsh input-output model.

The objective of this step is to break down the waste footprint of Wales in relation to final demand by economic sector. The total waste intensity is calculated using the following general formula:

$$\text{Total Waste Intensity} = \mathbf{F}\,(\mathbf{I}\text{-}\mathbf{A})^{-1}$$

where **F** is the direct waste intensity calculated in the step 1; **I** is the identity matrix, a matrix of 21 columns and rows of zeros, with 1 on the diagonal; **A** is the technical coefficient matrix, $(\mathbf{I}-\mathbf{A})^{-1}$ represents the Leontief inverse matrix, which reflects the monetary exchanges with other sectors required by each economic sector to produce one monetary unit of output. Finally, the total waste intensity is calculated by multiplying the Direct Waste Intensity with $(\mathbf{I}-\mathbf{A})^{-1}$, considering the entire supply chain.

### Step 3: Calculate the waste flow associated with final demand according to economic sectors

In this step, we calculate the waste flow associated with final demand according to the economic sector:

$$\text{Waste Flow} = \mathbf{F}\,(\mathbf{I}\text{-}\mathbf{A})^{-1}\,\mathbf{Y}_{\mathbf{wales}}$$

$\mathbf{Y}_{\mathbf{wales}}$ represents total final demand in Wales expressed in pounds (£). Final demand includes household consumption, government spending, and gross fixed capital formation; by multiplying Total Waste Intensity by the respective final demand, the waste flow of final demand in Wales is calculated. As described above, the extended environmental Input-Output analysis allows the calculation of the industrial waste footprint associated with the production and consumption of the Welsh region, which can be used to assess the impact on regional sustainability, propose waste reduction measures, and inform environmental policy decisions.

### Step 4: The Ecological Footprint of Waste resulting from domestic consumption in Wales was estimated from the waste flows (t) associated with final demand in step 3 and the Ecological Footprint intensity (gha/t) of the waste flows

The Ecological Footprint intensity of the waste flows was derived from Material Footprint results, which comprised four distinct components, biomass, metal ores, non-metal ores, fossil fuel, metal ores and non-metal ores. The ratio of embedded Ecological Footprint components in the corresponding Material Footprint for each sector was initially calculated by dividing the biomass Ecological Footprint by the biomass Material Footprint values (and Carbon Footprint by carbon-related Material Footprint values) in each sector. The Ecological Footprint of Waste was subsequently determined for 21 industrial sectors by multiplying the waste flow results with the ratio of embedded Ecological Footprint in Material Footprint. The Biomass Ecological Footprint and Carbon Footprint of waste were then aggregated to yield the total Ecological Footprint of Waste generated by domestic consumption in Wales.

## Differences to the previous method for calculating a Welsh Ecological Waste Footprint

In dealing with the issue of industrial waste, conventional waste policies are often formulated targeting specific waste streams or specific economic sectors, and rarely consider the impact of changes in waste volume. However, since the demand and production processes of one economic sector may affect the waste generation of another, a more comprehensive waste policy is needed. Therefore, an approach using industrial interconnection analysis can be useful.

To address the problem of industrial waste, Life Cycle Analysis (LCA) and Input-Output analysis are effective means. LCA is a method for evaluating the entire life cycle of products and services to understand the sources of waste generation and environmental impacts. On the other hand, Input-Output analysis can evaluate the interrelationships between industrial sectors to prevent waste reduction in one sector from causing an increase in another.

The advantage of LCA is that it can analyse the entire life cycle of products and services, enabling consideration of waste reduction from the design stage of products. In addition, it can consider not only environmental impacts but also economic and social impacts. However, there are also disadvantages to LCA. For example, it requires a lot of data, and data collection and analysis can be time-consuming and costly. Additionally, caution is required regarding the reliability of the data, which may affect the accuracy of the analysis.

On the other hand, the advantage of input-output analysis is the ability to evaluate the relationships between industrial sectors. This allows for reducing waste in a particular industrial sector without causing an increase in waste in other industrial sectors. Additionally, by tracking the flow of waste generated by industrial sectors, it is possible to select the optimal waste treatment method. In this study, we placed emphasis on this point and analysed the Ecological Footprint, industrial waste, and material flow based on the Input-Output table for Wales.

In future research projects, further improvement of input-output analysis using the Waste IO table is expected. By using the Waste IO table, it is possible to quantify changes in the amount of waste generated and examine hotspots of waste generation. However, due to limitations in the current WIO table, there may be missing information about the final state of waste or insufficient information about disposal methods. Therefore, future improvements are expected to enable more accurate analysis using the WIO table. A hybrid analysis combining LCA, and input-output analysis is effective for this purpose. By combining the advantages of both methods, more comprehensive and detailed analysis is possible. For example, by understanding the amount of waste generated by individual products or processes through LCA and clarifying the interrelationships between different industrial sectors through input-output analysis, it is possible to formulate the optimal waste reduction strategy. LCA is suitable for analysing individual products or processes, and it is possible to understand the amount of waste generated by each product or process that cannot be captured by input-output analysis. Furthermore, LCA can quantitatively evaluate the contribution to waste reduction, making it a useful tool for companies and policy makers.

## Appendix 3: Method used to calculate the Material Footprint

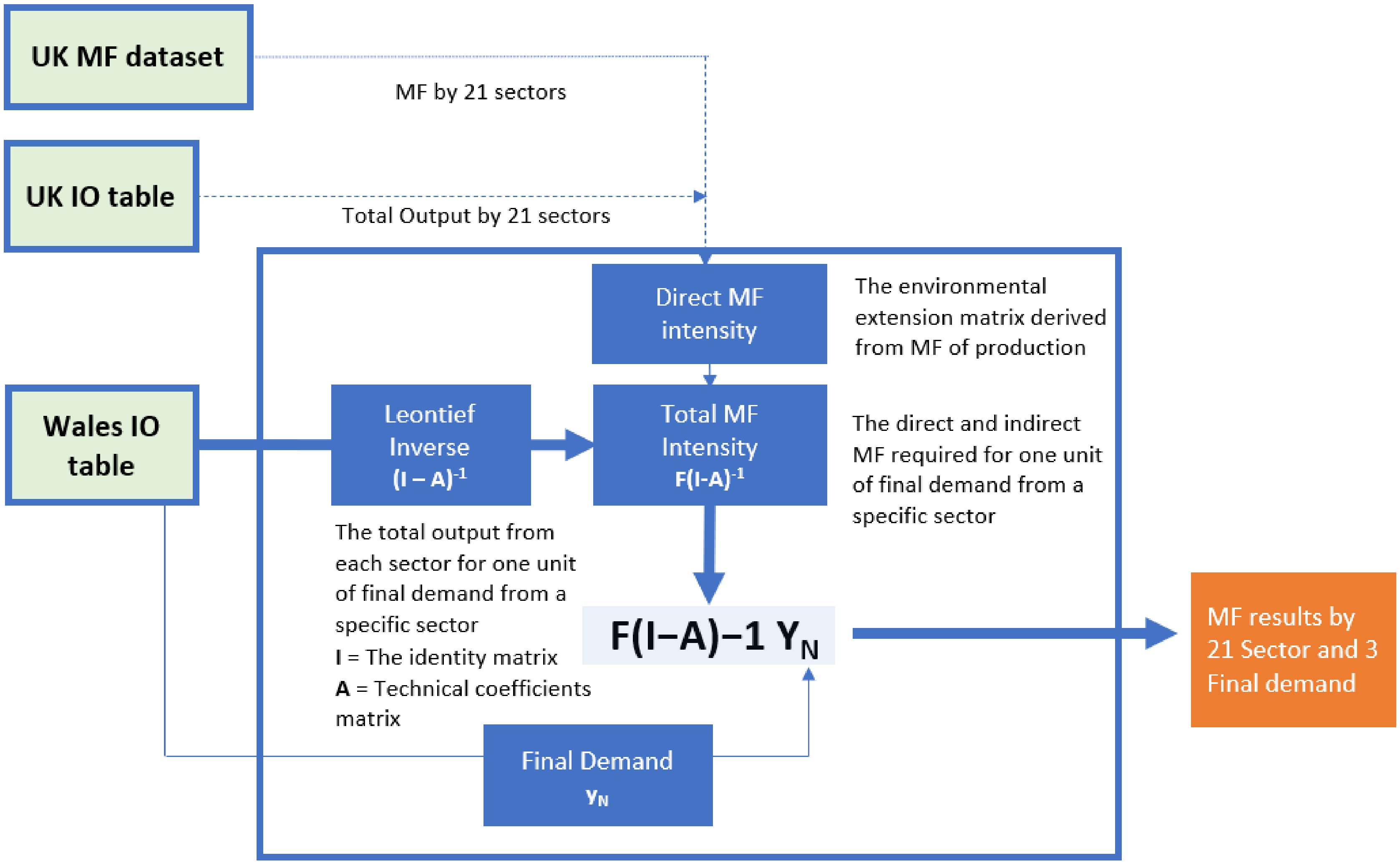


**Figure 47.** Method flowchart for calculating the Material Footprint for Wales.

The Material Footprint of Wales was calculated through an environmentally extended Input-Output (EEIO) analysis using the Input-Output table for Wales with UK based material flow data and UK Input-Output table. The method, illustrated in Figure 47, consisted in three steps: 1) allocation of the material flow data for the UK by the corresponding industrial sector, 2) development of an environmentally extended Input-Output table for the Material Footprint for Wales, and 3) derivation of the Material Footprint of final demand according to economic sector. The extended input-output analysis is a well-established and widely applied method.

### Step 1: Assigning Material flow Data for Wales to the Industrial Sectors (Direct MF Intensity)

In this step, Direct MF Intensity is calculated using material flow data for the UK and the 2018 UK Input-Output Table. Domestic extraction and imports material flow data used in this study was obtained from Department for Environment, Food and Rural Affairs and HM Revenue & Customs, Ricardo Energy & Environment. The Material Footprint for the UK dataset provided by the University of Leeds and the Office for National Statistics was utilized to make adjustments for unused domestic and imported value, as illustrated in Figure 47. This approach ensures the accuracy and reliability of the findings presented in this study.

The 127 industrial sectors of the 2018 UK Input-Output tables were consolidated into 21 categories, mirroring the waste calculation method. This decision was made because the Material Footprint results for Wales obtained in this section were utilized to convert waste results from tonnes to global hectares, as explained in Appendix 2. This methodological choice was imperative to guarantee the consistency and comparability of the analytical framework utilized in this research. The material flow data were then allocated to these 21 industrial categories and normalized by dividing each category's total output in the UK Input-Output table. This normalization process facilitated the derivation of a direct Material Flow (MF) Intensity vector for each category, which is a crucial analytical step in our investigation:

$$\text{Direct MF Intensity} = \mathbf{F}$$

### Step 2: Apply the direct MF intensity vector to the Welsh Input-Output table to create an environmental extension model.

In this step, the material flow associated with production in Wales is applied as an environmental extension to the Welsh input-output model.

The objective of this step is to break down the Material Footprint of Wales in relation to final demand by economic sector. The Total MF Intensity is calculated using the following general formula:

$$\text{Total MF Intensity} = \mathbf{F}\ (\mathbf{I}\text{-}\mathbf{A})^{-1}$$

where **F** is the direct MF intensity calculated in the step 1; **I** is the identity matrix, a matrix of 21 columns and rows of zeros, with 1 on the diagonal; **A** is the technical coefficient matrix, $(\mathbf{I}-\mathbf{A})^{-1}$ represents the Leontief inverse matrix, which reflects the monetary exchanges with other sectors required by each economic sector to produce one monetary unit of output. Finally, the total MF intensity is calculated by multiplying the direct MF intensity with $(\mathbf{I}-\mathbf{A})^{-1}$, considering the entire supply chain.

### Step 3: Calculate the Material Footprint of final demand according to economic sectors

In this step, we calculate the MF footprint of final demand according to the economic sector:

$$\text{Material Footprint} = \mathbf{F}\ (\mathbf{I}\text{-}\mathbf{A})^{-1}\ \mathbf{Y}_{\mathbf{wales}}$$

$\mathbf{Y}_{\mathbf{wales}}$ represents total final demand in Wales expressed in pounds. Final demand includes household consumption, government spending, and gross fixed capital formation; by multiplying Total MF Intensity by the respective final demand, the MF footprint of final demand in Wales is calculated. As described above, the extended environmental Input-Output analysis allows the calculation of the industrial MF footprint associated with the production and consumption of the Welsh region, which can be used to assess the impact on regional sustainability, propose MF reduction measures, and inform environmental policy decisions.

## Differences to previous methodology used to calculate a UK Material Footprint

The most relevant calculation to the Material Footprint of Wales (this study) is the UK material footprint, which calculated annually using both the Leeds methodology and the Eurostat methodology. The differences between the two methodologies are described by the UK Office of National Statistics (ONS 2019). The UK Material Footprint as computed by the University of Leeds, uses a multi-regional input-output (MRIO) model alongside a unique UK MRIO database developed by the University of Leeds.

There are fundamental differences in the approach to developing a national calculation compared to a sub-national generally related to the availability of globally standardized datasets and models at the national scale. More specifically, two primary factors distinguish the methodologies for calculating the UK and Wales Material Footprints: 1) MRIO framework vs single IO, and 2) differences in calculation of direct Material Footprint intensity.

The UK Material Footprint is calculated via the MRIO approach, which "reallocates estimates of domestic extraction by world region to measures of UK final demand, instead of calculating imports and exports in their raw material equivalent form." (ONS, 2019)

For this study, we adopted a single IO approach paired with the UK's direct Material Footprint intensity to compute the Welsh Material Footprint. The MRIO methodology use for the UK has the advantage of improved resolution for calculating the global supply chain's resource efficiency. The single IO approach used here produces results that 1) maintain coherence with other footprint computations, and 2) address data limitations by using the Input-Output sector framework to estimate region-specific total Material Footprint intensities. This method promotes a comprehensive understanding of the footprints' interconnectedness while managing data limitations.

Conducting a regional analysis necessitates the determination of direct Material Footprint intensity for each sector within every region. Yet, no consistent regional-level Material Footprint data presently exists. This calculation assumes that resource demand per unit of total output by sectors is consistent across regions. Thus, the UK's direct Material Footprint intensity is applied to Wales's 2019 Input-Output table's Leontief Inverse. Although energy source mixes vary by region, for instance, these differences have not been specifically considered. Consequently, in regions like Wales, where $CO_2$ emission factors in the Energy sector surpass the UK average, the estimated Material Footprint tied to carbon emissions may be underestimated.

# Appendix 4: Methods used to calculate the GEIC indicator

This Appendix explains the methods used to generate a Welsh-specific GEIC indicator. These methods are separate to methods used to calculate the other footprint-based metrics above. The basic premise is to 'downscale' the IOTA modelling framework, which underpins the UK GEIC indicator. In IOTA, physical production and export data from the Food and Agriculture Organization of the United Nations (FAO) are combined with data from the EXIOBASE Multi-Regional Input-Output (MRIO) table to estimate commodity-usage by economic sectors in each region of the MRIO. An estimated consumption profile of a region can then be calculated given that region's final demand profile, which specifies final demand on each sector of the MRIO. The impacts of this consumption are estimated by applying impact factors that are specific to commodity and country of production. In this context, to 'downscale' this framework means to add regional resolution to the UK component of the MRIO. Note that, in principle, the same downscaling method can be used with any MRIO that has the UK as a region. One example of such an MRIO is GTAP, which was used to compute the Ecological Footprint and biocapacity (See Appendix 1). The EXIOBASE MRIO is chosen over the GTAP MRIO as it has finer sectoral resolution and data are available for the same year for which there is a Welsh IO table. The production data are not downscaled since this would also require disentangling the UK imports and exports to provide Welsh-specific commodity-level trade data, including inter-UK trade, as well as downscaling production data themselves and associated indicators. These all present a considerable challenge to do in a meaningful way.

Two separate approaches were used, each of which is detailed below:

1. using Welsh-specific expenditure data to generate a Welsh final demand profile that is compatible with EXIOBASE sector and region classifications **(Phase 1)**;

2. using Welsh-specific Input-Output data and the EXIOBASE MRIO to generate a global MRIO with Wales as a region separate from the rest of the UK **(Phase 2)**.

The expenditure data used in Phase 1 is taken from the final demand component of the 2019 Input-Output table for Wales (Jones 2022). In Phase 1, Welsh trade is not distinguished from UK trade: all trade is considered at a UK aggregate level. Here, and in what follows, 'UK aggregate' or 'UK average' refers to data taken from, or derived using, the EXIOBASE MRIO. The resulting Welsh-specific GEIC differs from the UK GEIC only due to differences in expenditure by households, government and other actors. Hence, this method is simple to implement but ignores differences in UK-aggregate and Welsh trade that can be inferred from the trade component of the IO table for Wales.

In Phase 2, information about the structure of the Welsh and Scottish economies contained in the 2019 Input-Output table for Wales (Jones 2022) and the 2018 Input-Output table for Scotland produced by the Scottish Government is utilised. In particular, data on Welsh- and Scottish-specific intermediate demand, final demand, imports, and exports are used to estimate expenditure between Welsh economic sectors and economic sectors in all other regions globally. The modelling assumption used in this approach is that the structure of the Welsh and Scottish economies and their export and import propensities are 'as close as possible' to the UK average subject to the constraints imposed by the available Welsh- and Scottish-specific data. We note that the inclusion of Scottish data is not necessary for generating results for Wales but is likely to make the constraints more realistic. To implement this approach, in particular to make precise the notion of 'as close as possible [...] subject to [...] constraints', we use techniques from the mathematical field of constrained optimisation. Such techniques have a robust mathematical foundation – see for example (Wright 1999) – and have been widely implemented to reconcile economic datasets – see for example (Golan 2000), (Többen 2018) and (Bjelle *et al.* 2020).

Deforestation impact factors are not currently available for years after 2018. The 2019 Input-Output table for Wales is therefore used as a proxy for the year 2018. All other data sources that are considered relate to the year 2018.

## Phase 1: expenditure-based estimate

The approach used in this Phase is to generate a Welsh final demand profile that is compatible with EXIOBASE sector and region classifications. Estimates of Welsh consumption are then estimated by applying UK-average commodity-usage values within the IOTA framework.

In the EXIOBASE MRIO, economic activity is classified into 163 sectors and 49 regions (45 of which are countries and 4 of which are catch-all Rest-of-World regions), which results in 49 x 163 = 7987 sectors globally. This sector resolution is high relative to other MRIOs, with sectors such as agriculture split into several subsectors. In the Input-Output table for Wales, 2019 (Jones 2022), economic activity within Wales is classified into 64 sectors, with, for example, 'Crop and Animal Production [...]' grouped into a single sector. Final demand by Welsh actors, such as 'Households' and 'Government', is given for:

1. each of the 64 Welsh sectors;
2. the Rest of the UK, in total;
3. the Rest of the World, in total.

The aim of this approach is to appropriately disaggregate the given Welsh final demand values across the 7987 EXIOBASE sectors.

### Disaggregation of Rest of World final demand

For simplicity, it is assumed that Welsh final demand on Rest of World sectors is proportional to the UK average. A more detailed study of this aspect of Welsh final demand is beyond the scope of this project.

### Sectoral disaggregation of final demand on Welsh sectors

Some of the 64 sectors used in the IO table for Wales map directly onto a single EXIOBASE sector, and some combine to form a single EXIOBASE sector. This gives rise to a many-to-one concordance mapping from such sectors to the corresponding EXIOBASE sectors. Other sectors of the 64 contain multiple EXIOBASE sectors, so the corresponding final demand values must be disaggregated. Examples of such sectors include the energy sector, sewerage and waste collection, and several manufacturing sectors. A complete list is given in Table 20. This list is in descending order of Welsh final demand.

**Table 20.** List of sectors of the Welsh IO table that have multiple EXIOBASE subsectors.

| **Sector name** | **Number of EXIOBASE subsectors** |
|---|---|
| Retail trade, except of motor vehicles and motorcycles | 2 |
| Construction | 2 |
| Electricity, gas, steam and air conditioning supply | 17 |
| Manufacture of food products, beverages and tobacco products | 12 |
| Land transport and transport via pipelines | 3 |
| Manufacture of coke and refined petroleum products | 2 |
| Sewerage; waste collection, treatment and disposal activities [...] | 7 |
| Manufacture of furniture; other manufacturing | 7 |
| Manufacture of textiles, wearing apparel and leather products | 3 |
| Manufacture of paper and paper products | 3 |
| Manufacture of chemicals and chemical products | 3 |
| Crop and animal production, hunting and related service activities | 17 |
| Manufacture of machinery and equipment n.e.c. | 2 |
| Manufacture of wood and of products of wood and cork, except furniture [...] | 2 |
| Water transport | 2 |
| Manufacture of rubber and plastic products | 3 |
| Mining and quarrying | 15 |
| Manufacture of basic metals | 13 |

It is noted that the top four sectors account for over 70% of the Welsh final demand on these sectors. The top two sectors have only two EXIOBASE sub-sectors each, and at the UK level, final demand is almost entirely on only one of these subsectors. For these sectors, the Welsh final demand is therefore split according to the corresponding UK-on-UK final demand proportions. The same approach is used for any sectors that are similarly dominated by a single subsector, or that have relatively small Welsh final demand. This leaves the sectors:

1. electricity, gas, steam and air conditioning supply;
2. manufacture of food production, beverages and tobacco products;
3. crop and animal production, hunting and related service activities,

for which extra Wales-specific data sources are considered. This choice is motivated by the following observations: for each of these three sectors, UK-on-UK final demand is split evenly across many sectors; for the first two, Welsh final demand is relatively high; and for the third associated impacts are known to be high. As a proxy for the proportional split of final demand, proportions of total output in 2018 taken from reports by the Welsh government on ‘Energy Generation in Wales in 2018’ and ‘Aggregate Agricultural Output and Income, 2021’ are used for sectors 1 and 3, and ONS regional household expenditure is used for sector 2. Where any sub-sectors do not directly match EXIOBASE sectors, the disaggregation is once again based on the UK average.

## Sectoral disaggregation of Welsh final demand on Rest of the UK

It remains to disaggregate the total Welsh final demand on the Rest of the UK across EXIOBASE sectors. The working assumption is that Welsh final demand on the UK is as close as possible in proportion to that of the UK, subject to it containing the pre-calculated final demand on Welsh sectors. To make this precise, let $p^{\text{UK}}$ be the proportional split of UK-on-UK final demand, let $y^{\text{W}}$ be the disaggregated Welsh final demand on Welsh sectors, let $I$ be the total Welsh final on the Rest of the UK, and let $T$ be the total Welsh final demand on the whole of the UK. Note that $p^{\text{UK}}$ and $y^{\text{W}}$ are real vectors of length 163 (i.e., $p^{\text{UK}}, y^{\text{W}} \in \mathbb{R}^{163}$ ), while $I$ and $T$ are scalars. Welsh final demand on the UK being equal to that of the UK would require a probability vector $p$ such that:

$$p^{\text{UK}} = \frac{Ip + y^{\text{W}}}{T} .$$

A target vector $p^{\text{target}}$ is defined by rearranging the first equation for the unknown:

$$p^{\text{target}} = \frac{Tp^{\text{UK}} + y^{\text{W}}}{I}..$$

To be a probability vector, $p = (p_1, \dots, p_{163})$ must satisfy:

$$\sum_{i=1}^{163} p = 1, \text{ and } p_i \geq 0 \text{ for all } i \in \{1, \dots, 163\}.$$

While  satisfies the sum constraint, by construction, it does not satisfy the positivity constraint for all sectors. Indeed, there exist sectors for which Wales-on-Wales final demand is a higher proportion of total Wales-on-UK final demand than UK-on-UK final demand is of total UK-on-UK final demand. Hence, the probability vector $p^*$that is as ‘close’ to $p^{\text{target}}$ as possible is sought. This is defined via the constrained minimisation problem:

$$p^* = \arg\min_p \left\{ \left| p^{\text{target}} - p \right|^2 : \ p \text{ is a probability vector in } \mathbb{R}^{163} \right\} .$$

where $|\cdot|$ is the standard Euclidean distance on $\mathbb{R}^{163}$. Note that for sectors $i$ such that $p_i^{\text{target}} \leq 0$ it holds that $p_i^* = 0$, so, there is an implicit assumption that Wales is self-sourcing from such sectors. The Wales-on-RoUK final demand profile is then defined to be:

$$y^{\mathrm{RoUK}} = Ip^{*},$$

which gives rise to the desired Wales-on-UK final demand profile:

$$y = y^{\mathrm{W}} + y^{\mathrm{RoUK}}.$$

## Phase 2: integration of regional Input-Output tables

The approach used in this Phase is to disaggregate the UK component of EXIOBASE to obtain an MRIO with Wales as a region. This is done by using the 2019 Input-Output table for Wales (Jones 2022) and the 2018 Input-Output table for Scotland produced by the Scottish Government. The resulting MRIO has both Wales and Scotland as separate regions.

The regional Input-Output tables specify:

- intra-regional intermediate demand and final demand;
- per-sector import and export totals from and to Rest of UK, and Rest of World;
- and total final demand on Rest of the UK, and Rest of World.

A small proportion of this data is inconsistent with the UK component of the EXIOBASE MRIO. For example, the data suggests that sales from the Welsh Fishing and Aquaculture sector to the Welsh Crop and Animal Production sector exceeds the total for the respective UK sectors, in which the Welsh sectors are contained. This clearly cannot be true. The first step is therefore to reconcile the regional data to the EXIOBASE data. Once the regional data has been reconciled, the aims are to:

1. disaggregate the RoUK import, export and final demand totals (see ‘Filling data gaps to obtain downscaled UK intermediate and final demand’);
2. disaggregate the RoW import, export, and final demand totals (see ‘Implementation within IOTA framework’).

As described below, the reconciliation and the disaggregation of the regional data are each achieved via a constrained minimisation problem.

### Reconciling regional Input-Output tables with global data

For the Welsh and Scottish Input-Output data to be consistent with the UK component of the EXIOBASE MRIO, there are several inequality constraints that it must satisfy. These are summarised in Table 21. Each constraint simply reflects the fact that Wales and Scotland are regions within the UK.

**Table 21.** Inequality constraints imposed on regional data.

| | **Quantity** | **Inequality constraint bound** |
|---|---|---|
| **Per sales sector** | Intra-regional sales to final demand | UK sales to final demand |
| | Total intra-regional sales | Total UK sales |
| | Regional sales to RoW | UK sales to RoW |
| **Per purchasing sector** | Intra-regional purchases plus purchases from RoUK | UK purchases from UK |
| | Regional purchases from RoW | UK purchases from RoW |
| **Per pair of sectors** | Regional intermediate demand | UK intermediate demand |
| **Total over all sectors** | Regional final demand on UK | UK final demand on UK |
| | Regional final demand on RoW | UK final demand on RoW |

These constraints are linear and are linearly independent in the sense that not one of them is redundant. We additionally impose that the following quantities are conserved in each region:

- the total output and total purchases by each sector;
- the sum of all imports, exports and intermediate demand, over all sectors;
- the total final demand over all sectors.

This ensures that the resulting tables are balanced, and that the total economic activity in each region is not diminished. The aim is to make the smallest possible modification to the Welsh and Scottish Input-Output tables while satisfying these equality and inequality constraints. To achieve this, the following constrained minimisation problem is solved:

$$p^* = \arg\min_p \{D_{\mathrm{KL}}(p|q) : Ap \le b,\ A^{\mathrm{eq}}p = b^{\mathrm{eq}}\}.$$

Here, $q$ is a vector representing the given regional data; the matrices $A$ and $A^{\mathrm{eq}}$, and vectors $b$ and $b^{\mathrm{eq}}$, encode the linear inequality and equality constraints; and, given a candidate for the reconciled regional data $p$ , the quantity $D_{\mathrm{KL}}(p|q)$, defined by:

$$D_{\mathrm{KL}}(p|q) = \sum_{\{i=1}^{163} p_i \log\left(\frac{p_i}{q_i}\right),$$

is the so-called 'Kullback-Leibler divergence' of $p$ given $q$ . This is a statistical divergence which quantifies the difference between two distributions. Intuitively, $D_{\mathrm{KL}}(p|q)$ is a measure of the information gained by revising one's beliefs from the prior $q$ to the posterior $p$. As such, the strategy finds the regional Input-Output tables that satisfy the constraints imposed by the EXIOBASE data with minimal information gain given the original regional Input-Output tables. There are several different statistical divergences or mathematical distances that could be considered in this context. (For example, in Phase 1 a squared Euclidean distance is used.) Notice that if $q_i = 0$, then $D_{\text{KL}}(p|q)$ is only well defined for $p$ such that $p_i = 0$. Thus, the minimiser $p^*$ is zero at any data points where the given data $q$ is zero. In the context of this project, this means that solving this minimisation problem does not create fictitious relationships between sectors that are not present in the given data, which is not necessarily true for other distances and divergences. This is the main motivation for choosing the Kullback-Leiber divergence.

Note that in practice the above minimisation problem is solved for sectorally aggregated datasets. This is because the Welsh and Scottish tables use the Standard Industrial Classification of economic activities (SIC) but EXIOBASE tables use a different sector classification, which does not map directly on to the SIC sectors. The aggregated datasets are classified into 48 sectors.

### Filling data gaps to obtain downscaled UK intermediate and final demand

Having reconciled the Welsh and Scottish tables to the UK component of the EXIOBASE MRIO, an intermediate and final demand matrix is constructed for the UK consisting of three regions: Wales, Scotland, and an aggregate of England & Northern Ireland. The structure of this matrix is illustrated in Figure 48. Each combination of sales region and purchasing region is represented by a block in the matrix. Each block has 48 rows – one for each sales sector – and 49 columns – one for each purchasing sector and one for final demand, separated by a dotted line. Where the background is white, all entries are known and taken to be fixed. Where the background is pale grey, all entries are unknown. Our aim is to construct a realistic estimate for the unknown data, which satisfies constraints implied by the existing data.

The existing data gives totals for:

1. imports to each regional sector to RoUK;
2. exports from each regional sector to RoUK;
3. intra-UK intermediate demand by each purchasing sector on each sales sector;
4. intra-UK total final demand on each sector.

In Figure 46, the red boxes illustrate the entries that are constrained by the known total imports from RoUK to a given sector in both Wales and Scotland. Similarly, the blue boxes illustrate the entries that are constrained by the known total exports from a given sector in Wales or Scotland to RoUK. The green circles illustrate the entries of this matrix that sum to the total intra-UK intermediate demand (resp. final demand) by a given purchasing sector (resp. actors) on a given sales sector. Each total gives rise to an equality constraint to be satisfied.

The above equality constraints are not sufficient to determine the unknown data. Hence, a prior estimate for the unknown data is created, and the Kullback-Leibler divergence is minimised given this prior, subject to these equality constraints. This is a constrained minimisation problem with the same structure as that used to construct the reconciled regional Input-Output tables, only that there are no inequality constraints.

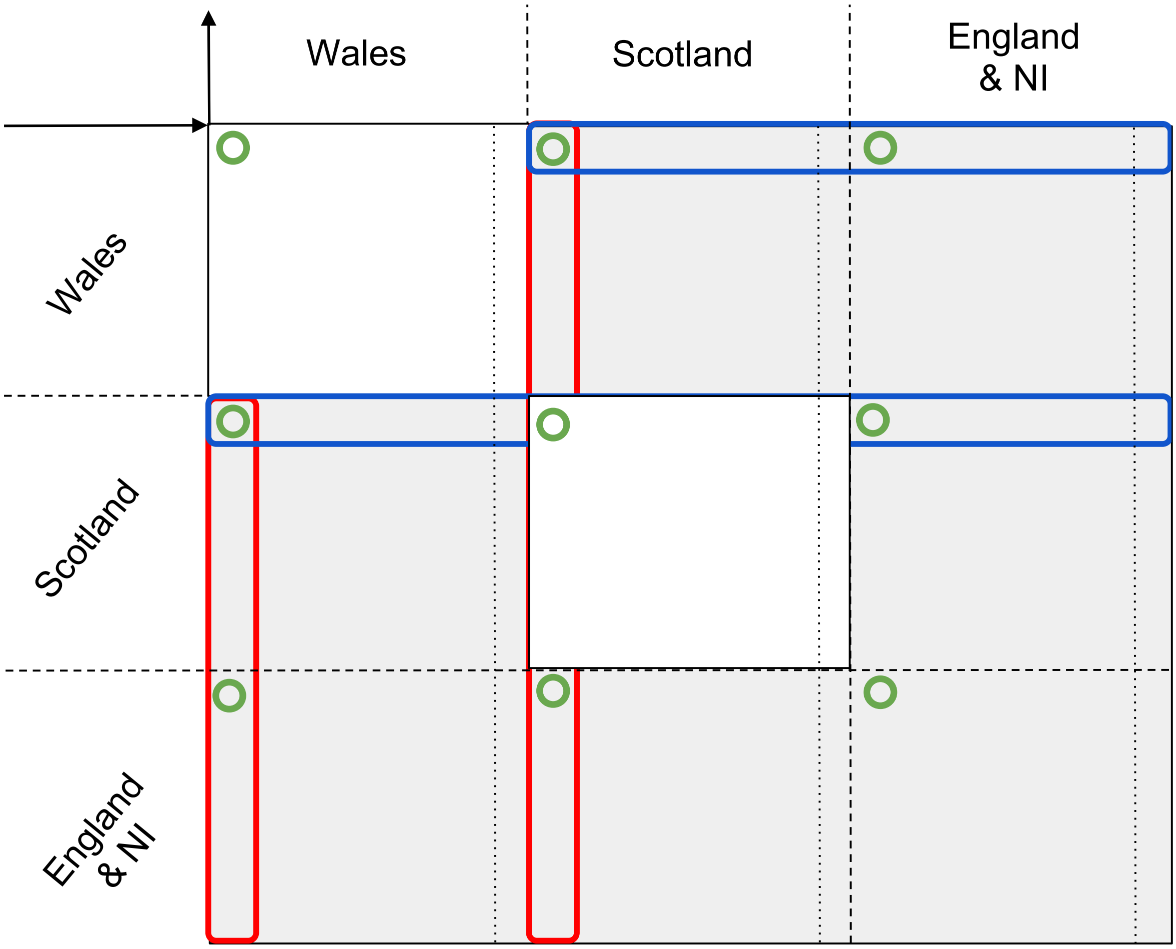


**Figure 48.** Structure of constraints and unknowns when generating downscaled UK intermediate demand and final demand. White boxes are known intra-regional intermediate demand and final demand (separated by a dotted line). Grey entries are unknown. Blue boxes represent export constraints, red boxes represent import constraints, and green circles represent pairwise intermediate and final demand constraints.

The method used for creating a prior estimate for the unknown data is now described. Final demand is treated the same as any purchasing sector, so in this description refer only to purchasing sectors, for simplicity. For each Welsh and Scottish purchasing sector, the total imports from RoUK are disaggregated across sectors by supposing that its proportional purchasing profile is as close to the UK average for that sector as possible. In other words, it is assumed that the inputs from the UK required by a sector are independent of the location of that sector within the UK. As explained in the description of the Phase 1 method, there are cases where exact proportionally is not possible. In such cases, as in Phase 1, a target vector is constructed and the distance to this target vector among all probability vectors is minimised. Next, the imports from each RoUK sector are disaggregated between the two RoUK regions (e.g. for a Welsh sector, between Scotland and England & Northern Ireland). For each sector selling to Wales, this is done using the relative sizes of (a) exports from Scotland to RoUK, and (b) total output by England & Northern Ireland. Similarly for sectors selling to Scotland. Note that this introduces some bias towards importing from England & Northern Ireland because intra-regional intermediate demand is excluded. This is potentially desirable since England shares a land border with both Wales and Scotland, whereas Wales and Scotland do not. Having estimated purchases by Welsh and Scottish sectors, an initial estimate of UK-aggregated purchases is generated by sectors in England & Northern Ireland by subtracting Welsh and Scottish purchases from UK purchases. Each sales sector is disaggregated across the three sales regions using relative output from each sales region to

England & Northern Ireland, which can be calculated from the hitherto estimated data. Since the estimates for Welsh and Scottish purchases are calculated using only import totals and not export totals, some of the initial estimates for purchases by England & Northern Ireland turn out to be negative. To derive a final estimate with only positive values, the initial estimate is treated as a target and the square Euclidean distance to this estimate is minimised, subject to a derived constraint on the total purchases by each sector in England & Northern Ireland.

## Implementation within the IOTA framework

So far, the method for constructing reconciled and regionally downscaled intra-UK intermediate and final demand matrices, and extra-UK export and import totals has been described, with reference to 48 aggregated sectors. This section describes how these data are used within the IOTA framework to obtain the Welsh-specific GEIC.

First, for each of the 48 aggregated sectors, total exports to and imports from RoW are disaggregated across all 47 x 163 = 7661 RoW EXIOBASE sectors using UK-average proportions. Similarly, the intra-UK intermediate and final demand matrices are disaggregated across all 163 EXIOBASE sectors using UK-average proportions. When integrated into the EXIOBASE MRIO, this results in global intermediate and final demand matrices with Wales, Scotland, and England and Northern Ireland as three distinct regions. These data can be used directly in the MRIO component of IOTA.

In the production and trade component of IOTA, the production of a given commodity in each country is associated with a sector in the region of production. A re-export algorithm is used to determine the physical quantity of that commodity that is produced in each country and is exported to the UK. This quantity then is allocated proportionally to UK sectors according to their relative expenditure on the corresponding producing sector. The same approach is also applied to all other purchasing regions. This is the so-called ‘hybridisation’ of the physical (FAO) and monetary (MRIO) data. Within the downscaled GEIC, exports from the UK to the rest of the world are allocated to RoW sectors as in the UK GEIC. However, imports into the UK must be treated differently. Within the UK GEIC, the allocation of imported commodities to UK sectors is straightforward since the UK is listed as both an FAO country and a region of the MRIO. The same is not true of the regions of the downscaled GEIC. The hybridisation step must therefore be adapted. To do so, UK aggregate import quantities are allocated proportionally to regional UK sectors according to their expenditure on the producing sector relative to the UK total. The use of UK aggregate import quantities, as opposed to Welsh-specific import quantities, is a limitation that can only be overcome by using Welsh-specific, commodity-specific production and trade data. The collection of such data is beyond the scope of work for this project.