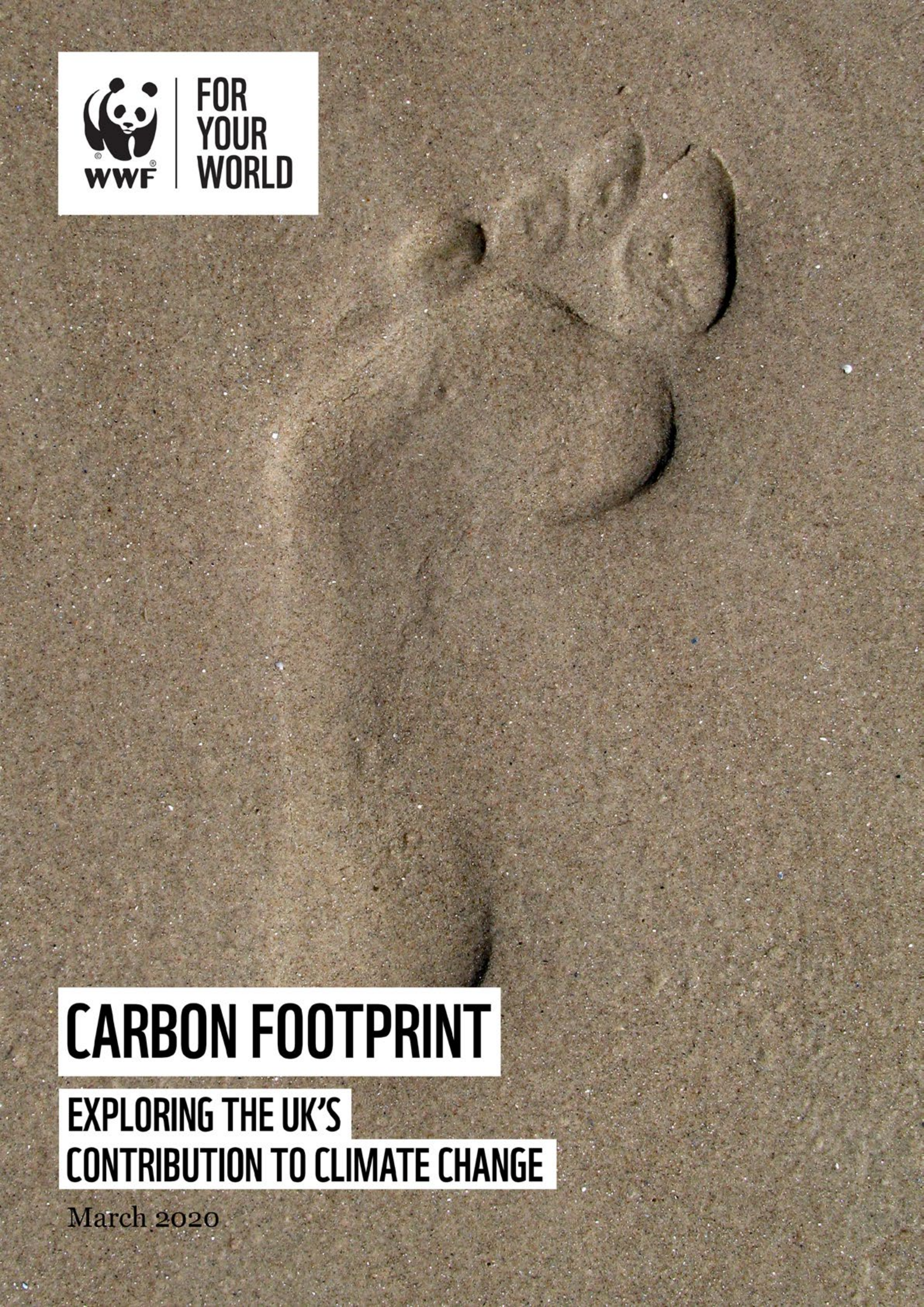
WWF FOR YOUR WORLD



CARBON FOOTPRINT

EXPLORING THE UK'S CONTRIBUTION TO CLIMATE CHANGE

March 2020

WWF is an independent conservation organisation, with over 5 million supporters and a global network active in over 100 countries. WWF's mission is to stop the degradation of the Earth's natural environment and to build a future in which humans live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

WWF-UK

The Living Planet Centre
Rufford House,
Brewery Rd,
Woking GU21 4LL,
United Kingdom

Sustainability Research Institute, School of Earth and Environment, University of Leeds:
Dr Anne Owen, Dr Diana Ivanova, Prof John Barrett

WWF:
Stephen Cornelius, Angela Francis, Shirley Matheson, Gareth Redmond-King, Lucy Young

Design:
Jo Curnow / 1tightship.co.za

Front cover photo:
© Germund Sellgren / WWF-Sweden

Back cover photo:
© NicoElNino / Shutterstock

Copyright Credit © Global Warming Images / WWF

EXECUTIVE SUMMARY

In this report we examine the UK greenhouse gas (GHG) emissions between 1990 and 2016 using a new 15 trade-region global multi-regional input output (MRIO) model database ("WWF-UKMRIO") developed by researchers from the University of Leeds. We examine the territorial-, production- and consumption-based GHG emissions in the UK and their development between 1990 and 2016. This report aims to contribute to a body of literature exploring the trade-linked UK carbon footprint[1].

The new WWF model outputs compare well with those from the four trade-region MIRO database used to produce the 1997-2016 carbon footprint for the UK Government[2]. As our dataset runs from 1990 to 2016, comparisons between the UK carbon footprint and the reported UK territorial emissions decline can now be made. The finer disaggregation of world regions in the WWF-UKMIRO model allows for new insights into the origin of the UK's carbon footprint.

MAIN RESULTS

Between 1990 and 2016 the UK reported a 41% reduction in greenhouse gas emissions within the UK's national borders.[3] While this measures progress towards the UK's domestic and international climate targets it does not reflect the full contribution of UK-based consumption to climate change.

Between 1990 and 2016 the UK's consumption-based emissions (carbon footprint) declined by 15%.[4] The marked difference to the territorial figure is due to the large share of emissions relating to goods and services imported from overseas. The difference, therefore, implies that while the UK has made progress to reduce its contribution to climate change, it is not as substantial as claimed (fig ES1).

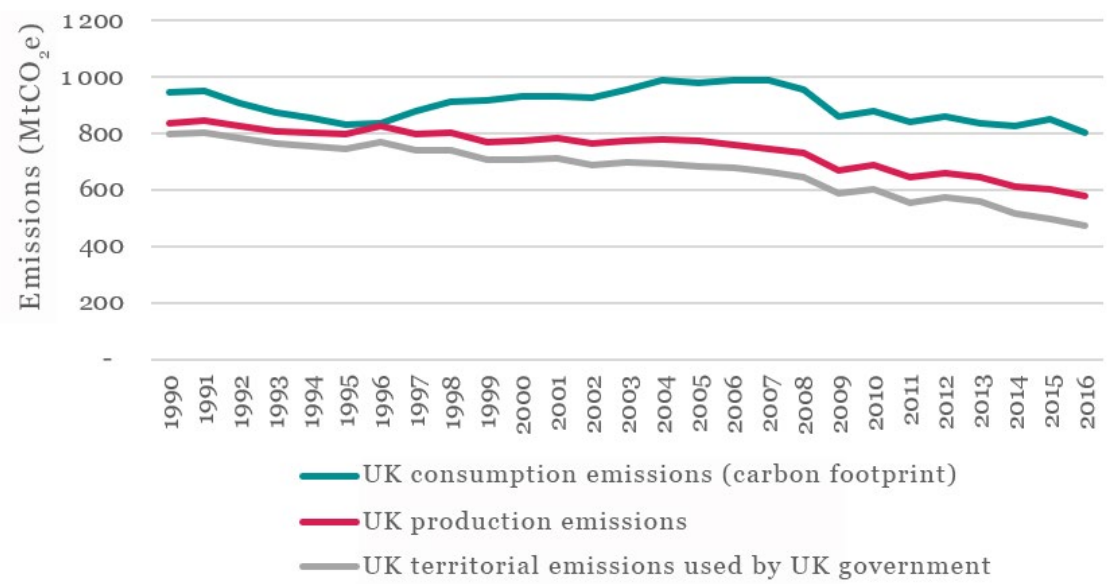


Figure ES1: *UK consumption, and production emissions (in million tonnes of carbon dioxide equivalent) calculated using the WWF-UKMRIO database and UK territorial emissions 1990-2016*

1 Your carbon footprint is the total amount of greenhouse gas released in the production and consumption of all the goods and services you use, wherever in the world they are produced. The UK carbon footprint sums up the consumption demands of everyone living in the UK.

2 https://www.gov.uk/government/statistics/uks-carbon-footprint

3 National GHG inventories monitor territorial emissions, considering emission embedded in imports is outside this metric.

4 Consumption-based accounting of GHG emissions reassigns global emissions to the point of consumption rather than production. The consumption-based GHG account for the UK is the sum of the emissions emitted to meet final demand consumption by UK households and government.

In 2016, 54% of the UK's carbon footprint was domestically sourced with the remaining 46% coming from emissions released overseas to satisfy UK consumption. The overseas proportion of the UK's carbon footprint increased substantially – from just 14% in 1990 – thus reducing the scope of UK climate policy to affect emissions associated with consumption.

UK-based consumption drives emissions across the globe (fig ES2). The biggest six regions/countries with their percentage of the overall UK carbon footprint are: the EU (9.9%), China (7.3%), Africa (5.3%)[5], the Middle East (5.3%), the USA (3.6%), and Russia (3.1%). Imported emissions are mostly associated with manufactured goods such as processed food, clothes and electronics.

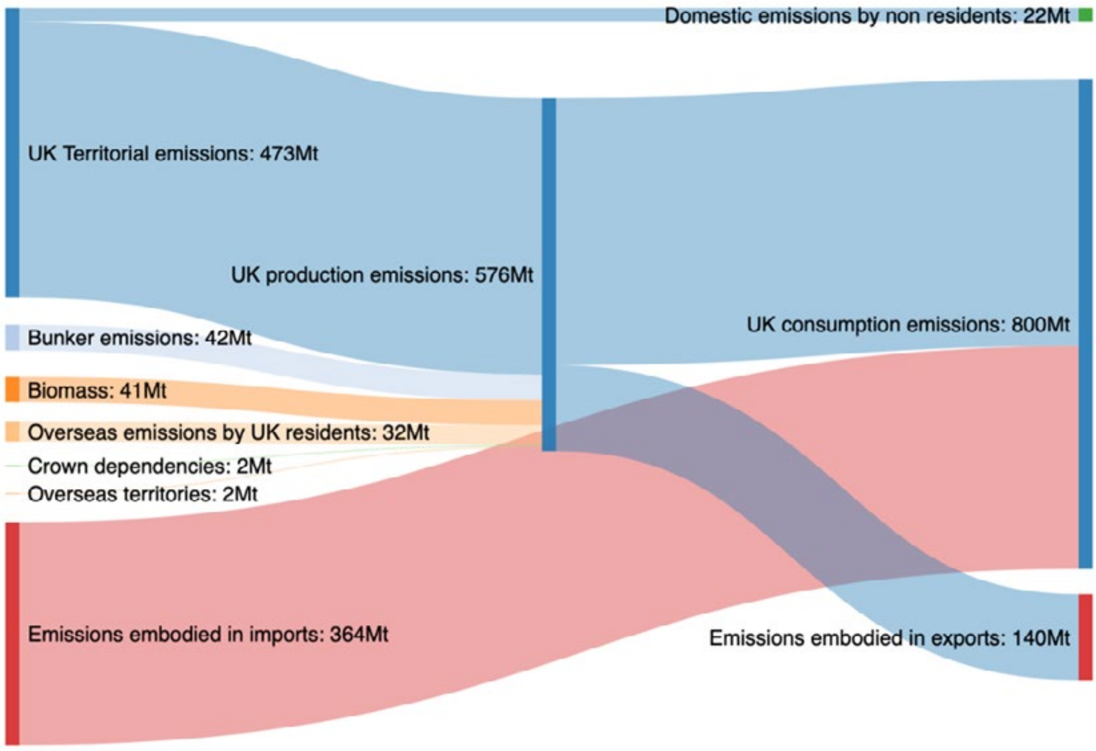


Figure ES2: *UK emissions from territorial, production and consumption in 2016. Measured in MtCO2e. Numbers may not add due to rounding to nearest million tonnes.*

In 2016, six sectors contributed to almost half (46%) of the UK's carbon footprint – these emissions are a combination of those arising domestically and from emissions released overseas to satisfy UK consumption. The biggest six sectors and their contribution to the UK carbon footprint are: heating homes (9.7%), car fuel (8.6%), electricity (8%), construction (6.7%), agriculture (6.6%) and air travel (5.9%)[6]. The largest three of these are associated with sectors which are expected to fully decarbonise domestically by 2050 under the UK Committee on Climate Change's pathway to decarbonisation. A greater understanding of impacts of UK decarbonisation on these and other sectors will better inform both national and international sustainability policies.

Air travel saw the greatest percentage increase in carbon footprint between 1990 and 2016 – up 245%, from 19 to 47 million tonnes of carbon dioxide equivalent (MtCO2e). At present these carbon dioxide emissions are monitored by airlines as part of a UN aviation scheme which aims to ensure any rise in aviation is offset elsewhere. International aviation does not form part of UK net-zero targets under the Climate Change Act. This means the UK government has not formally recognised that we need to take responsibility for our aviation footprint.

5 The Africa figure is a summation of the WWF-UKMRIO model regions "South Africa" and "Rest of Africa".

6 The six sectors with identifier in the underlying database are: (107) *Direct home heating*, (108) *Direct transport fuel*, (52) *Electricity, transmission and distribution*, (58) *Construction*, (1) *Products of agriculture, hunting and related services*, and (65) *Air transport services*.

The carbon footprint from construction increased from 49 to 54 $MtCO_2e$ between 1990 and 2016. Over that period emissions originating in the UK decreased from 36 $MtCO_2e$ (74% of the total) to 28 $MtCO_2e$ (52%) suggesting a trend of significant and increasing offshoring of emissions.

IMPLICATIONS AND RECOMMENDATIONS

OFFSHORING

The UK has expressed a commitment to end its contribution to climate change through the territorial net-zero emissions target in the Climate Change Act. However, the UK has been deindustrialising and increasing the proportion of food it imports which have offshored the production and associated emissions for many goods we rely on.

This new work unpacks the dynamics of such offshoring and shows that nearly half of the UK's carbon footprint is from emissions released overseas and so are not covered by national emission reporting and are not targeted by domestic climate policy.

Better understanding the implications of UK decarbonisation to offshoring production and associated emissions will help identify additional policies and partnerships the Government should pursue to ensure domestic efforts do indeed help end the UK's contribution to climate change.

CARBON FOOTPRINT

Consumption-based accounting – or carbon footprint – can help connect UK national policy actions to global emission reduction and not only reductions within our national borders. Integrating carbon footprint accounting into national climate policy provides a stronger link to climate science and global mitigation efforts.

Carbon footprint is complementary to the existing framing of territorial emissions which follow agreed guidance from the Intergovernmental Panel on Climate Change (IPCC). It is important that Government strategies account for the UK carbon footprint to ensure that measures to reduce territorial emissions do not lead to an increase in global emissions.

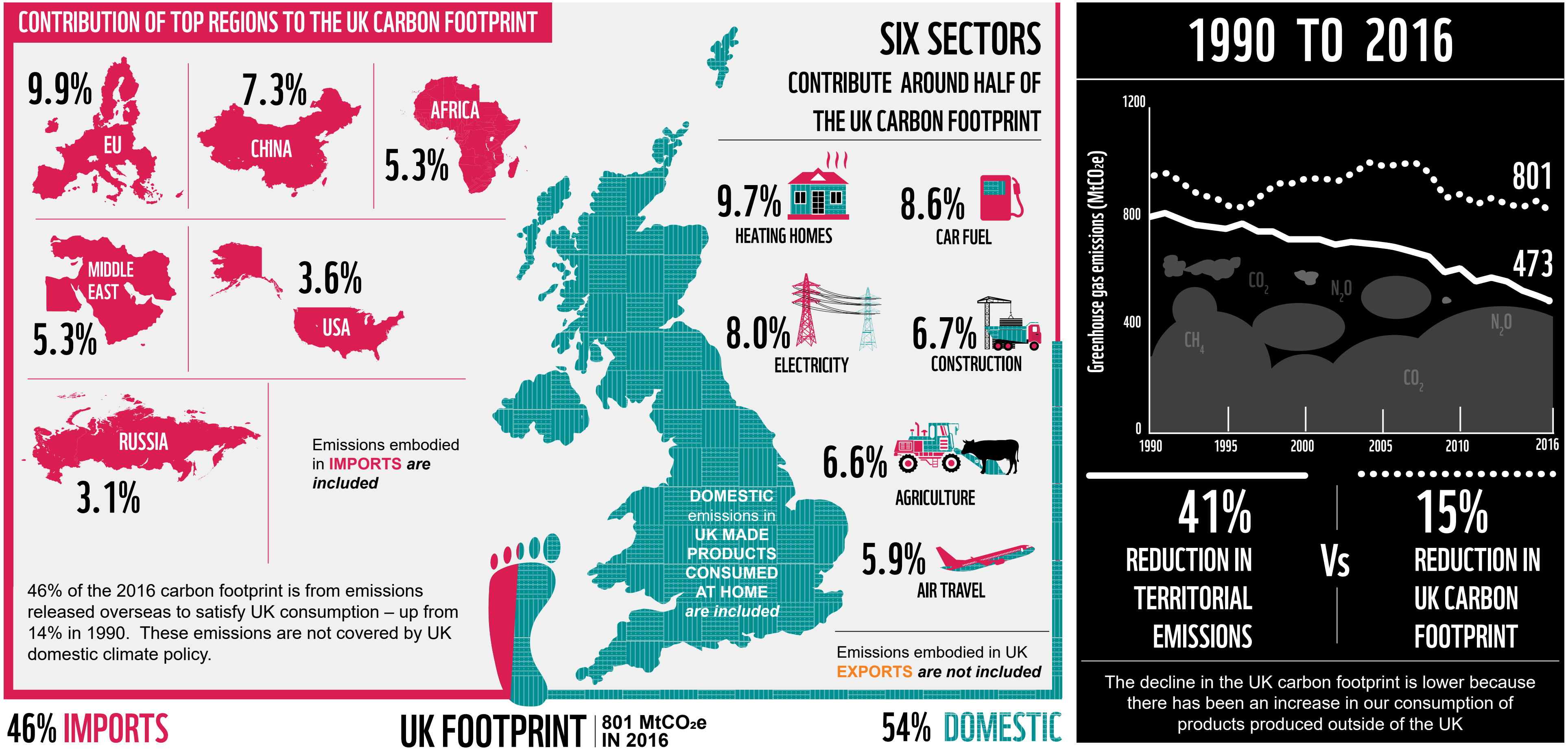
Benefits of accountability of the UK carbon footprint include:

- Identifying additional strategies and policies needed to address risks of offshoring rather than reducing emissions reaching the atmosphere. For example, footprint could be addressed in policies targeting consumption patterns and more efficient use of resources, and trade.
- Providing businesses and consumers with the tools to understand risks of offshoring emissions and how this relates to wider environmental footprint.

Focusing policy solely at national-level decarbonisation cannot end the UK's contribution to climate change. To do this we must also consider the carbon footprint due to UK-based consumption in policy making.

UK CARBON FOOTPRINT

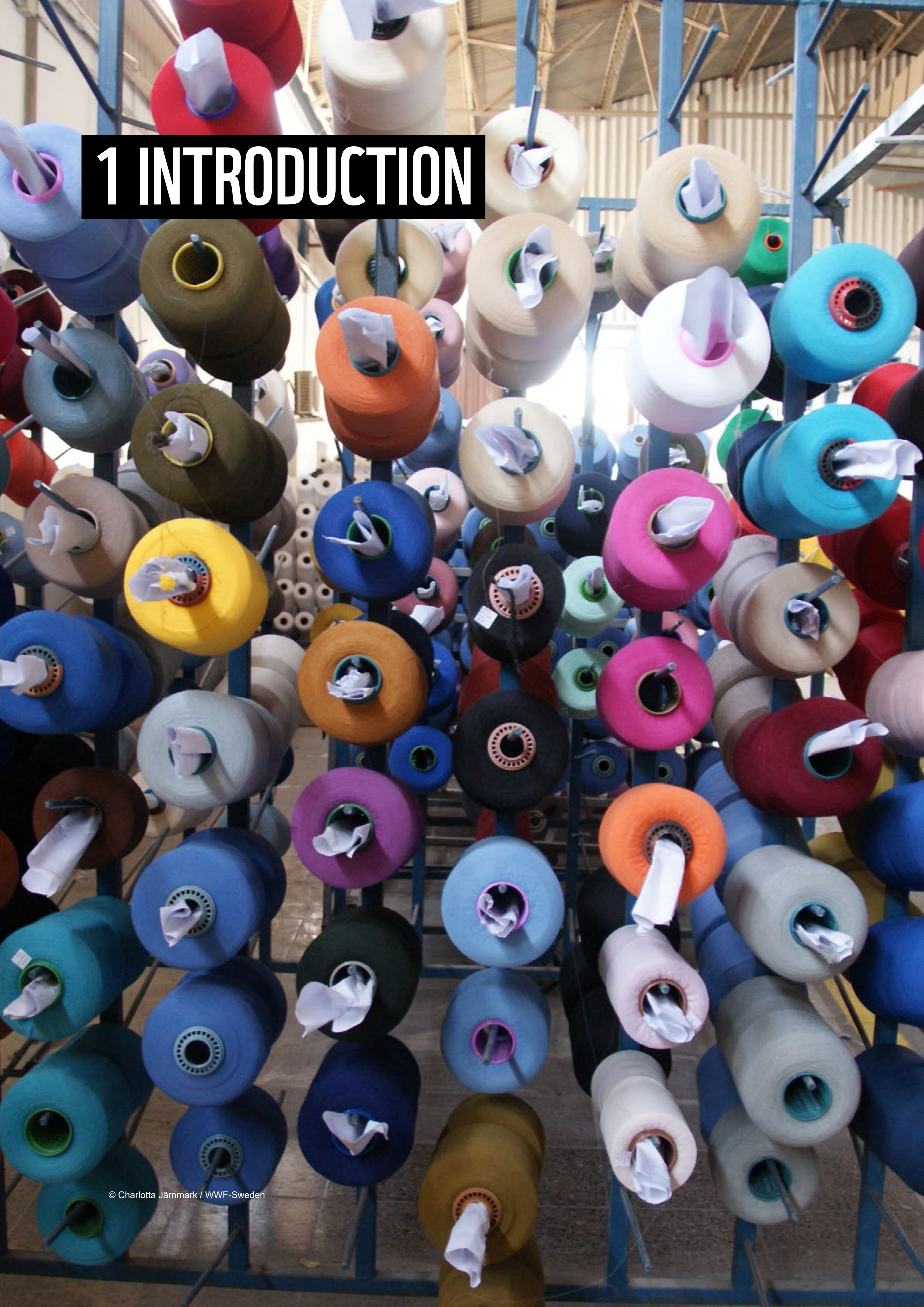
Your carbon footprint is the total amount of greenhouse gas released in the production and consumption of all the goods and services you use, wherever in the world they are produced. The UK carbon footprint sums up the consumption demands of everyone living in the UK.



Data from *Carbon Footprint: Exploring the UK's contribution to climate change* a report by the University of Leeds Sustainability Research Institute for WWF-UK

CONTENTS

1 INTRODUCTION



A number of global multiregional input-output (MRIO) databases have been developed in the last decade in order to trace and monitor greenhouse gas (GHG) emissions and other environmental and social impacts associated with consumption and trade, e.g. Dietzenbacher et al., 2013; Lenzen et al., 2013; Peters et al., 2011; Stadler et al., 2018; Wood et al., 2015; Yamano & Webb, 2018.

The recent advancements in data management have allowed for more transparency and traceability in GHG emissions and other environmental and social impacts which are embodied in the global supply chains. These impacts occur during various industrial processes and activities of production, distribution, consumption and disposal of goods and services. At the origin of embodied trade flows are producing industries, while at their end are households and other final consumers purchasing end-use goods and services (Wiedmann & Lenzen, 2018). Yet there are multiple ways in which these impacts can be allocated to different actors (Steininger et al., 2016). Perhaps even more importantly, the same impacts can be addressed by different actors at various social, spatial and political scales, although they may differ in their capacity to make a change.

In this report, we examine the territorial-, production- and consumption-based GHG emissions in the UK and their development between 1990 and 2016. This report aims to contribute to a body of literature exploring the trade-linked UK carbon footprint, e.g. Barrett et al., 2013; Hertwich & Peters, 2009; Wood et al., 2018. This report provides further detail about the products contributing most significantly to the UK consumption emissions and their temporal and regional implications. It also enables a better understanding of the role of trade, and particularly whether "decarbonisation" is being achieved by offshoring (that is, when territorial-based GHG emissions associated with specific sectors are falling in the UK, while impacts originating abroad associated with the consumption of the same sectors in the UK are rising). UK territorial GHG emissions have fallen by 42% between 1990 and 2017[1], which can be interpreted as a decoupling of UK emissions and GDP. However, these estimates reflect territorial-based emissions and do not account for the emissions produced through "offshoring" of UK consumption elsewhere. That is, GHG emissions associated with goods and services for UK consumption which originate elsewhere are not included. Our objective is to provide necessary detail for the design of adequate climate change mitigation policies in the UK addressing both GHG emissions occurring domestically or originating abroad to support domestic consumption.

The report is organised as follows: first, we introduce the main concepts of territorial-, production- and consumption-based emission inventories, and provide an overview of the methodologies and data used. Prior publications of UK carbon footprints using the UKMRIO database, which is consistent with national accounts, have documented impacts from 1997. The current report extends the footprint time series back to 1990, a reference year often adopted with regards to climate targets and negotiations. Second, we provide a comparison of territorial-, production- and consumption-based emissions in the UK at larger product and emission origin detail. Third, we investigate whether "decarbonisation" of certain processes in the UK has led to increased production elsewhere through a product-level analysis of the development of production and consumption emissions between 1990 and 2016. Finally, this report links to the UK policy context and provide policy recommendations.

1.1 TERRITORIAL, PRODUCTION AND CONSUMPTION-BASED EMISSIONS

GHG emissions can be allocated to a country in three main ways. Here we discuss: (I) territorial-based, (II) production-based, and (III) consumption-based emission reporting.

1.1.1 TERRITORIAL EMISSIONS

The United Nations Framework Convention on Climate Change (UNFCCC) requires (Annex I and/or national governments that are Parties to the UNFCCC and/or the Kyoto Protocol) countries to submit annual National Emission Inventories. These inventories are used to assess the progress made by individual countries in reducing GHG emissions.

1 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/776083/2017_Final_emissions_statistics_one_page_summary.pdf

The UNFCCC follows the Intergovernmental Panel on Climate Change's (IPCC) Guidelines for National GHG Inventories which is, "emissions and removals taking place within national (including administered) territories and offshore areas over which the country has jurisdiction" (IPCC, 2007). According to this definition, however, GHG emissions emitted in international territory, international aviation and shipping, are only reported as a memo and not allocated to individual countries. In the UK, the department for Business, Energy and Industrial Strategy (BEIS) reports these emissions as the UK's Greenhouse Gas Inventory and they form the basis for reporting on progress towards our domestic and international emissions reduction targets. In this report, we call this account "territorial-based emission inventories".

1.1.2 PRODUCTION EMISSIONS

In official reporting to Eurostat[2], GHG emissions are allocated in a consistent manner to the system boundary for economic activities such as the Gross Domestic Product (GDP) used in the System of National Accounts (SNA). This boundary reporting is known as the residence principle. In the SNA, international aviation and shipping are typically allocated to countries based on the operator of the vessel. Particularly in Europe (Eurostat), these inventories are often known as "National Accounting Matrices including Environmental Accounts (NAMEAs)". In the UK, the Office for National Statistics (ONS) publishes this account as part of the UK Environmental Accounts. The figures represent emissions caused by UK residents and industry whether in the UK or abroad, but exclude emissions within the UK which can be attributed to overseas residents and businesses. In this report, we call these "production-based emission inventories".

2 The statistical office of the European Union

1.1.3 CONSUMPTION EMISSIONS

Consumption-based emissions allocate emissions to the consumers in each country, usually based on final consumption as in the SNA but also as trade-adjusted emissions (Peters, 2008). Conceptually, consumption-based inventories can be thought of as consumption equals production minus exports plus imports (see Figure 1). Consumption-based emissions do not have to be reported officially by any country, but they are increasingly estimated by researchers (see review by Wiedmann 2009). In the UK, the Department for Environment, Foot and Rural Affairs (Defra) publishes the consumption-based emissions calculated by the University of Leeds. In this report, we call these "consumption-based emission inventories" or "the Carbon Footprint".

Table 1 provides a simplified view of what is included and excluded in each emissions account. In the UK, all three emissions accounts are National Statistics[3].

Table 1: *Types of emissions inventory included in UK territorial, production and consumption accounts. Green indicated inclusion and red indicates exclusion*

EMISSIONS FROM...	UK TERRITORIAL	UK PRODUCTION	UK CONSUMPTION
industries owned by UK, located in UK making products consumed by UK	Green	Green	Green
industries owned by UK, located in UK making products consumed by RoW	Green	Green	Red
industries owned by RoW, located in UK making products consumed by UK	Green	Red	Green
industries owned by RoW, located in UK making products consumed by RoW	Green	Red	Red
industries owned by UK, located in RoW making products consumed by UK	Red	Green	Green
industries owned by UK, located in RoW making products consumed by RoW	Red	Green	Red
industries owned by RoW, located in RoW making products consumed by UK	Red	Red	Green
industries owned by RoW, located in RoW making products consumed by RoW	Red	Red	Red
bunker aviation & shipping owned by UK and used by UK residents	Red	Green	Green
bunker aviation & shipping owned by RoW and used by UK residents	Red	Red	Green
bunker aviation & shipping owned by UK and used by RoW residents	Red	Green	Red
bunker aviation & shipping owned by RoW and used by RoW residents	Red	Red	Red
UK citizens' activities within UK territory	Green	Green	Green
RoW citizens' activities within UK territory	Green	Red	Red
UK citizens' activities within RoW territory	Red	Green	Green
RoW citizens' activities within RoW territory	Red	Red	Red
land use, land use change and forestry	Red	Red	Red

Figure 1 demonstrates the relative sizes of the UK territorial, production and consumption emissions accounts in 2016. The additional flows that are included in the production account include: bunker fuels from aviation and shipping; emissions from using biomass; the inclusion of emissions from crown dependencies and overseas territories (the Channel Islands and Gibraltar) and the net emissions from the inclusion of overseas emissions from UK residents and the removal of domestic emissions from non-residents. The figure also reveals the portion of UK consumption emissions that originate abroad (the emissions embodied in imports) and those UK production emissions which are exported. It is clear that there is a marked difference in end results depending on the chosen emissions accounting system (Barrett et al., 2013). Due to issues of national sovereignty, binding agreements on emissions may focus primarily on territorial-based emission estimates meaning that no targets are set for emissions associated with bunker fuels and imported products.

3 The UK is the only country to report consumption-based emissions as a National Statistic

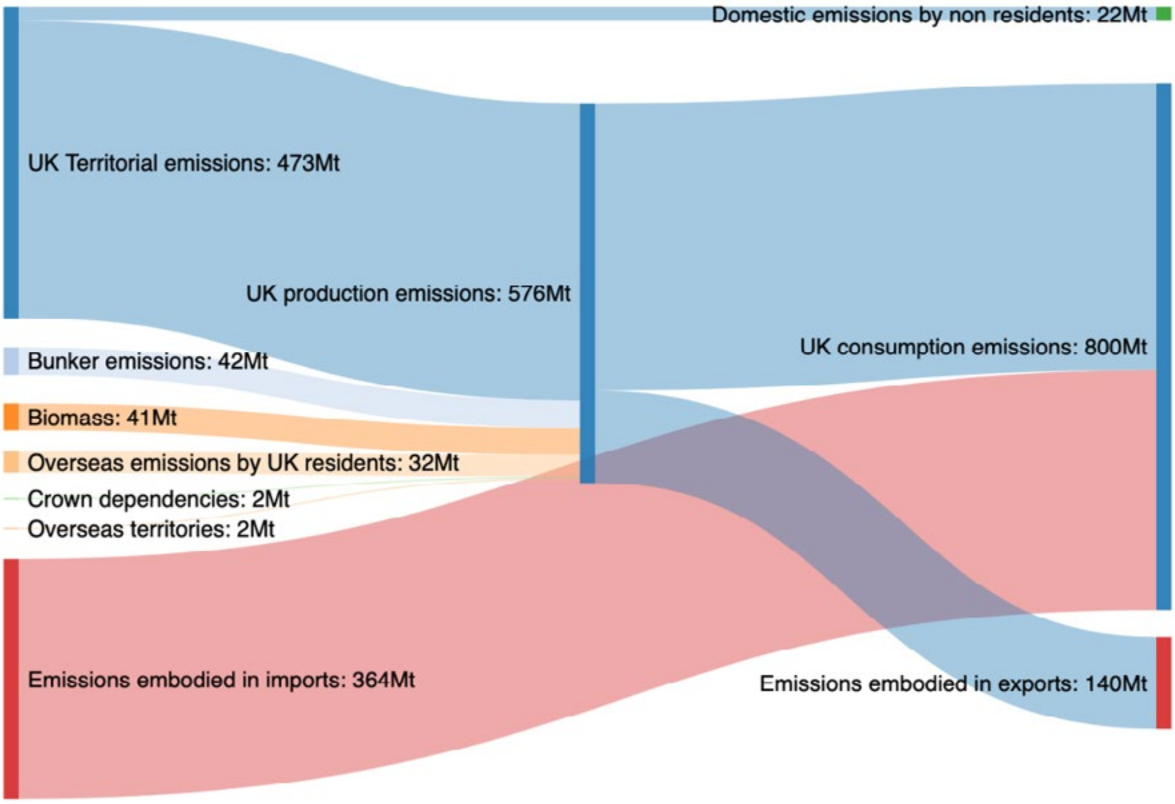


Figure 1: *UK emissions from territorial, production and consumption in 2016. Measured in MtCO2e. Numbers may not add due to rounding to nearest million tonnes.*

1.2 EMISSIONS INVENTORIES AND SCOPE 1, 2 AND 3

The Greenhouse Gas Protocol is an international accounting tool that is widely-used by companies to report on the emissions that they are responsible for. The protocol defines emissions into three 'scopes'[4]:

- **Scope 1: Direct GHG emissions**
  Scope 1 covers all direct GHG emissions by a company. It includes fuel combustion, company vehicles and fugitive emissions.
- **Scope 2: Electricity indirect emissions**
  Scope 2 covers indirect GHG emissions from consumption of purchased electricity, heat or steam.
- **Scope 3: Other indirect GHG emissions**
  Scope 3 covers other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. transmission and distribution losses) not covered in Scope 2, outsourced activities, waste disposal, etc.

4 We do not tend to use these definitions when dealing with emissions relating to a country and rather use the terms territorial, production and consumption. Scopes 1,2 and 3 have, however, been used for sectoral accounts and for city-level analyses.

1.3 CALCULATING THE UK'S CARBON FOOTPRINT USING THE UKMRIO DATABASE

In order to calculate the UK's carbon footprint (or the country's consumption-based emissions), three pieces of information are required:

I. **Data on the carbon intensity**, measured in tonnes of CO_2e per £ of output for industrial and service sectors in the UK and every other region in the world

II. **Information on the 'production recipes' of global products and services.** This data delineates how each industry type contributes to making each product type, considering full global supply chains of multiple stages. This information is usually in the form of global trade data.

III. **Data on the final demand expenditure on products** by UK final consumers which include households, government and capital

A multiregional input-output (MRIO) database can be used to produce these three pieces of information. In the last decade, several global MRIO databases have been developed by international organisations such as the OECD and research groups at leading universities (see Table 2). These databases have been developed to calculate carbon footprints for major world regions can also used to provide carbon footprint results for the UK.

Global MRIO databases contain data on the economic transactions between industries in every world region. Because this trade data is supplied in different currencies and industry groupings and is often poorly reported, we often find that what a country reports as receiving in imports does not match the export figures supplied by the exporting nation. This means that the tables have to be optimised and the numbers shift from what is originally reported in the final balanced solution. The scientific consensus is that a global MRIO is most suited to inter-country comparisons and that the Single country National Accounts Consistent (SNAC) footprint approach should be used for the most accurate national level estimates (Edens et al., 2015; Tukker et al., 2018). The SNAC approach treats the data from the country in focus as being correct and allows trade region data to change in finding the balanced solution. Thus, the region in focus preserves their information at the expense of other country's data.

Table 2: *Features of the main global MRIO databases*

NAME OF CONSUMPTION-BASED ACCOUNT DATASETS	YEARS AVAILABLE	NUMBER OF COUNTRIES/ REGIONS	NUMBER OF SECTORS
Eora (Lenzen et al., 2013)	1970-2015	189	Varies from 25 to >500
Eora26 (Lenzen et al., 2013)	1970-2015	189	26
EXIOBASE (Wood et al., 2018)	1995-2016	49	200 products and 163 industries
GTAP (Peters et al., 2011)	2004, 2007, 2011	140	57
OECD (Yamano & Webb, 2018)	1995-2011	67	36
WIOD (Dietzenbacher et al., 2013)	1995-2009	41	35
Global Carbon Budget	1990-2016	119	N/A

Since the UK's carbon footprint is a national statistic, it is important that it uses UK data on industry interactions, trade and final demand spends; that the currency is in GBP; and that the sectoral classification systems use match UK reported datasets. The carbon footprint reported by UK Government, is calculated using a UKMRIO database developed by the University of Leeds. The UKMRIO database follows the SNAC approach by using National Accounts data from the UK's Office for National Statistics (ONS, 2014). Further details of the UKMRIO database construction is provided in the appendix. The UKMRIO database covers the years 1997-2016 because these are the years where consistent sets of national account data exist. In 2020, the 2017 national account data will become available and a new estimate of the consumption-based account will be released. For this report, the database has been updated for the years 1990-2016.

The global warming potential (GWP) metric is used to convert GHGs to equivalent amounts of CO_2 by weighting their radiative properties for a time horizon of 100 years. In addition to the consumption-based emissions embodied in the global supply chains, here we consider direct household emissions, which occur in the use phase of products. Two sectors represent direct household emissions in our analysis: (107) Consumer expenditure – non travel, which includes household emissions associated with burning fuel at home for heating/cooking purposes etc., and (108) Consumer expenditure – travel, which includes tailpipe emissions from driving.

1.4 EXTENDING THE UK CARBON FOOTPRINT TEMPORALLY AND REGIONALLY

In this report we present UK carbon footprint results from 1990-2016. The carbon footprint database has been extended back in time by seven years using national account data from the National Archives. In addition, the regional breakdown for the UKMRIO database has been improved from UK and three trade regions (used to produce UK statistics for Defra) to UK and fourteen trade regions. This extended database is the WWF-UKMRIO database. In the appendix we discuss the uncertainty surrounding building the UKMRIO database and in particular, extending back to 1990 using datasets that are not always consistent. Table 3 gives an overview of the existing and improved UKMRIO databases.

Table 3: *Features of the UKMRIO database and the extended WWF-UKMRIO database*

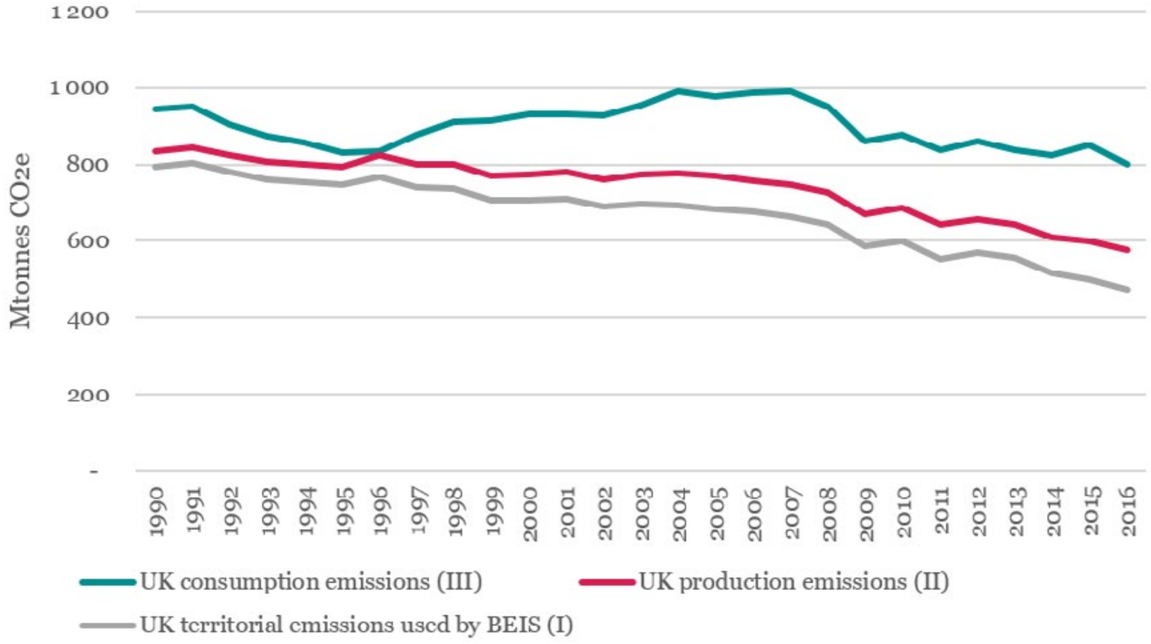
	UKMRIO DATABASE	WWF-UKMRIO DATABASE	
Years available	1997-2016	1990-2016	
Number of sectors	106 plus two sectors for direct household emissions for fuel burning in the home and from private vehicles	106 plus two sectors for direct household emissions for fuel burning in the home and from private vehicles	
Regions	UK Rest of the European Union China Rest of the World		UK Brazil Russia India China South Africa USA Japan Rest of the European Union Rest of Europe Rest of the OECD (non-Europe) Rest of Africa Rest of Americas Rest of Asia and Oceania Rest of Middle East

2 CARBON FOOTPRINT RESULTS

2.1 COMPARING THE UK'S TERRITORIAL, PRODUCTION AND CONSUMPTION-BASED EMISSIONS FOR 1990-2016

Figure 2 shows the new UK consumption-based emissions extended back to 1990. These results are compared to the production and territorial emissions accounts as explained in section 1.1.

Figure 2: *UK consumption and production emissions calculated using the WWF-UKMRIO database 1990-2016*



Between 1990 and 2016, UK emissions from the territorial perspective reduced by 40%. The UK's legally binding carbon budget requires a reduction of UK emissions of 57% by 2030[5] and the UK has met the targets set by the first two carbon budgets (2008-12 and 2013-17). During the same time period, emissions from a production perspective reduced by 31% and consumption emissions by just 15%. Consumption emissions are more closely correlated to changes in UK GDP because they are calculated final demand data – a component of GDP. This is the reason why consumption emissions have not decoupled from GDP. The 2007-2009 recession coincides with a 13% reduction in GHG emissions from consumption. The recession in the early 1990s also results in emissions reductions but in this instance, reductions were 3% per year.

In Figure 3, the territorial, production and consumption results for 2016 are disaggregated by the broad sectors used by the Department for Business, Energy and Industrial Strategy (BEIS) when reporting the territorial emissions inventory (final use). The residence principle (see section 1.1.2) of emissions accounting, used to generate the production accounts inventory, allocates emissions to the aviation and shipping industries. It also includes emissions from UK residents and UK-registered businesses, regardless of whether they are based in the UK or overseas. Data relating to foreign visitors and foreign businesses in the UK are excluded (see Table 1). The breakdown between other industrial and business sectors differs due to differences in sector definitions. For example, the territorial account does not allocate emissions to the energy sectors; rather it allocates the emissions to the industry using energy. For example, the emissions associated with the production of the electricity which is used in a steel factory is allocated to the steel factory in the territorial account, whereas the production account would allocate it to the electricity sector. Similarly, electricity use by residents is categorised as 'residential' in the territorial breakdown but belongs to electricity (energy) in the production account.

When emissions are allocated to consumption categories rather than production sectors, the pattern is different again. Emissions associated with the consumption of industrial and service products are much larger than the production emissions associate with these sectors. The reasons for this difference are explored in detail later in this report. Consumption emissions for industrial products and services will cover the full supply chain including emissions released abroad to meet UK demand.

5 https://www.theccc.org.uk/our-impact/reducing-the-uks-emissions/

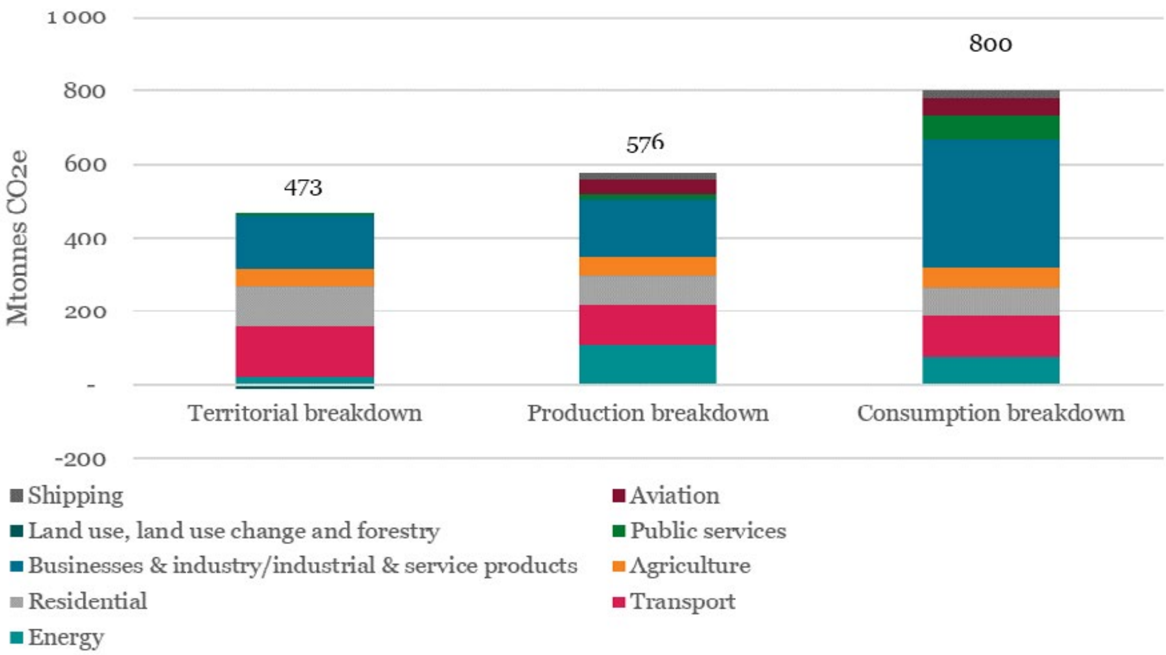


Figure 3: Breakdown of territorial, production and consumption emissions by sector 2016

2.2 COMPARING THE WWF-UKMRIO CONSUMPTION RESULTS WITH THE DEFRA RESULTS

Figure 4 compares the consumption emissions results produced by the extended WWF-UKMRIO database with the results reported by Defra using the older UKMRIO database. The two models similarly track the rise and fall of UK consumption-based emissions. The older UKMRIO database traces imported emissions from the rest of the EU, China and the rest of the world. Differences in the results are due to the WWF-UKMRIO disaggregating the 'rest-of-world' trade region into the trade regions of Brazil, Russia, India, South Africa, USA, Japan, Rest of Non-EU Europe, Rest of Americas, Rest of OECD, Rest of Africa, Rest of Asia and Oceania, and Rest of the Middle East. By calculating specific product level carbon conversion factors by these individual trade regions rather than having one set of conversion factors for a 'rest of world' region, the WWF-UKMRIO provides a more accurate estimate of the UK's Carbon Footprint. It is anticipated that future reports to UK Government of the footprint will use this more accurate version of the model.

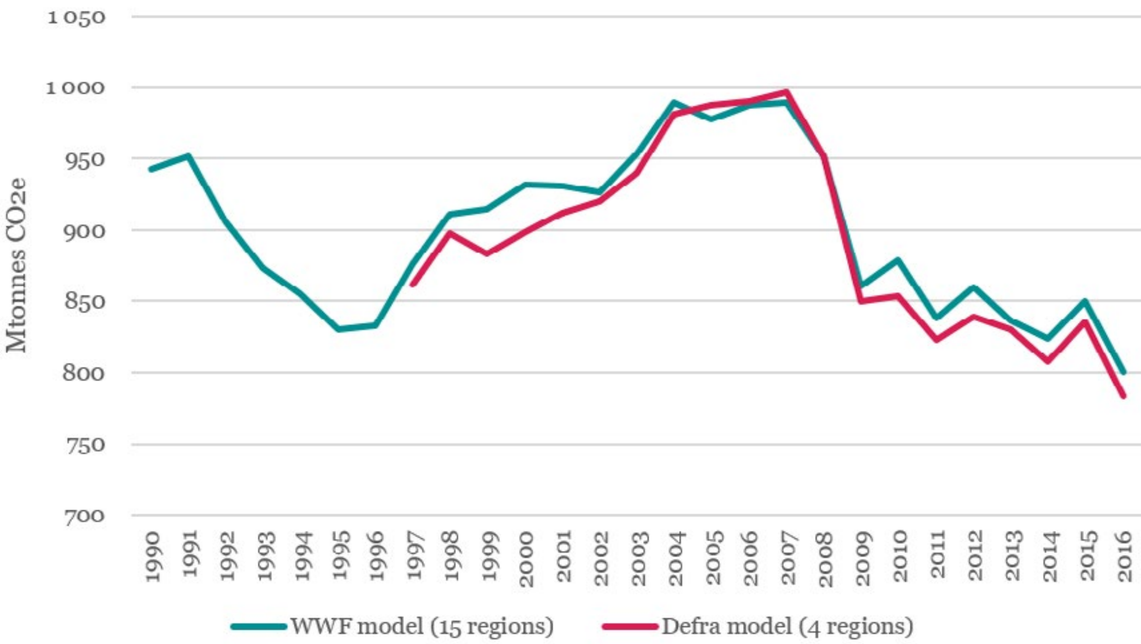


Figure 4: Comparison of the WWF consumption emissions and the Defra reported consumption emissions

2.3 WHICH TRADE REGIONS CONTRIBUTE MOST TO THE UK'S CARBON FOOTPRINT?

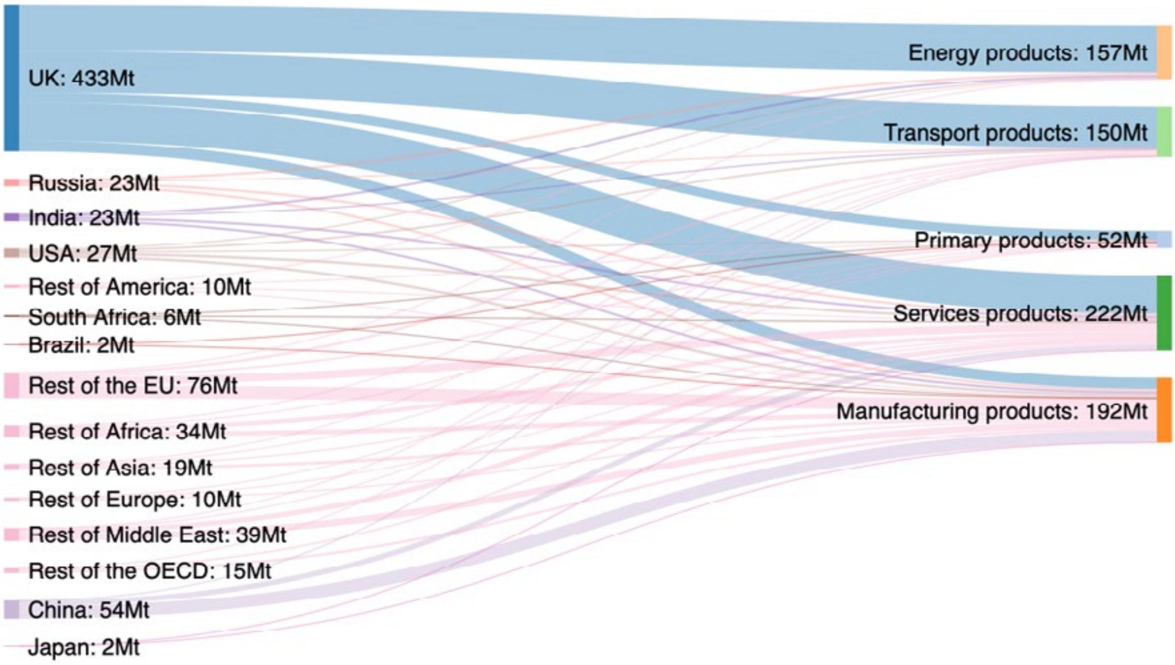


Figure 5: *Breakdown of the UK's Carbon Footprint in 2016 by source trade region and final product measured in MtCO2e*

Figure 5 reveals the origin region of the emissions associated with UK consumption in 2016. For a detailed breakdown of the nations that make up each of the regions see table 3 in the appendix. 54% of the UK's carbon footprint is domestically sourced. The rest of the EU contributes a further 9.9%, and China 7.3%, with the remaining emissions from other world regions. The UK, USA and 17 EU countries (Sweden, Romania, France, Ireland, Spain, Bulgaria, the Netherlands, Italy, Germany, Denmark, Portugal, Austria, Hungary, Belgium, Finland and Croatia) show signs of "peak-and-decline" of production emissions between 2005 and 2015 (Le Quéré et al., 2019). Over that period, emissions declined by -2.4% (-2.9 to -1.4%) per year on average. The strongest driver behind the emission decrease was the decreasing fossil fuel share of industrial energy use (including electricity and heat generation and reflecting displacement of fossil fuels by renewables and nuclear) with a median of 47% (36 to 73%) (Le Quéré et al., 2019). Another key driver of the emission decrease of "peak-and-decline" countries is the decrease in energy use (attributable to changes in the efficiency with which energy services are produced and consumed), accounting for a median of 36% (18 to 56%) (ibid). Countries such as China and India have rising emissions driven by rapid industrialization(Le Quéré et al., 2019; Peters, Le Quéré, et al., 2017). Nevertheless, emission growth slowed down between 2005 and 2015 – particularly in China - due to lower GDP growth and declining carbon intensity of energy particularly associated with a decline in coal use (Peters, Andrew, et al., 2017).

Figure 5 also shows the contribution that the source regions make to the footprint of final product groups. Energy products (electricity and gas consumption) and transport products (car fuel, public transport and aviation) are predominantly made up of emissions from domestic industries. Domestic industries are the source of emissions for just under half of the footprint of services products (finance, insurance and health services) and primary products (agriculture, mining, fishing and forestry). Manufactured goods, which include processed food, clothes and electronics contain most of their supply chains abroad and domestic emission make up a around one tenth of the total footprint.

2.4 WHICH PRODUCTS CONTRIBUTE MOST TO THE UK'S CARBON FOOTPRINT?

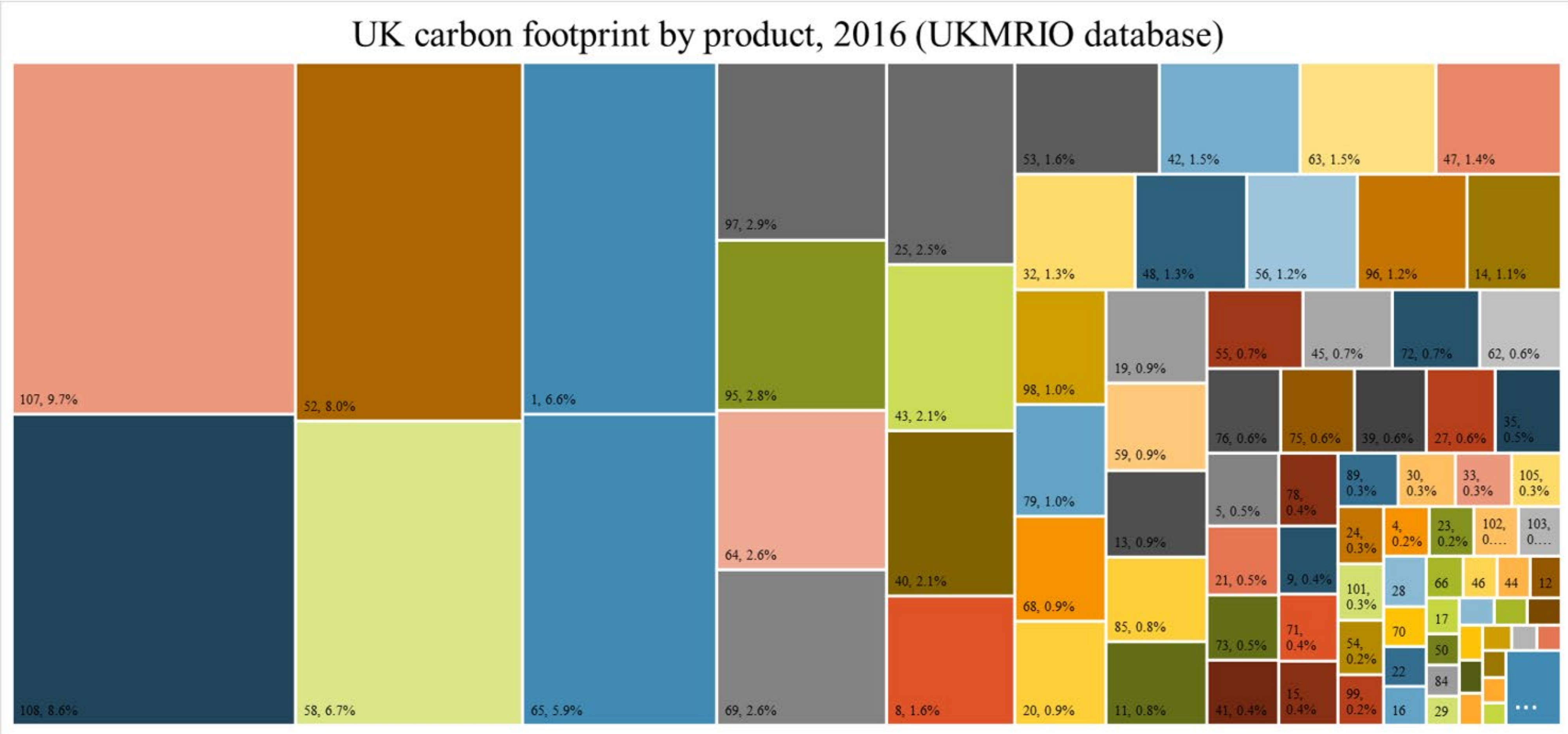


Figure 6: *UK carbon footprint by product in 2016. The largest six sectors are (107) Direct home heating, (108) Direct transport fuel, (52) Electricity, transmission and distribution, (58) Construction, (1) Products of agriculture, hunting and related services, and (65) Air transport services. See Appendix table 4 for the full list of product classification.*

Figure 6 presents the UK carbon footprint by product in 2016. In this report we will use an identifying number of the product and the product classification, e.g. (65) *Air transport services*. See table 4 in the Appendix for the full product classification. Six sectors contributed to almost half (45.5%) of the UK's carbon footprint, namely, (107) *Direct home heating,* (108) *Direct transport fuel,* (52) *Electricity, transmission and distribution,* (58) *Construction,* (1) *Products of agriculture, hunting and related services,* and (65) *Air transport services.*

(65) *Air transport services* shows the highest relative change among the six largest sectors with its carbon footprint increasing from 19 $MtCO_2e$ (2 %) in 1990 to 47 $MtCO_2e$ (6%) in 2016 (Figure 7). This is equivalent to an increase of 245% in 2016 compared to 1990-levels. This increase makes (65) *Air transport services* the product sector with the highest change in percentage contribution to the UK carbon footprint between 1990 and 2016. In 2016, most emissions associated with (65) Air transport services originated in the UK (63%), the USA (12%) and the Rest of EU (8%). In comparison, in 1990 only 28% of the sectoral carbon footprint originated in the UK, with a substantial share from the USA (40%) and Rest of Africa (11%). Between 1990 and 2016, production emissions associated with the sector increased as well from 20 to 41 $MtCO_2e$ (Figure 8).

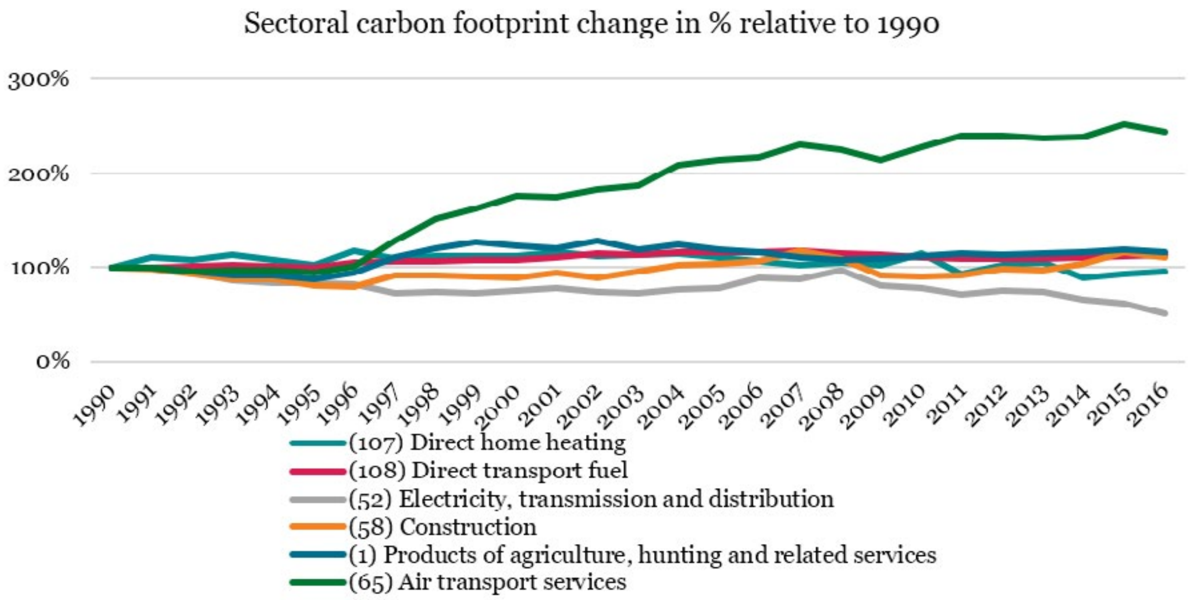


Figure 7: *Relative change in the carbon footprint contribution (1990-2016) of the six sectors with the higher carbon footprint in 2016 in % relative to 1990-level.*

(52) *Electricity, transmission and distribution* decreased in consumption carbon contribution from 125 to 63 $MtCO_2e$ between 1990 and 2016 (Figure 8). Between 1990 and 1995, about 13% of the UK's carbon footprint was associated with that sector. Since, it reduced in relative importance to a share of 8% in 2016. The emission share associated with inputs from (4) *Mining Of Coal And Lignite* in the consumption of (52) *Electricity, transmission and distribution* increased from 10% to 14% between 1990 and 2016. Furthermore, in 1990 about 90% of the emissions originated in the UK, while the share dropped to 79% in 2016 with 9% of the related emissions originating in Russia. Thus, while production emissions and consumption emissions originating in the UK decreased between 1990 and 2016, there was an increase in the share of consumption emissions originating in other countries (Figure 8).

The UK carbon footprint associated with (58) *Construction* increased slightly from 49 to 54 $MtCO_2e$ from 1990 to 2016. That being said, the consumption emissions originating in the UK decreased in the same period, from 36 $MtCO_2e$ (74%) in 1990 to 28 $MtCO_2e$ (52%) in 2016. Figure 8 shows that the share of carbon footprint originating elsewhere increased steadily in the same period.

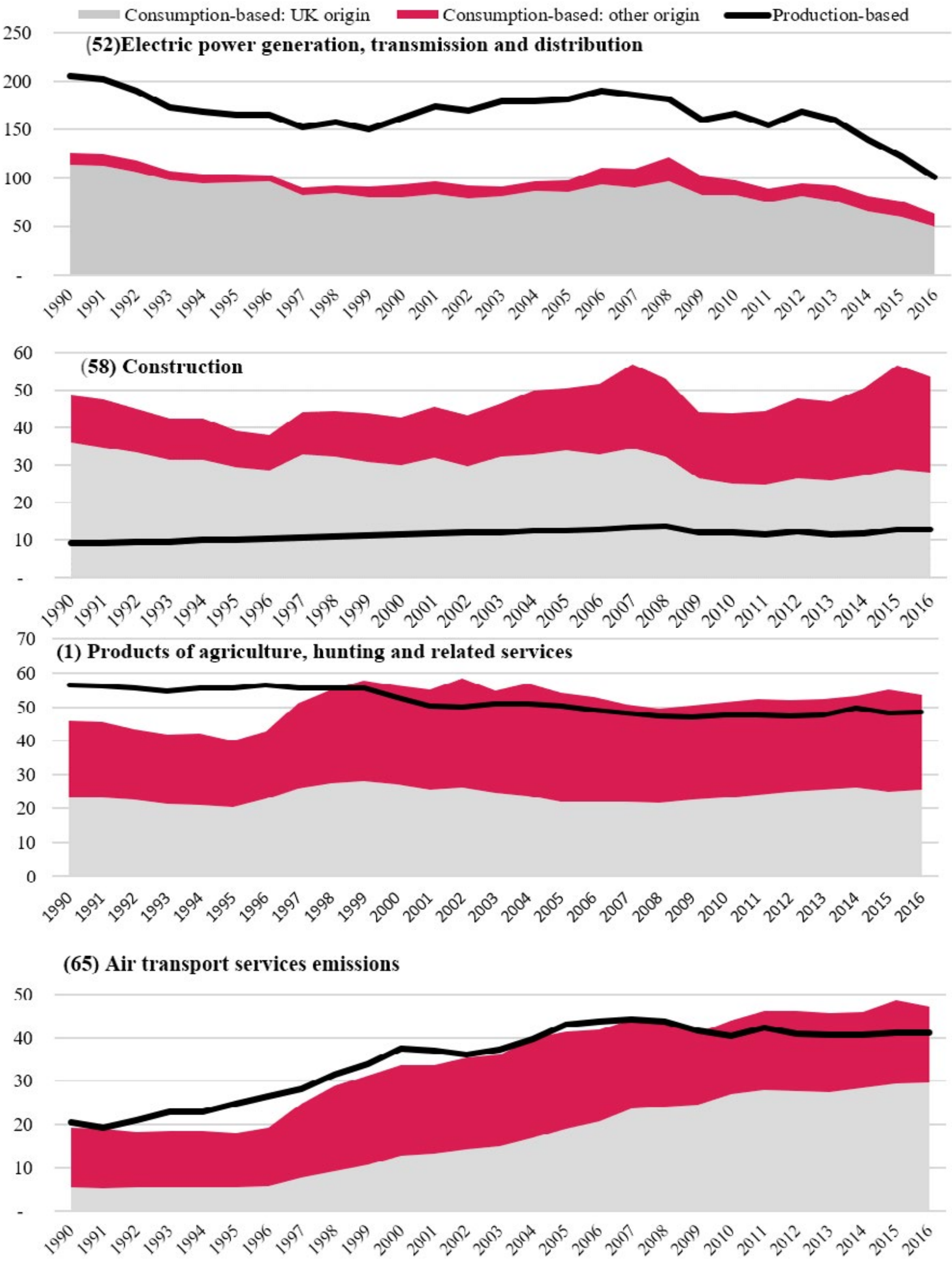


Figure 8: *Development in production-based and consumption-based emissions of high-footprint sectors in Mtonnes CO_2e. Note the different scales on each sub-figure.*

The carbon footprint associated with (108) *Direct transport fuel* and (1) *Products of agriculture, hunting and related services* also increased, though at a much lower rate. The agricultural sector was associated with a more drastic increase in consumption emissions between 1995 and 2000. This was as a result of increases in consumption emissions originating both in the UK and other countries (Figure 8). In 2016, about 48% of the emissions associated with the sector originated in the UK, with other important regions including the Rest of the EU (11%), Rest of America (9%) and Rest of Asia (8%). While consumption emissions – and particularly those of non-UK origin – increased between 1990 and 2016, production emissions associated with the agricultural sector decreased by 14%. In 1990 they amounted to 56 $MtCO_2e$ dropping to 49 $MtCO_2e$ in 2016.

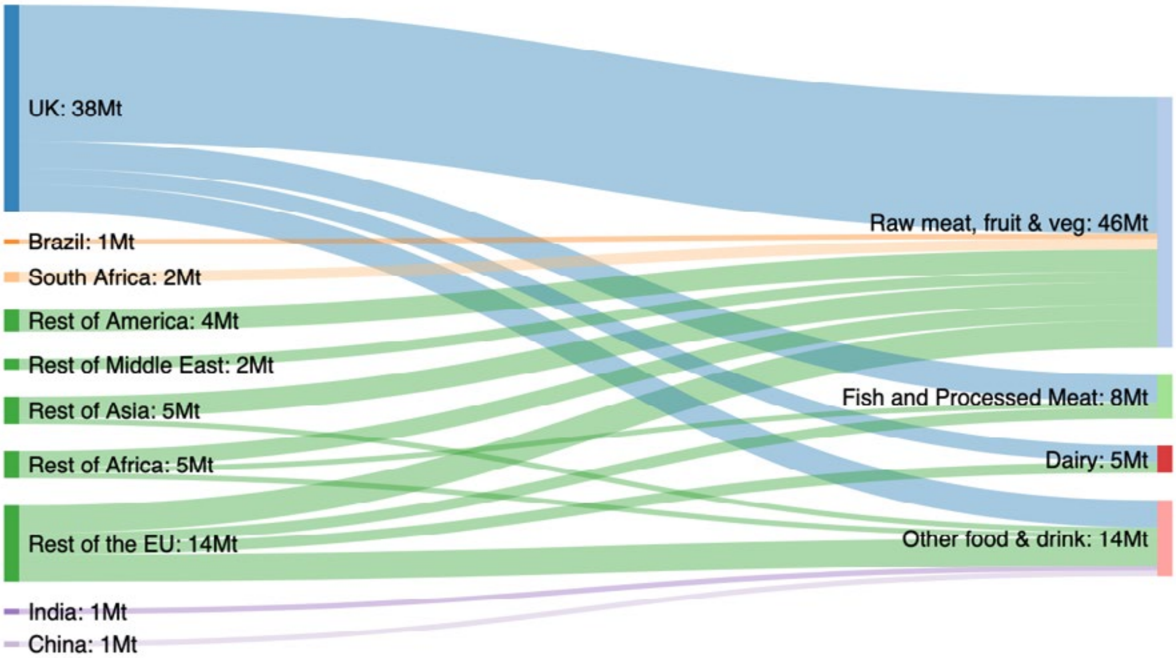


Figure 9: *Sources of emissions from associated with UK food consumption 2016 – flows that are less than 1 $MtCO_2e$ have been excluded*[6]

Figure 9 dives deeper into emissions from agriculture and food. While domestic and EU emissions make up 59% of the UK's carbon footprint of agriculture and food, 9.7 $MtCO_2e$ (10%) is sourced from the continent of Africa and 4.7 $MtCO_2e$ (5%) from India and China. This is in conflict with current food policy which encourages consumers to buy British and to locally source food items.

Agricultural practices differ vastly around the globe for a wide range of climatic, resource and cultural reasons. For example, the average mineral fertilizer use ranges from 1 kg of nitrogen per ha in Uganda to 300 kg in China (Poore & Nemecek, 2018). In an analysis of the environmental impacts associated with a set of domestically produced and imported food products, Webb and colleagues noted that sourcing from productive areas rather than trying to boost yields with large energy inputs (directly – e.g. in the case of heated greenhouse production, or indirectly – e.g. through the use of fertilizer) is a potential way of reducing emissions per tonne of product – even where there is a greater transport-related emissions involved (Webb et al., 2013). Poultry production in Brazil has been found to have 25% lower energy requirements compared to UK-based product, mainly due to local soya feed (i.e. less transport), naturally ventilated poultry houses and lower housing requirements (ibid). In cases where production emissions are relatively low, for example consider an apple produced in South Africa, the emissions associated with transporting the product to the UK become more important. The same study concludes that while production of food outside of the UK may be associated with lower amounts of primary energy used and GHG emissions – e.g. tomatoes and strawberries from Spain – there may be an adverse effect on water use and quality of that country (Webb et al., 2013). There is some evidence for mitigation of food-related impacts from producers. For example, there has been an increase in the use of digital tools for monitoring multiple environmental impacts, e.g. in the USA, Africa, South Asia and China (Poore & Nemecek, 2018).

Eighteen other products each contributed to more than 1% of the UK carbon footprint in 2016. These include (97) *Human, health services*, (95) *Public administration, defence and social security services*, (64) *Water transport services*, (69) *Food and beverage serving services*, (25) *Coke and refined petroleum products*, (43) *Motor vehicles, trailers and semi-trailers*, (40) *Computer, electronic and optical products*, (53) *Gas, distribution of gaseous fuels, steam and air conditioning supply*, (8) *Preserved meat and meat products*, (42) *Machinery and equipment*, (63) *Land transport services and transport services via pipelines*, (47) *Furniture*, (32) *Basic pharmaceutical products and preparations*, (96) *Education services*, (48) *Other manufactured goods*, (56) *Waste collection and disposal services*, (14) *Other food products*, (98) *Residential care and other social work activities*. Together with the six sectors associated with the highest GHG emissions highlighted above, these contribute to 78% of the UK's carbon footprint.

6 The emissions accounts analysed in this report do not include emissions from Land Use, Land Use Change and Forestry. If these emissions were included, we would see large flows from regions where there have been substantial reductions in forestry due to beef farming

2.5 WHAT IS THE EFFECT OF OFFSHORING?

Figure 2 shows that UK production-based and consumption-based emission of a similar magnitude around 1995 and 1996. Since then they have diverged, with production-based emissions reducing steadily. Instead consumption emissions rose steadily until peaking in 2007 before the recession, after which they decreased sharply (by 13% between 2007 and 2009) and remained relatively stable with small fluctuations up and down. In this section, we compare the patterns of production- and consumption-based emissions on a product level.

Figure 10 depicts in green the sectors which experienced the largest absolute decreases in production-based emissions between 1990 and 2016. The sector which decarbonised the most by far in absolute terms is that of (52) *Electricity, transmission and distribution*. Its production emissions halved between 1990 and 2016, from 205 to 101 $MtCO_2e$. This decrease in emissions is substantial, equivalent to 18% of UK's production-based emissions in 2016. The emission decreases in the sectors of (56) *Waste collection, treatment and materials recovery*, (30) *Petrochemicals* and (4) *Coal and lignite* together amount to about 19% of UK's production-based emissions in 2016. For a relative change in production-based emissions by product, see Table 4 in Appendix.

In this section, we aim to unpack the difference between the consumption-based and production-based emission trends. We explore the direction of changes in production-based emissions together with the direction of the change in consumption-based emissions originating abroad. For example, (1) Products of agriculture, hunting and related services were associated with a decrease in production-related emissions from 56 to 49 $MtCO_2e$, while consumption-related emissions originating abroad increased from 22 to 28 $MtCO_2e$ between 1990 and 2016 (Figure 8). Figure 11 depicts other sectors with a carbon footprint contribution about 1% of the UK carbon footprint, which are relevant for offshoring. We focus on sectors associated with a decrease in production-related emissions between 1990 and 2016. This is an oversimplification, as we may not capture incidents of offshoring where UK-based impacts are also increasing. For example, sectors that are of key importance for the UK carbon footprint such as (65) *Air transport services* and (58) *Construction* are associated with increases in both production-based emissions and consumption-based emissions originating abroad (Figure 8), and are also among the ten sectors associated with largest increase in production-based sectoral emissions between 1990 and 2016 (Figure 10).

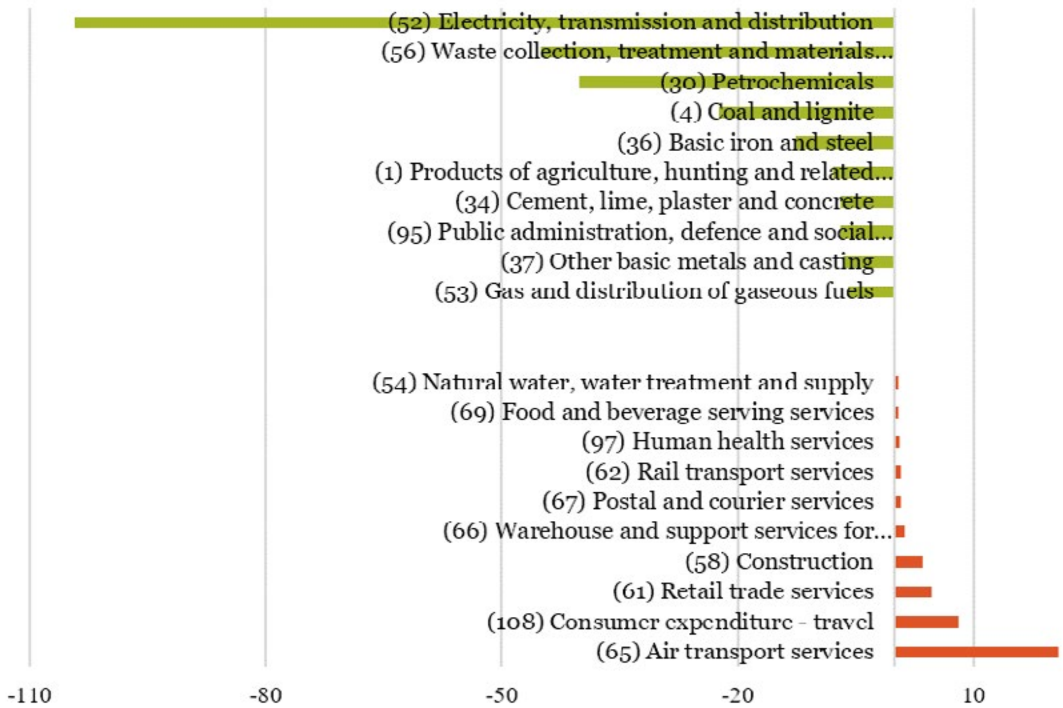
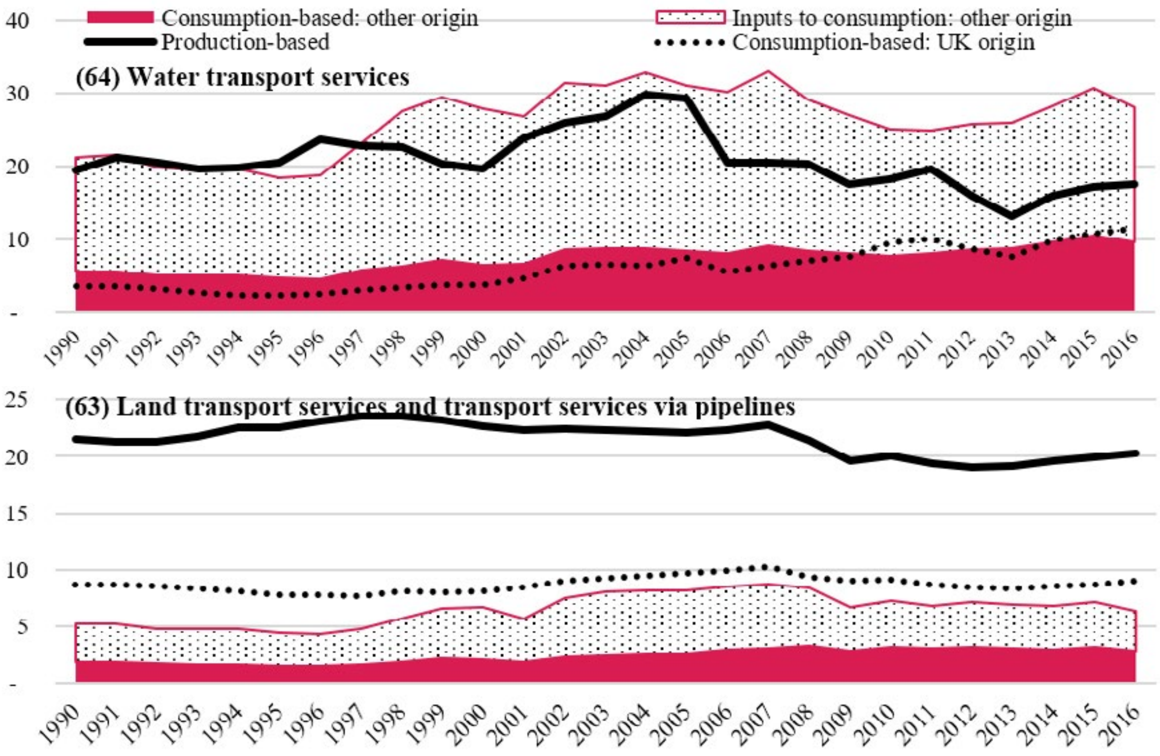


Figure 10: *The ten product sectors with the largest absolute increase and decrease in production-based emissions between 1990 and 2016 ($MtCO_2e$). Decrease in emissions are depicted in green and increases in emissions in red.*

The focus of this section is on tracing production- (and territorial-) based emission decreases to potential increases elsewhere. We have chosen to focus on products with both a non-trivial carbon footprint contribution, and which stand out as very relevant with regards to offshoring. These products include (64) *Water transport services*[7], (63) *Land transport services and transport services via pipelines*[8], (47) *Furniture*[9], (96) *Educational services*[10], (48) *Other manufactured goods*[11], and (20) *Wearing apparel*[12]. Each of these products contributed to between 2.6 - 0.9% of the UK carbon footprint in 2016 (Figure 6). Figure 11 shows the changes in production and consumption emissions of the offshoring-relevant products with non-trivial carbon contribution to the UK carbon footprint in 2016 (>1% contribution). Particularly striking are the cases of (47) *Furniture*, (48) *Other manufactured goods* and (20) *Wearing apparel*, where the majority of sectoral-related emissions originate abroad, equivalent to 91%, 99% and 98% respectively.

There are other products that may have low final carbon contribution – as they are not demanded by UK final consumers – but are relevant in terms of their use as inputs. For example, (4) *Coal and lignite* was associated with a substantial emission increase as an input to other UK consumption. Even though the sector is associated with only 0.2% of the UK carbon footprint (due to the low final demand for the sector), accounting for its emissions originating abroad as an input to other UK consumption amounted to close to 27 $MtCO_2e$, or more than 3% of UK's carbon footprint in 2016 (Figure 11). Appendix 4 provides more product detail, particularly on the change in production-based and consumption-based emissions originating abroad on a product level.

Similarly, the emissions embodied in inputs to other consumption increased between 1990 and 2016 for other sectors such as (64) *Water transport services*, (63) *Land transport services and transport services via pipelines* and (48) *Other manufactured goods*. The overseas share of emissions associated with inputs to other consumption is substantial for these products, making the case of offshoring even more critical (Figure 11).



7 This includes sea and coastal passenger water transport, sea and coast freight water transport, inland passenger water transport and inland freight water transport

8 This includes passenger rail transport, freight rail transport, passenger railway transportation by underground and metro, other passenger land transport, taxi operation, freight transport by road, removal services and transport via pipeline

9 This includes office and shop furniture, kitchen furniture, mattresses and other furniture

10 This includes pre-primary, primary, secondary, post-secondary, degree, post-graduate, sports and recreation and cultural educations. This also includes driving schools.

11 This includes jewellery, imitation jewellery, musical instruments, sports goods, arcade games and toys, other games and toys, medical and dental instruments and supplied and brooms and brushes

12 This includes men's and women's outer and underwear, other wearing apparel and accessories, articles of fur and knitted and crocheted hosiery and apparel

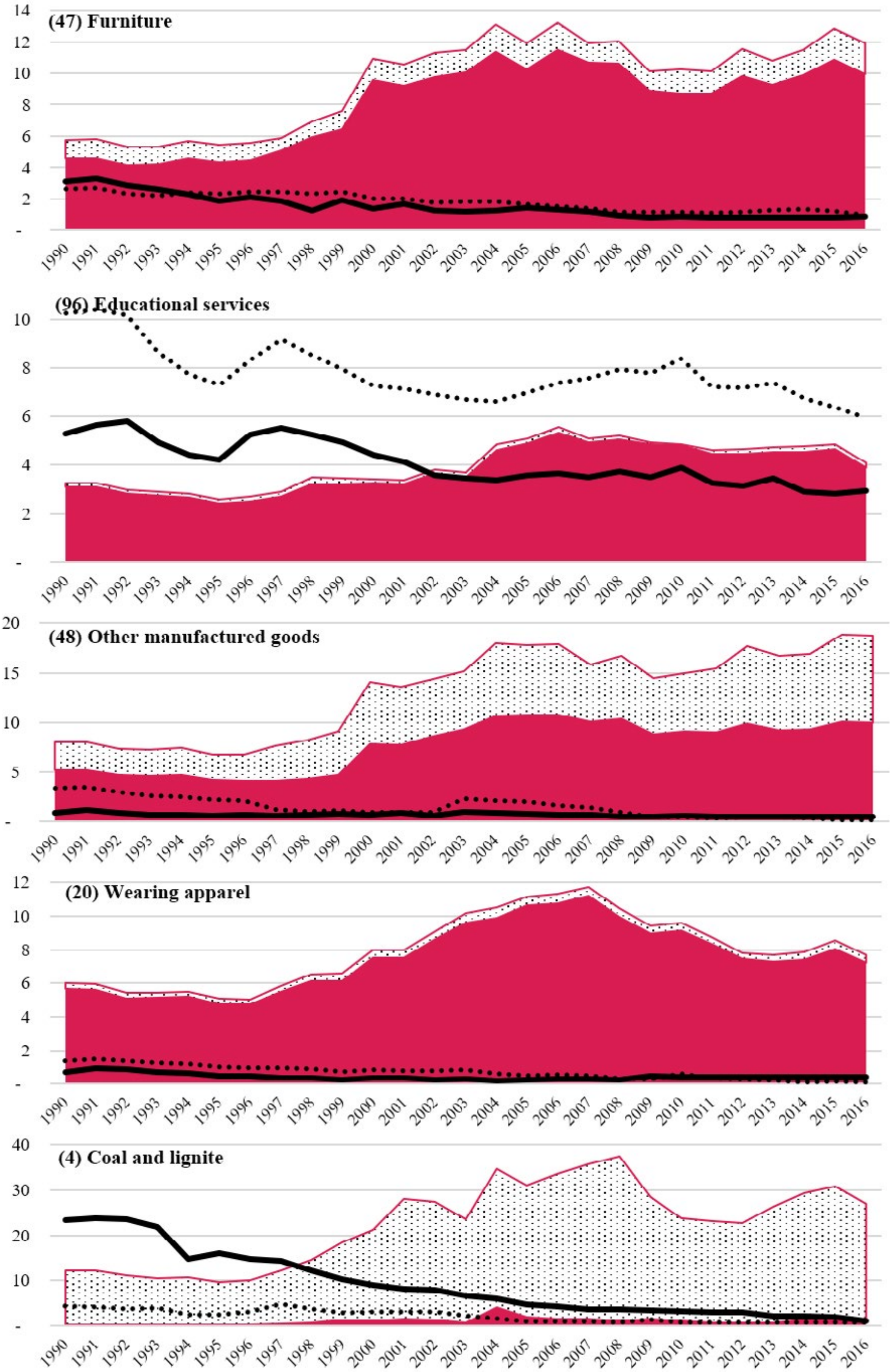


***Figure 11:** UK production-based emissions and consumption-relevant emissions originating abroad between 1990 and 2016 for offshoring relevant products. Key: Each sector depicted on the figure is associated with a decrease of production-based emissions and an increase of consumption-relevant emissions of other (non-UK) origin. Consumption emissions here include consumption-based emissions on non-UK origin (associated with the demand of these products by final consumers) and emissions associated with inputs to consumption of non-UK origin (associated with the inputs to products demanded by final consumers). The size of the stacked area (consumption-based and inputs to consumption of other origin) reflects the importance of offshoring for that product. All products have non-negligible contribution to the UK carbon footprint in 2016, with a total contribution (consumption-based and inputs to consumption of other origin)≥ 1%. Production-based emissions and consumption-based emissions originating in the UK are depicted with lines. Note the different scales on each sub-figure.*

3 POLICY RECOMMENDATIONS

3.1 FRAMING POLICY OPTIONS

The strategies and policies to reduce the UK's consumption emissions have significant cross over with those to reduce our territorial emissions. This is not surprising as 54% of our consumption emissions occur within the territory of the UK. However, the ever-increasing percentage of consumption emissions embodied in imports suggest that additional strategies and policies are required. The key issues being that:

- In 1990, emissions embodied in imports accounted for 14% of UK consumption emissions. In 2016 this had risen to 46% thus reducing the scope of UK climate policy to affect emissions associated with consumption.
- Accounting for emissions embodied in imports could reveal perverse climate policies – those that reduce territorial emissions but increase global emissions. An example is biofuels that have the potential to have higher emissions than natural gas. This would need to be considered on a product by product basis as long-term benefits might outweigh short-term carbon costs.
- Again, with the additional knowledge gained from consumption-based accounts, strategies that identify a small reduction in territorial emissions could reveal greater reduction potential overall (resource efficiency strategies for example). As Barrett et al., (2013) explain, energy production, energy-intensive sectors and transportation are the main sources of emissions coming under the spotlight of territorial accounting, whereas a consumption-based accounting approach would bring to the forefront the contribution of services, plus that of manufactured products like electrical appliances, food, and textiles.
- Consumption based accounting provides a stronger framing of justice and equity issues by providing an insight into a country's global contribution to emissions. This links more closely to the principle of common but differentiated responsibility and respective capabilities (CBDR-RC), which acknowledges that countries have contributed by varying scales to the mounting problem of climate change, will be exposed to different levels of impacts, and have different capabilities (e.g., financial and technological) to mitigate emissions.

While several studies have argued for the adoption of consumption-based accounting to replace the existing UNFCCC approach there is a consensus among policy makers that this is an unnecessary distraction. In fact, it has the danger of polarising the debate where one becomes an advocate or opposer to consumption-based accounting. This polarisation reduces the opportunity to identify and implement the additional strategies and policies that are revealed under consumption-based accounting. The general conclusion is that consumption-based accounting is a complementary approach and does not challenge the existing framing of territorial emissions.

In summary, consumption-based accounting links national policy actions to global emission reduction and not just reductions within a specific country. This provides a stronger link between climate science and mitigation options as it is the total volume of carbon dioxide that determines temperature rises, irrespective of where the emissions are produced.

3.2 STRATEGIES TO REDUCE CONSUMPTION EMISSIONS

3.2.1 IMPROVE, SHIFT AND AVOID FRAMEWORK

To explore the additional mitigation options highlighted or made more significant by consumption-based accounting, we have adopted the framework applied by the Intergovernmental Panel on Climate Change (IPCC) that considers strategies from three perspectives. These being:

- **Improve** – changing energy and/or carbon intensity to ensure that the emissions per product is reduced
- **Shift** – shifting from the use of one product to another that has lower emissions per functional unit
- **Avoid** – reducing consumption

All strategies could be categorised under one of these options. The prominent strategy adopted by the UK Government is to "improve" i.e. reducing the carbon intensity of production. Decarbonisation of the electricity grid is a good example. There are fewer strategies attempting to shift consumption. An example would be public transport as opposed to car use. Finally, "avoid" has had very little attention from a policy perspective.

The framing of consumption emissions reminds us that all energy is ultimately produced to provide services to households. Globally, renewable energy supply increased by 81 million tonnes of oil equivalent (Mtoe) in 2017 (IEA, 2018[13]). At the same time, energy demand grew by 328 Mtoe (2.3% more than the previous year) (IEA, 2018). Therefore, the increase in renewable energy did not even meet growing demand for energy let alone replace the existing use of fossil fuels. To ensure that renewable energy replaces fossil fuels as opposed to merely meeting increased demand, an absolute reduction in global energy demand is required. This then gives greater emphasis for the need to explore "Shift" and "Avoid" strategies, as well as improving efficiency.

As highlighted, many of these options (considered below) only demonstrate substantial reduction potential when a consumption emissions accounting system is applied. Examples are provided below under the headings of "Avoid", "Shift" and "Improve".

- **Improve – Re-industrialisation –** The UK could decide to undertake more basic material production in the UK to ensure that the materials are produced at maximum efficiency. This could involve producing more steel in the UK using electrolysis that has considerably lower emissions that the traditional blast furnace. Under a territorial accounting system, this would increase emissions. From a consumption accounting system, the emissions would reduce (therefore reducing overall global emissions).
- **Shift – Material substitution in packaging –** Reducing the reliance on oil-based plastics could reduce emissions by replacing the packaging with paper, for example. With most paper products being imported into the UK, only part of the emission reduction would reduce the territorial emissions therefore producing an under estimate of the full emissions reduction potential and looking like a less attractive policy option.
- **Avoid – Light-weighting of buildings –** It is possible to construct a building with fewer materials. However, when compared with other policy options, the reductions look minimal because of the accounting system alone. Due to being heavily reliant on the imports of construction materials, a policy appraisal makes this option look less favourable than energy efficiency in industry for example despite the emission reduction being more significant

We stress that the examples above and in Tables 4 to 12 are not exhaustive and other policies may exist which have greater emissions reduction potential. In addition to reducing emissions these policy examples may make space for new industrial solutions, encourage innovation and investment and business models which are ultimately going to be more competitive in a low carbon resource efficient world.

13 https://www.iea.org/geco/

3.2.2 STRATEGIES FOR MITIGATION

This section provides an overview of some of the strategies and policies being discussed in the literature. It is by no means an exhaustive list but acts as a discussion on the various options available. We do not necessarily support all these options.

Table 4: *Mitigation strategies for Air Travel*

GENERAL STRATEGY	CARBON MITIGATION POTENTIAL	DOMESTIC POLICIES	IMPORT POLICIES
Improve: Fuel and aircraft efficiency	A conventional ammonia fuel aircraft (1.08kGCO2e/tonnes/ km) by comparison a hydropower-based ammonia fuelled aircraft releases about 0.24 CO2e/tonne/ km (Bicer & Dincer 2017)	Fuel innovation options such as biofuels, liquid hydrogen and electric propulsion (Kivits et al., 2010)	Robust International efficiency standards for aviation products (Dmitriev & Mitroshkina, 2019)
Shift: Encourage train travel.	Carbon reduction potential of long distance travel substitution =0.7 MtC- 0.5 MtC. (Hickman & Banister, 2007)	Reduced train fare to encourage shift to domestic train travel	Expand the international high-speed train operations from UK (D'Alfonso et al., 2016)
Avoid: Reduce number of domestic and international flights		Limit airport expansion (Williams & Noland, 2006) Carbon prices on flight tickets (Pye, 2015)	Include in EU ETS (Anger & Köhler, 2010) Abolish global Kerosene subsidies and implement kerosene tax (Mills, 2017)

Copyright Credit © WWF / Richard Stonehouse

Table 5: *Mitigation strategies for Animal protein and agriculture*

GENERAL STRATEGY	CARBON MITIGATION POTENTIAL	DOMESTIC POLICIES	IMPORT POLICIES
Improve: More energy efficient food production.		Abatement subsidies for farmers (Gerber et al., 2009	International policy makers and farming organisations to agree on comprehensive standards to which manage worst and hardest-to-quantify environmental issues enabling the extension of existing schemes and promoting a flexible mitigation approach (Poore & Nemecek, 2018)
Shift: Shifting away from high carbon animal protein to lower carbon plant based protein	846 million tonnes GHG emissions by 2050, assuming gradual global meat (and dairy) consumption reduction to reach 75% reduction by 2050 (Barrett & Scott, 2012)	Environmental labelling of food products (Grankvist et al., 2004) Investment in artificial or cultured meat (Dagevos et al., 2017) Carbon labelling (Committee on Climate Change, 2013)	EU tax on meat according to carbon contribution. (Nordgren, 2012)
Avoid: Avoid household and industry food waste	A reduction of 17.3 $MtCO_2e$ (household), 6.82 $MtCO_2e$ (industry	Information campaigns to increase awareness of the climate change implications of household food waste. Investment in food redistribution programmes (Schanes et al., 2016) Changing nutritional guidelines (Reynolds et al., 2019)	

Table 6: Mitigation strategies for Clothing

GENERAL STRATEGY	CARBON MITIGATION POTENTIAL	DOMESTIC POLICIES	IMPORT POLICIES
Improve: Reduce waste in manufacturing.	30% reduction in supply chain waste could lead to a reduction of 1.01 $MtCO_2e$ (Peak, 2018)	Actions by local and national government promoting waste reduction and reuse with clear policy targets (Cooper et al., 2010) Mandatory labelling for expected lifetime (Cooper et al., 2010)	Multi-country agreement for the ban of incineration and landfilling of unsold clothing stock. (EAC)
Shift: Shift in consumption patterns towards lower carbon clothing.		Domestic tax based on carbon based accounting (Afionis et al., 2017)	Border carbon tax adjustment to reflect embodied carbon on imports (Böhringer et al., 2012)
Avoid: Longer lifetime of products.	30% demand reduction reflecting longer lifetimes (assuming 33% uptake rate) could lead to emission reduction of 3 Mt CO_2-eq with rebound amounting to 75% of the direct emissions savings. (Wood et al., 2017)	Longer guarantees (for a minimum of 10 years) (Cooper et al., 2010)	Sector specific targets that aim to achieve absolute reductions in whole life carbon emissions and material use (Peak, 2018)

Table 7: Mitigation strategies for Construction

GENERAL STRATEGY	CARBON MITIGATION POTENTIAL	DOMESTIC POLICIES	IMPORT POLICIES
Improve: Improving energy efficiency	Up to 40% reduction in embodied carbon (The Green Construction Board, 2013)	Independent body to develop and enhance the decarbonisation of the materials used in the construction sector Reporting requirements should be extended to include scope 3 emissions associated with developing new facilities.	EU: Introduction of embodied carbon measurement in public and regulated sectors (Roelich & Giesekam, 2019)
Shift: Increase reuse of construction materials	22.3 $MtCO_2e$ (Peak, 2018)	Incentives for improving efficiency by introducing modern construction methods, for example, modular design and off-site construction (Barrett & Scott, 2012)	Tax incentives for recovered materials (Giesekam et al., 2014)
Avoid: Replace high carbon materials with low carbon substitutes.	47.91 $MtCO_2e$ reduction (plus potential for 8.93 $MtCO_2e$ reduction with reduction in material inputs through design optimisation) (Peak, 2018)	Manufacturers to require Environmental product Declaration to support environmental claims (Giesekam, 2018)	EU standards on Environmental Product Declaration (Roelich & Giesekam, 2019) International embodied carbon intensity targets in construction (Giesekam et al., 2018)

Table 8: *Mitigation strategies for Carbon intensive supplies (Coal)*

GENERAL STRATEGY	CARBON MITIGATION POTENTIAL	DOMESTIC POLICIES	IMPORT POLICIES
Improve: Reduce carbon contribution of coal.		Investment Carbon capture and storage for coal fired power plants (Ekins et al., 2011) Require a carbon intensity of production within trade deals that excludes the use of coal	
Shift: Shift towards renewable energy supplies		Continued R&D for emerging technologies as well as increasingly strong market signals against fossil fuels and support for balancing technologies instead of any new-build major gas generation.	
Avoid: Reduce coal consumption.		A ban on the most carbon intensive supplies (Committee on Climate Change, 2013)	

Table 9: *Mitigation strategies for Furniture*

GENERAL STRATEGY	CARBON MITIGATION POTENTIAL	DOMESTIC POLICIES	IMPORT POLICIES
Improve: More efficient manufacturing processes		Incentives for lean production (Abu et al., 2019)	Extending European energy efficiency standards to include material use (Scott et al., 2017)
Shift: Increased consumption of products that use recycled content or lower carbon intensive materials.		Information campaigns on embodied carbon (Schanes et al., 2016)	Trade restrictions by prohibiting of imposing higher taxes on imports of material (Afionis et al., 2017)
Avoid: Extending the life of products through reuse and sharing economies.	Product sharing potential for all materials up to 7MtCO2e (Cherry et al., 2018)	Local and national government could facilitate reuse organisations to access more reusable items by providing them with physical or financial assistance to expand their operations (Cooper, 2016)	

Table 10: *Mitigation strategies for Other manufactured goods*

GENERAL STRATEGY	CARBON MITIGATION POTENTIAL	DOMESTIC POLICIES	IMPORT POLICIES
Improve: Increased efficiency of products	Potential of increasing the efficiency of all products is around 13 $MtCO_2e$ (Cherry et al., 2018)	Comprehensive resource efficiency programme based on common data reporting. Partnerships with the sector should be established to identify best practice and set standards (Peak, 2018)	Embedded carbon products standards (Afionis et al., 2017)
Shift -A move away from carbon intensive materials	Equivalent to around 80 euro/ tCO_2 could potentially reduce the EU's total (energy plus process) CO_2 emissions by up to 10% by 2050 (Pollitt et al., 2019)	Carbon taxes on good produced in the UK (Pollitt et al., 2019)	Carbon pricing on imported goods (Pollitt et al., 2019) Mandatory emissions allowance purchases by importers (Afionis et al., 2017)
Avoid: Longer lasting and repairable products	Potential of increasing the efficiency of all products is around 13 $MtCO_2e$ (Cherry et al., 2018)	Mandatory warranties and guarantees Improving infrastructure for repair and reuse of products (Cox et al., 2013)	

Table 11*: Mitigation strategies for Electricity*

GENERAL STRATEGY	CARBON MITIGATION POTENTIAL	DOMESTIC POLICIES	IMPORT POLICIES
Improve: Decrease the carbon potential of the electricity system.		CCS (carbon capture and storage) and CDR (carbon dioxide removal) deployment (incentives to achieve deployment at necessary scale) (Daggash & MacDowell, 2019)	Reduce intensity of imported electricity
Shift: Shift to renewable energy for electricity.		Increased investment in wind and solar power (Stamford & Azapagic, 2014)	Low carbon standards for imported electricity
Avoid: Reduce electricity consumption		Electricity saving campaigns (Jones & Lomas, 2016) Maintain EU standards for energy efficiency on goods, vehicles Retrofitting of homes to bring all homes to decent EE standard; net-zero standards for new homes.	

Table 12: *Mitigation strategies for Land transport*

GENERAL STRATEGY	CARBON MITIGATION POTENTIAL	DOMESTIC POLICIES	IMPORT POLICIES
Improve: Improving vehicles to be more energy-efficient and fuels to be less carbon intensive.	Carbon reduction potential=9.1 MtC–1.8 MtC. (Hickman & Banister, 2007)	Eco-driving Electric vehicle innovation Smaller, light weight vehicles (Creutzig et al., 2018) Modal shift, vehicle sharing - i.e. fewer vehicles on the road. Modal shift and investment in active transport infra - fewer vehicles on the road Ban on sale of petrol and diesel vehicles from 2030	Import standards for energy efficiency (Afionis et al., 2017)
Shift: Shift to lowest carbon mode of transport		Purchase tax/ feebate on new cars Vehicle Exercise Duty graded by fuel type Scrappage rebate (Brand et al., 2013) Investment in cycling and walking infrastructure (Creutzig et al., 2012) Financial support to increase uptake of Electric Vehicles (Pye, 2015)	
Avoid: Improved urban planning to avoid the need to travel (Creutzig et al., 2018)	Could reduce GHG emissions 5-15% (Creutzig, 2016)	Teleworking Compact cities (Creutzig et al., 2018)	

3.2.3 ADDRESSING THE MOST IMPORTANT PRODUCTS

The analysis provided in section 2.5 shows the effects of off-shoring on a range of different products. This reveals the key products that would benefit from additional mitigation options that would affect both territorial and emissions embodied in imports. As previously stated, there are a range of materials and products that become more significant when we consider emissions from a consumption perspective. In particular, the embodied emissions in construction become extremely important. In fact, the embodied emissions in construction are greater than all aviation and shipping emissions. There is also considerable evidence that there is still a lot of "low-hanging fruit" options including light-weighting through better design, material substitution and improvements in the efficiency of use. In our recent analysis of resource efficiency measures, it is construction that offers the greatest reduction (as shown in Figure 12 below).

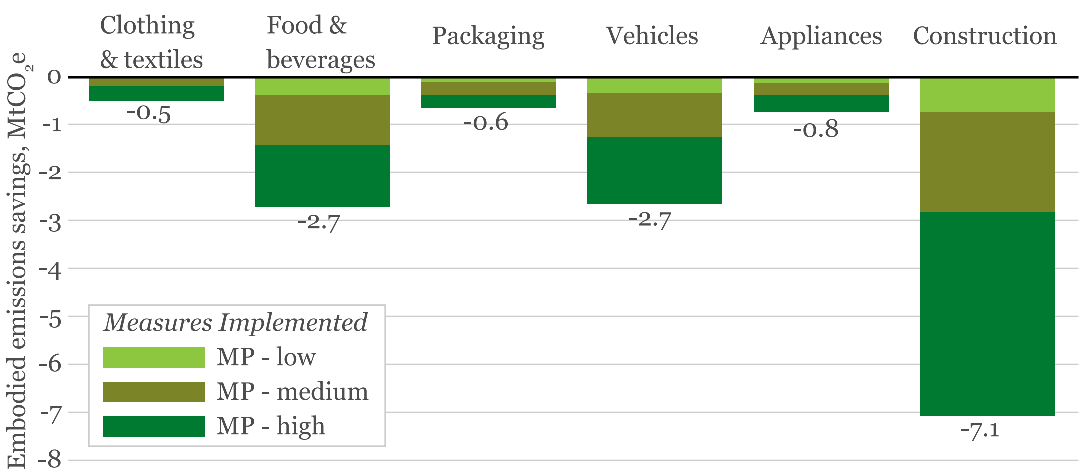


Figure 12: *Emission reduction potential of a range of resource efficiency strategies (Scott et al., 2018) MP = Material Productivity*

Other materials and products, including vehicles and food, feature strongly in consumption-based accounting. For vehicles, the attention across the EU has been to reduce the in-use emissions through improved efficiency. The consumption-based accounting approach informs us that it is not just the efficiency of the vehicle, but the embodied emissions associated with the manufacturing of the vehicle. As with construction, the embodied emissions can account between 25 and 50% of the total impact including the in-use emissions.

3.3 POLICIES TO IMPLEMENT CONSUMPTION-BASED EMISSIONS STRATEGIES

To deliver many of the strategies listed above, policies will be required to overcome the inertia in the individual sectors. As with all policies, there is an option to implement supporting (carrot) or enforcing (stick) approaches. Supporting policies include funding innovation through the Industrial Strategy for example, providing support and advice to households and/or businesses and technology support across countries. Enforcing policies include pricing emissions within a trading scheme, a carbon tax, regulatory measures to ban / limit the use of products or setting standards to enforce improvements.

It is very rare that one policy approach would be used in isolation to deliver emission reductions. For example, the EU has implemented a trading scheme, provides subsidies to drive innovation in low carbon technologies and sets standards for vehicles. In this analysis, we have not attempted to analyse every existing policy option and its effect on consumption-based emissions. Instead we consider some of the policy options under two key areas. **These being:**

- **Improving the efficiency** of production in imports.
- **Shifting and avoiding consumption** in the UK of key products highly dependent on imports.

3.3.1 IMPROVING EFFICIENCY OF PRODUCTION IN IMPORTS

While the emissions associated with imports are currently outside the jurisdiction of the UK, there are many policy options available to improve the energy and carbon efficiency of imported materials and products. Enforcing policies include introducing Border Carbon Adjustments or attaching a tax to the import of carbon intensive materials. Supporting policies include channelling foreign investment and aid to ensure that emerging economics and developing countries leapfrog many of the high carbon technologies that underpinned the development of the developed world.

Border carbon adjustments have been widely discussed (see Sakai & Barrett, (2016) for a comprehensive discussion). There have been suggestions that placing a traded value of imports would break World Trade Organisation rules. However, this has been widely dismissed as tariffs are allowed to be introduced under environmental concerns. What is clear is that imports could not be given a financial penalty greater than the penalty allocated in the importing country. For example, if the EU Emission Trading Scheme carried a price of 10 Euros per allowance, the same price would have to be applied to imports, not more. It becomes more confusing by the fact that any carbon trading scheme in the country of production must also be considered. For example, if China had a carbon price of 5 Euros, then only an additional price of 5 Euros could be added. There is even more complexity involved as the key products, such as steel, is not just imported as a raw material, but embodied in thousands of individual products. This makes it very difficult to know what carbon price to apply. There are further issues related to a poor understanding of the exact carbon intensity of different forms of production. Finally, the EU ETS carries a very low carbon price that has no effect on emissions. Therefore, extending a scheme that is currently ineffectual would clearly have limited impact.

Supporting policies relate to the UK playing its role as a leader in international climate negotiations and ensuring that technological advances in the UK are shared widely with the rest of the world. In addition, there are many climate funds and other funding approaches that the UK could support to ensure the more rapid uptake of low carbon technologies.

3.3.2 SHIFTING AND AVOIDING CONSUMPTION

Our analysis highlighted that it is a limited number of sectors / product groups that account for the majority of the UK's carbon footprint. This suggests that targeted support for management of supply-chain emissions and resource use in key sectors could drive substantial changes in national outcomes[14]. This finding is supported by a body of case study evidence within sectors that have already adopted such an approach. For instance, signatories to the Infrastructure Carbon Review have demonstrated substantial capital cost and carbon savings across a wide range of projects by measuring and managing embodied carbon in the design of new assets[15]. However, these case studies represent the minority of industry practice. Insufficient price signals (due to the relatively low cost of materials and carbon) and a shortage of information and expertise within companies, has restricted the range of material productivity improvements that have been investigated or implemented.

To date mitigation policies have largely focussed on delivering reductions in operational carbon emissions from products in use (such as tailpipe emissions from vehicles, emissions attributable to space heating in buildings etc.), and ignored opportunities to leverage emission reductions in the supply chains that manufacture these products. As operational emissions reduce due to existing policy levers, many of the most cost-effective opportunities for continued reductions will sit elsewhere in the product life cycle. Measuring and managing whole life carbon emissions (including manufacture and end of life options) opens up additional opportunities that can deliver savings in resource use, emissions and cost. Widespread adoption of such an approach could be consistent with improving UK competitiveness, delivering economic growth, growing employment and developing international markets in resource efficient products and services. In essence, forming a key delivery opportunity within the Industrial Strategy.

14 Our conservative analysis of the role of material productivity in climate change mitigation demonstrates potential annual reductions of greenhouse gas emissions of between 16 and 32 million tonnes by 2032.

15 See, for instance, Green Construction Board (2014) Infrastructure Carbon Review One year on…which compiles over 50 pages of case studies

In light of this opportunity, we suggest advancing a 3 stage Government programme which focusses on establishing carbon management structures; demonstrating innovation and regulating performance where necessary. This could be delivered through a series of partnership agreements with UK industry and the Government. Initial work to establish such REPs could be supported through the Industrial Strategy Challenge Fund and developed as part of the proposed sector deals.

3.4 SETTING TARGETS

There is a growing interest in establishing legally binding targets for consumption-based emissions in the UK. This was first considered in the report produced by the University of Leeds for the CCC in 2013. The CCC's conclusion at the time was to continue monitoring the UK's consumption-based emissions but not to establish a target. The hope was that emissions relating to imports into the UK would decline as the carbon intensity of production in other countries improved over time. In reality, while there has been a decline in the UK's consumption-based emissions this is mainly related to a decrease in territorial emissions that relate to UK consumption. Any improvements in the carbon intensity of imports has been outpaced by an increase in the level of imports.

At present the UK has a clear target of net zero emissions by 2050 from a territorial perspective. Therefore, there is already a target for approximately 55% of the UK's consumption-based emissions. Any additional target would have to relate to the remaining (and growing) 45% of emissions related to UK imports. Concern has been raised by UK Government representatives that the UK would be establishing a target that they did not have enough control to affect. For example, it is difficult for UK climate policy to affect the efficiency of steel production in China. At the same time, it is very common for the UK Government to establish targets that require multiple actors to achieve the desired outcome. For example, targets related to GDP require productivity improvements across the whole economy and are heavily influenced by investment patterns of international companies.

Therefore, if one believes that a target would provide additional focus to reducing the UK's emissions associated with imports, the UK Government would need to feel that they can introduce strategies and policies to reduce emissions. Many of the examples listed above provide evidence of the ability of the UK Government to reduce emissions associated with imports. Domestic policies could be introduced that reduce the UK's reliance on carbon intense materials and reduce the impact of consumption. Improving the carbon intensity of imports would require cooperation with other countries. This leaves the option of a "carrot or stick" approach, i.e. border carbon taxes or innovation funding and technology transfer. From an international policy perspective, there is an opportunity to submit joint "Nationally Determined Contributions" with other countries that seek to improve the carbon intensity of materials and minimise the use of the most carbon intensive products. These do not currently exist but would be a major step forward to demonstrate that emission reduction requires close cooperation trust between countries.

4 REFERENCES

Abu, F., Gholami, H., Zameri, M., Saman, M., & Zakuan, N. (2019). The implementation of lean manufacturing in the furniture industry : A review and analysis on the motives , barriers , challenges , and the applications, 234, 660–680.

Afionis, S., Sakai, M., Scott, K., Barrett, J., & Gouldson, A. (2017). Consumption-based carbon accounting: does it have a future? *Wiley Interdisciplinary Reviews: Climate Change*, 8(1), 1–19. doi:10.1002/wcc.438

Anger, A., & Köhler, J. (2010). Including aviation emissions in the EU ETS: Much ado about nothing? A review. Transport Policy. doi:10.1016/j.tranpol.2009.10.010

Barrett, J., Peters, G. P., Wiedmann, T., Scott, K., Lenzen, M., Roelich, K., & Le Quéré, C. (2013). Consumption-based GHG emission accounting: a UK case study. *Climate Policy*, 13(4), 451–470. doi:10.1080/14693062.2013.788858

Barrett, J., & Scott, K. (2012). Link between climate change mitigation and resource efficiency: A UK case study. *Global Environmental Change*, 22(1), 299–307. doi:10.1016/j.gloenvcha.2011.11.003

Bicer, Y., & Dincer, I. (2017). Life cycle evaluation of hydrogen and other potential fuels for aircrafts. *International Journal of Hydrogen Energy*, 42(16), 10722–10738. doi:10.1016/j.ijhydene.2016.12.119

Böhringer, C., Balistreri, E. J., & Rutherford, T. F. (2012). The role of border carbon adjustment in unilateral climate policy : Overview of an Energy Modeling Forum study (EMF 29), 34, 97–110.

Brand, C., Anable, J., & Tran, M. (2013). Accelerating the transformation to a low carbon passenger transport system: The role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK. *Transportation Research Part A: Policy and Practice*, 49, 132–148. doi:10.1016/j.tra.2013.01.010

Cherry, C., Scott, K., Barrett, J., & Pidgeon, N. (2018). Public acceptance of resource-efficiency strategies to mitigate climate change. *Nature Climate Change*, 8(11), 1007–1012. doi:10.1038/s41558-018-0298-3

Committee on Climate Change. (2013). Reducing the UK's carbon footprint, (April).

Cooper, T. (2016). *Longer lasting products: Alternatives to the throwaway society*. (CRC Press, Ed.).

Cooper, T., Fisher, T., Goworek, H., & Woodward, S. (2010). Excessive speed / short lives: attitudes to clothing longevity and disposal.

Cox, J., Griffith, S., Giorgi, S., & King, G. (2013). Resources , Conservation and Recycling Consumer understanding of product lifetimes, 79, 21–29.

Creutzig, F. (2016). Evolving Narratives of Low-Carbon Futures in Transportation. *Transport Reviews*, 36(3), 341–360. doi:10.1080/01441647.2015.1079277

Creutzig, F., Mühlhoff, R., & Römer, J. (2012). Decarbonizing urban transport in European cities: Four cases show possibly high co-benefits. *Environmental Research Letters*, 7(4). doi:10.1088/1748-9326/7/4/044042

Creutzig, F., Roy, J., Lamb, W. F., Azevedo, I. M. L., Bruine de Bruin, W., Dalkmann, H., ... Weber, E. U. (2018). Towards demand-side solutions for mitigating climate change. *Nature Climate Change*, 8(4), 260–263. doi:10.1038/s41558-018-0121-1

D'Alfonso, T., Jiang, C., & Bracaglia, V. (2016). Air transport and high-speed rail competition: Environmental implications and mitigation strategies. *Transportation Research Part A: Policy and Practice*, 92(635867), 261–276. doi:10.1016/j.tra.2016.06.009

Dagevos, H., Voordouw, J., Dagevos, H., & Voordouw, J. (2017). Sustainability and meat consumption : is reduction realistic ?, 7733. doi:10.1080/15487733.2013.11908115

Daggash, H. A., & MacDowell, N. (2019). Structural Evolution of the UK Electricity System in a below 2°C World. Joule, 3(5), 1239–1251.

Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M., & de Vries, G. (2013). the Construction of World Input–Output Tables in the Wiod Project. *Economic Systems Research*, 25(1), 71–98. doi:10.1080/09535314.2012.761180

Dmitriev, A., & Mitroshkina, T. (2019). Improving the Efficiency of Aviation Products Design Based on International Standards and Robust Approaches. *IOP Conference Series: Materials Science and Engineering*, 476(1). doi:10.1088/1757-899X/476/1/012009

Druckman, A., & Jackson, T. (2009). The carbon footprint of UK households 1990–2004: A socio-economically disaggregated, quasi-multi-regional input–output model. Ecological Economics, 68(7), 2066–2077. doi:10.1016/j.ecolecon.2009.01.013

Edens, B., Hoekstra, R., Zult, D., Lemmers, O., Wilting, H. C., & Wu, R. (2015). Economic Systems Research A METHOD TO CREATE CARBON FOOTPRINT ESTIMATES CONSISTENT, (August). doi:10.1080/09535314.2015.1048428

Ekins, P., Jah, G. A., Strachan, N., Ekins, P., Anandarajah, G., & Strachan, N. (2011). Towards a low-carbon economy : scenarios and policies for the UK Towards a low-carbon economy : scenarios and policies for the UK, 3062. doi:10.3763/cpol.2010.0126

Gerber, J. F., Veuthey, S., & Martínez-Alier, J. (2009). Linking political ecology with ecological economics in tree plantation conflicts in Cameroon and Ecuador. *Ecological Economics*, 68(12), 2885–2889. doi:10.1016/j.ecolecon.2009.06.029

Giesekam, J. (2018). Reducing carbon in construction : a whole life approach. CIEMAP.

Giesekam, J., Barrett, J., Taylor, P., & Owen, A. (2014). The greenhouse gas emissions and mitigation options for materials used in UK construction. *Energy and Buildings*, 78, 202–214. doi:10.1016/j.enbuild.2014.04.035

Giesekam, J., Densley, D., & Cotton, I. (2018). Energy & Buildings Aligning carbon targets for construction with (inter) national climate change mitigation commitments, 165, 106–117.

Grankvist, G., Dahlstrand, U., & Biel, A. (2004). The Impact of Environmental Labelling on Consumer Preference : Negative vs . Positive Labels. *Journal of Consumer Policy*, 27, 213–230.

Hertwich, E., & Peters, G. (2009). Carbon footprint of nations: A global, trade-linked analysis. *Environmental Science & Technology*, 43(16), 6414–6420. doi:10.1021/es803496a

Hickman, R., & Banister, D. (2007). Looking over the horizon: Transport and reduced CO_2 emissions in the UK by 2030. *Transport Policy*, 14(5), 377–387. doi:10.1016/j.tranpol.2007.04.005

Jones, R. V., & Lomas, K. J. (2016). Determinants of high electrical energy demand in UK homes: Appliance ownership and use. *Energy and Buildings*, 117, 71–82. doi:10.1016/j.enbuild.2016.02.020

Kivits, R., Charles, M. B., & Ryan, N. (2010). A post-carbon aviation future: Airports and the transition to a cleaner aviation sector. *Futures*. doi:10.1016/j.futures.2009.11.005

Le Quéré, C., Korsbakken, J. I., Wilson, C., Tosun, J., Andrew, R., Andres, R. J., … van Vuuren, D. P. (2019). Drivers of declining CO 2 emissions in 18 developed economies. *Nature Climate Change*, 9(3), 213–217. doi:10.1038/s41558-019-0419-7

Lenzen, M., Moran, D., Kanemoto, K., & Geschke, A. (2013). Building Eora: a Global Multi-Region Input–Output Database At High Country and Sector Resolution. *Economic Systems Research*, 25(1), 20–49. doi:10.1080/09535314.2013.769938

Mills, E. (2017). Global Kerosene Subsidies: An Obstacle to Energy Efficiency and Development. *World Development*. doi:10.1016/j.worlddev.2017.05.036

Moran, D., & Wood, R. (2014). CONVERGENCE BETWEEN THE EORA, WIOD, EXIOBASE, AND OPENEU'S CONSUMPTION-BASED CARBON ACCOUNTS CONVERGENCE BETWEEN THE EORA, WIOD, EXIOBASE, AND OPENEU'S CONSUMPTION-BASED CARBON ACCOUNTS. *Economic Systems Research*, 26(3), 245–261. doi:10.1080/09535314.2014.935298

Nordgren, A. (2012). Ethical Issues in Mitigation of Climate Change : The Option of Reduced Meat Production and Consumption. *Journal of Agricultural Environmental Ethics*, 25, 563–584. doi:10.1007/s10806-011-9335-1

ONS. (2014). Supply and Use Tables. Retrieved from http://www.ons.gov.uk/ons/taxonomy/index.html?nscl=Supply+and+Use+Tables

Peak, L. (2018). Less in more out.

Peters, G. P., Andrew, R., & Lennox, J. (2011). Constructing an Environmentally-Extended Multi-Regional Input–Output Table Using the Gtap Database. *Economic Systems Research*, 23(2), 131–152. doi:10.1080/09535314.2011.563234

Peters, G. P., Andrew, R. M., Canadell, J. G., Fuss, S., Jackson, R. B., Korsbakken, J. I., … Nakicenovic, N. (2017). Key indicators to track current progress and future ambition of the Paris Agreement. *Nature Climate Change*, 7(2), 118–122. doi:10.1038/nclimate3202

Peters, G. P., Le Quéré, C., Andrew, R. M., Canadell, J. G., Friedlingstein, P., Ilyina, T., … Tans, P. (2017). Towards real-time verification of CO_2 emissions. *Nature Climate Change*, 7(12), 848–850. doi:10.1038/s41558-017-0013-9

Pollitt, H., Neuhoff, K., & Lin, X. (2019). The impact of implementing a consumption charge on carbon-intensive materials in Europe. *Climate Policy*, 0(0), 1–16. doi:10.1080/14693062.2019.1605969

Poore, J., & Nemecek, T. (2018). Reducing food ' s environmental impacts through producers and consumers, 992(June), 987–992.

Pye, S. (2015). Deep Decarbonization PathwaysPathways to deep decarbonization in the United Kingdom, SDSN - IDDRI. Retrieved from http://unsdsn.org/what-we-do/deep-decarbonization-pathways/

Reynolds, C., Goucher, L., Quested, T., Bromley, S., Gillick, S., Wells, V. K., … Jackson, P. (2019). Review: Consumption-stage food waste reduction interventions – What works and how to design better interventions. *Food Policy*, 83(April 2018), 7–27. doi:10.1016/j.foodpol.2019.01.009

Roelich, K., & Giesekam, J. (2019). Decision making under uncertainty in climate change mitigation : introducing multiple actor motivations , agency and influence introducing multiple actor motivations , agency and in fl uence. *Climate Policy*, 19(2), 175–188. doi:10.1080/14693062.2018.1479238

Sakai, M., & Barrett, J. (2016). Border carbon adjustments : Addressing emissions embodied in trade, 92, 102–110.

Schanes, K., Giljum, S., & Hertwich, E. (2016). Low carbon lifestyles: A framework to structure consumption strategies and options to reduce carbon footprints. *Journal of Cleaner Production*, 139, 1033–1043. doi:10.1016/j.jclepro.2016.08.154

Scott, K., Giesekam, J., Barrett, J., & Owen, A. (2018). Bridging the climate mitigation gap with economy-wide material productivity, 1–14. doi:10.1111/jiec.12831

Scott, K., Roelich, K., Owen, A., & Barrett, J. (2017). Extending European energy efficiency standards to include material use: an analysis. *Climate Policy*. doi:10.1080/14693062.2017.1333949

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., … Tukker, A. (2018). EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. *Journal of Industrial Ecology*, 22(3), 502–515. doi:10.1111/jiec.12715

Stamford, L., & Azapagic, A. (2014). Energy for Sustainable Development Life cycle sustainability assessment of UK electricity scenarios to 2070. Energy for Sustainable Development, 23, 194–211. doi:10.1016/j.esd.2014.09.008

Steen-Olsen, K., Weinzettel, J., Cranston, G., Ercin, a E., & Hertwich, E. G. (2012). Carbon, Land, and Water Footprint accounts for the European Union: Consumption, production, and displacements through international trade. *Environmental Science & Technology*, 46(20), 10883–10891. doi:10.1021/es301949t

Steininger, K. W., Lininger, C., Meyer, L. H., Munõz, P., & Schinko, T. (2016). Multiple carbon accounting to support just and effective climate policies. *Nature Climate Change*, 6(1), 35–41. doi:10.1038/nclimate2867

The Green Construction Board. (2013). Low carbon routemap for the UK built environment.

Tukker, A., Bulavskaya, T., Giljum, S., Koning, A. De, Lutter, S., Simas, M., … Wood, R. (2014). *The global resource footprint of nations: Carbon, water, land and materials embodied in trade and final consumption*.

Tukker, A., de Koning, A., Owen, A., Lutter, S., Bruckner, M., Giljum, S., … Hoekstra, R. (2018). Towards Robust, Authoritative Assessments of Environmental Impacts Embodied in Trade: Current State and Recommendations. *Journal of Industrial Ecology*. doi:10.1111/jiec.12716

Tukker, A., de Koning, A., Wood, R., Hawkins, T. R., Lutter, S., Acosta-Fernández, J., … Kuenen, J. (2013). Exiopol – Development and Illustrative Analyses of a Detailed Global MR EE SUT/IOT. *Economic Systems Research*, 25(1), 50–70. doi:10.1080/09535314.2012.761952

Webb, J., Williams, A. G., Hope, E., Evans, D., & Moorhouse, E. (2013). Do foods imported into the UK have a greater environmental impact than the same foods produced within the UK? *International Journal of Life Cycle Assessment*, 18(7), 1325–1343. doi:10.1007/s11367-013-0576-2

Wiedmann, T. (2009). A review of recent multi-region input–output models used for consumption-based emission and resource accounting. *Ecological Economics*, 69(2), 211–222. doi:10.1016/j.ecolecon.2009.08.026

Wiedmann, T., & Lenzen, M. (2018). Environmental and social footprints of international trade. *Nature Geoscience*, 11(5), 314–321. doi:10.1038/s41561-018-0113-9

Wiedmann, T., Wood, R., Minx, J., Lenzen, M., Guan, D., & Harris, R. (2010). A Carbon Footprint Time Series of the UK – Results From a Multi-Region Input–Output Model. *Economic Systems Research*, 22(1), 19–42. doi:10.1080/09535311003612591

Williams, V., & Noland, R. B. (2006). Comparing the CO_2 emissions and contrail formation from short and long haul air traffic routes from London Heathrow. *Environmental Science and Policy*, 9(5), 487–495. doi:10.1016/j.envsci.2005.10.004

Wood, R., Moran, D., Stadler, K., Ivanova, D., Tisserant, A., & Hertwich, E. G. (2017). Prioritizing Consumption-Based Carbon Policy Based on the Evaluation of Mitigation Potential Using Input-Output Methods, 22(3). doi:10.1111/jiec.12702

Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., Koning, A. De, … Tukker, A. (2015). Global Sustainability Accounting—Developing EXIOBASE for Multi-Regional Footprint Analysis. Sustainability, 7, 138–163. doi:10.3390/su7010138

Wood, R., Stadler, K., Simas, M., Bulavskaya, T., Giljum, S., Lutter, S., & Tukker, A. (2018). Growth in Environmental Footprints and Environmental Impacts Embodied in Trade: Resource Efficiency Indicators from EXIOBASE3. *Journal of Industrial Ecology*, 22(3), 553–564. doi:doi:10.1111/jiec.12735

Yamano, N., & Webb, C. (2018). Future Development of the Inter-Country Input-Output (ICIO) Database for Global Value Chain (GVC) and Environmental Analyses. *Journal of Industrial Ecology*. doi:10.1111/jiec.12758

5 APPENDIX I: MULTIREGIONAL INPUT-OUTPUT DATABASES: DATA AND CONSTRUCTION

5.1 DATA REQUIREMENTS

A UK carbon footprint model needs to be able to measure the impact of UK consumption of products considering domestic and foreign supply chains involved in production. This means the MRIO table needs to have information about flows of products from abroad to both UK intermediate and final demand. Production efficiencies vary between different producers meaning that the impact per pound spent may be larger for a product from country A than from country B.

The most accurate representation of the UK consumption-based account would need to measure the flow of products from every country and understand the emissions intensities associated with each industry in every country. However, when we consider how the model may be used and practicalities such as model size, data storage capacity and model run times, aggregating trade partner countries is preferable. The UMRIO databased used for the Defra figures contains four regions: the UK, the rest of the EU, China and the rest of the world.

For the WWF-UKMRIO database it was decided to disaggregate the trade regions further. The database contains 16 regions: the UK, Brazil, Russia, India, China, South Africa, the USA, Japan, the rest of the EU, the rest of Europe, the rest of the OECD, the rest of Africa, the rest of Americas, the rest of Asia and Oceania and the Middle East.

5.1.1 UK DATA

UK Supply and Use tables (SUTs) are currently available from the Office of National Statistics (ONS) at the 106 sector level for the years 1997-2016 and the 123 sector level for the years 1992-1996.. The ONS also disaggregates UK production emissions to sectors in the economy and reports on these emissions as Environmental accounts. Since the revision of the national Environmental Accounts in 2011, emissions data map to this 106 sector classification system. All SUT tables follow the structure shown in Figure 13.

	INDUSTRIES	PRODUCTS			
industries		industry by product supply table			Sum of industrial output
products	Combined use table measured in purchaser's prices. Sum of domestic intermediate use, imports to UK intermediate demand and margins and taxes and products		Combined final demand for products (UK and foreign) by hholds, NPISH, national & local government, gross fixed capital valuables, changes in inventories	Exports of UK products	
	Value added – wages and tax on production				
	Sum of industrial output	Sum of products			

Figure 13: *The UK supply and use table structure*

Analytical tables (see Figure 14) are available for 1990, 1995, 2005, 2010, 2013-2015. Analytical tables split the combined use table into a domestic use matrix and rows for imports, product tax and further value-added components. The 1990-2005 tables are at the older 123 sector classification. A mapping showing how to convert from 123 sectors to 110 sectors is given in Annex b of the Blue Book 2011. This data has been used to make a 106 by 123 weighted concordance matrix and all tables at 123 sectors are converted to 106 using this.

Domestic use table in basic prices (106x106 or 123x123)
Imports row (1x106 or 1x123)
Product tax row (1x106 or 1x123)
Value added – wages and tax on production
Total output in purchasers prices

Figure 14: *UK Analytical table structure*

5.1.2 MRIO TABLE STRUCTURE

The ideal table structure requires an MRIO table with all other nations' data at the 106 sector level. Each table in the MRIO database will be structured as show in Figure 15. Blank cells are zero.

		UK supply table at 106 sectors			
			Other nations' supply tables at 106 sectors		
UK domestic use table at 106 sectors	Other nations' intermediate demand of UK products			UK final demand of UK products	Other nations' final demand of UK products
UK intermediate demand of other nations' products	Other nations' domestic use table at 106 sectors			UK final demand of other nations' products	Other nations' final demand of other nations' products
UK value added	Other nations' value added				

Figure 15: *Table structure for the the UKMRIO database*

5.1.3 OTHER NATIONS' DATA AVAILABLE FROM EXIOBASE V3.3

EXIOBASE v3.3, produced by the NTNU, TNO, SERI, Universiteit Leiden, WU and 2.-0 LCA Consultants (Tukker et al., 2013; Wood et al., 2015), is an MRIO database encompassing data for 49 regions for the years 1995-2016. The database is available in a Supply and Use Table structure with a homogenous sectoral classification comprising 163 industries and 200 products. We use data from 48 (all but the UK) regions of the EXIOBASE database to help populate the sections of our MRIO model that show:

- **Exports from the UK to other nations' intermediate demand**
- **Exports from the UK to other nations' final demand**
- **Imports to UK intermediate demand from other nations**
- **Imports to UK final demand from other nations**
- **Trade between other nations' intermediate demand**
- **Final demand of other nations from other nations**

Before the data can be used in the UK MRIO, it needs to be manipulated to the correct structure. We transform EXIOBASE so that the number of sectors is 106 and the regions are Brazil, Russia, India, China, South Africa, the USA, Japan, the rest of the EU, the rest of Europe, the rest of the OECD, the rest of Africa, the rest of Americas, the rest of Asia and Oceania and the Middle East (see Table 13). In addition, the data must be transformed from Euros to GBP.

Table 13: EXIOBASE regions aggregated to UKMRIO regions

WWF-UKMRIO DATABASE REGION	REGIONS FROM EXIOBASE
UK	UK
Brazil	Brazil
Russia	Russia
India	India
China	China
South Africa	South Africa
USA	USA
Japan	Japan
Rest of the European Union	Austria Belgium Bulgaria Croatia Cyprus Czech Republic Germany Denmark Estonia Spain Finland France Greece Hungary Ireland Italy Latvia Luxembourg Lithuania Malta Netherlands Poland Portugal Romania Sweden Slovakia Slovenia
Rest of Europe	Switzerland Norway Rest of Europe
Rest of the OECD (Non-Europe)	Canada Korea Mexico Australia Turkey
Rest of Africa	Rest of Africa
Rest of the Americas	Rest of the Americas
Rest of Asia and Oceania	Taiwan Indonesia Rest of Asia and Oceania
Rest of the Middle East	Rest of the Middle East

5.2 MODELLING AND DATA ISSUES AND SOLUTIONS

There are a number of steps and data manipulations that have to be made to construct the UKMRIO database. This section aims to describe the nature of any data or modelling issue, how a solution was developed and applied and discuss any assumptions or uncertainties that arise due to the steps taken.

5.2.1 NEGATIVE NUMBERS, ZEROS AND BLANKS IN THE UK DATA

Before using any of the data tables, any negative numbers are removed and replaced with 1x10-9. This is because some of the balancing techniques applied later do not work with negative values. Many of the data manipulations required to format the data into the correct structure involve a division. Division by zero is not possible, so any zeros or blanks are also replaced with 1x10-9.

5.2.2 MAKING A DOMESTIC USE TABLE, AN IMPORTS ROW AND A PRODUCT TAX ROW FROM THE COMBINED USE TABLE

The ONS supplied combined use tables for 1990-2016 need to be split into a domestic use matrix and a single row vector of imports to UK intermediate demand. This row vector shows the sum of all foreign imports to each UK industry but does not give the detail of regional and sectoral origin. Later, this row vector will be disaggregated using information from the EXIOBASE database.

Figure 15 below shows in diagram form how the combined use table is broken down first into a domestic use table, a UK imports row vector and a UK tax on products vector. The imports row vector is used to form three further 106 by 106 matrices (UK intermediate demand of UK, UK intermediate demand of China and UK intermediate demand of RoW) and the row vector of UK tax on products is eventually added to the value added row.

In order to split each of the combined use tables from 1990-2015 into a domestic use table, UK imports row vector and a UK tax on products row vector the analytical tables from 1990, 1995, 2005, 2010 and 2013 are used.

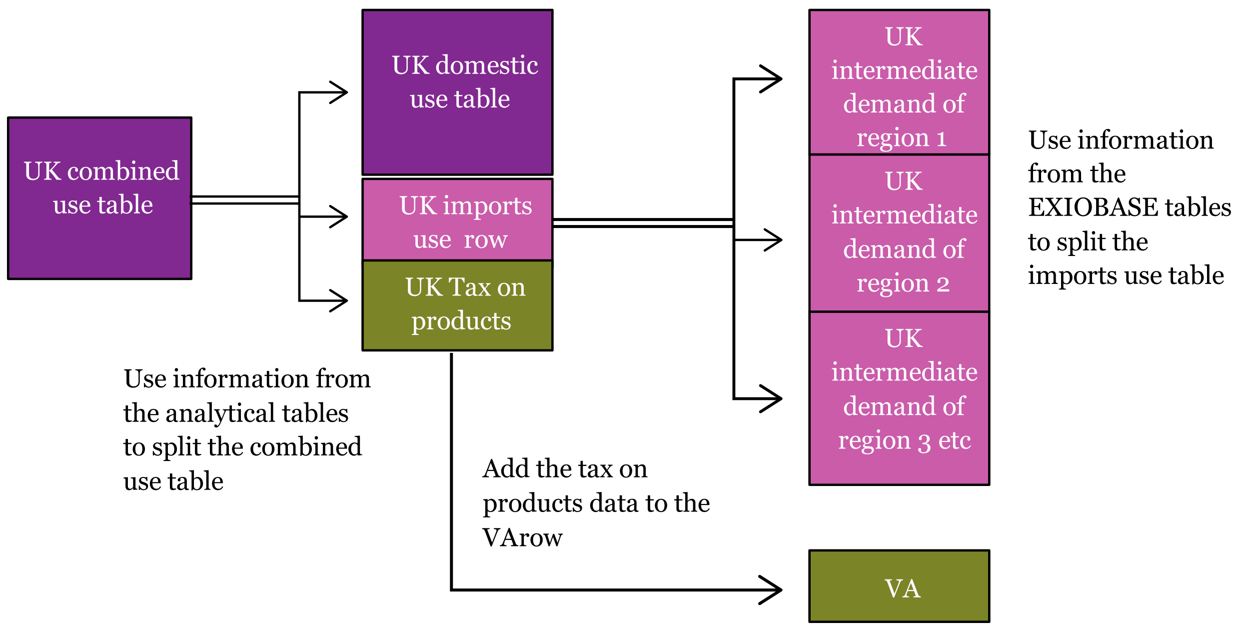


Figure 16: *Splitting the combined use table into its component parts*

5.2.3 PROPORTIONING THE COMBINED USE TABLE

Analytical tables (AT), which indicate the proportion of product to industry flow that is satisfied by domestic production are available for the years 1990, 1995, 2005, 2010, 2013-2015. Using these tables we can calculate the proportion of all intermediate flows to UK industry that are domestic (by industry), imported (by total) and the tax on products.

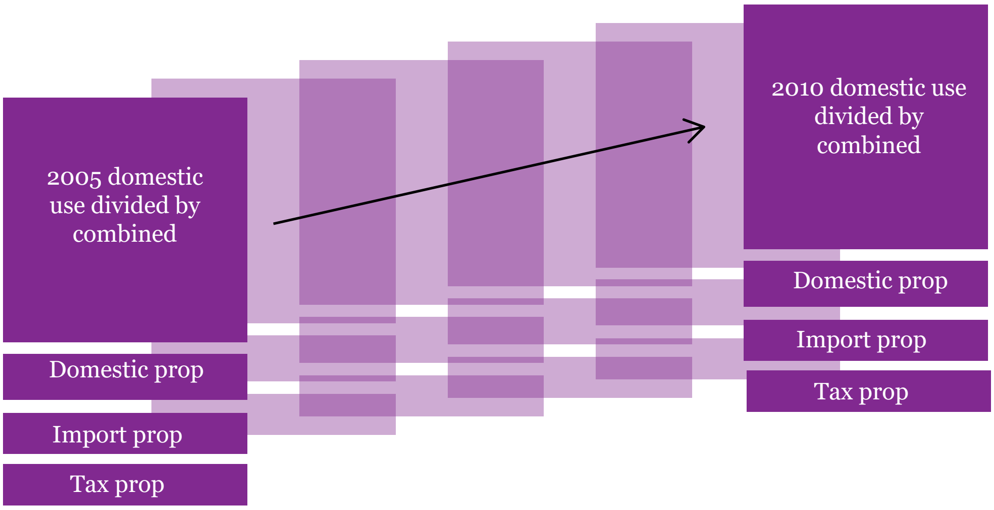


***Figure 17**: Constructing proportioning matrices*

We construct a proportioning matrix for each of the years 1990 to 2016. For 2016 we use the 2015 matrix. For the ears between 1990 and 1995; 1995 and 2005; 2005 and 2010; and 2010 and 2013, we make linearly interpolated matrices bridging the known matrices as shown in Figure 16. Due to lack of data we are making assumptions about the exact proportions of products supplied to intermediate demand from domestic industry for the years 1991-1994, 1996-2004, 2006-2009 and 2011-2012.

To ensure that the sum of the domestic, imports and tax proportions is equal to 100%, these rows are re-proportioned again in estimated matrices.

5.2.4 RECONCILING THE EXIOBASE DATA TO THE UK MRIOT STRUCTURE

Now that we have data on the total imports to UK intermediate demand, we need to disaggregate this row by industrial sectors from Brazil, Russia, India, China, South Africa, the USA, Japan, the rest of the EU, the rest of Europe, the rest of the OECD, the rest of Africa, the rest of Americas, the rest of Asia and Oceania and the Middle East to show the source of imports. This data is taken from EXIOBASE but as discussed above, EXIOBASE needs to be transformed to the UKMRIOT structure. We transform the whole of the EXIOBASE MRIOT because we will be using sections elsewhere.

- First, we transform the 163 industries and 200 products to 106 sectors. This can mean aggregating some sectors together and also splitting some sectors into two or more parts. We use the UK's industrial output breakdown as weights to disaggregate other region's Use table columns and the UK's product output breakdown to disaggregate other region's Supply table columns. Using the UK data as weights for disaggregation is an assumption. Final Demand, value added and environmental extension data are similarly aggregated and disaggregated
- Secondly we aggregate the regions to form the 16 traded regions used in the WWF-UKMRIO.
- Finally, the data is converted to GBP from Euros using currency conversion factors from the appropriate year. We use a 12 month average conversion rate

Some of the EXIOBASE data, such as the portion representing trade between non UK regions, is slotted straight into the UK model. Other data, such as the imports to UK intermediate demand and the Exports from UK intermediate demand are used as proportions to help disaggregated information that we already know from the ONS UK tables.

5.2.5 IMPORTS TO UK INTERMEDIATE DEMAND

The first data requirement is a matrix showing the proportion of each intermediate flow to UK industry that is from Brazil, Russia, India, China, South Africa, the USA, Japan, the rest of the EU, the rest of Europe, the rest of the OECD, the rest of Africa, the rest of Americas, the rest of Asia and Oceania and the Middle East products. This is a 15x106 by 106 rectangular matrix with column sum equal to one. The 318 rows are flows from foreign sectors. Because this is a matrix of proportions, we need not convert the matrix to GBP from Euros, and currency exchange rate issues are avoided.

The 'imports from' row (calculated from the UK Combined Use tables) is then multiplied down this proportional matrix to give the full intermediate flows to UK industry table.

5.2.6 EXPORTS FROM UK TO INTERMEDIATE DEMAND

The next use of the EXIOBASE data set is to fill in the rows showing where UK products are intermediate demands to Brazil, Russia, India, China, South Africa, the USA, Japan, the rest of the EU, the rest of Europe, the rest of the OECD, the rest of Africa, the rest of Americas, the rest of Asia and Oceania and the Middle East industry and final demand. EXIOBASE is used to make a proportional matrix of the use of UK products in RoW intermediate and final demand. As described above, the trade block data from the full Eora model is used and manipulated to make 15 matrices of 106x106. However, at this stage we do not use the 'exports from' column from the UK combined use tables as the exports total. Instead we know that the sum of the 'exports from' is equal to the sum of the imports to UK intermediate demand plus the different in the UK's value added and the final demand for UK products from both domestic and foreign consumers. This total is multiplied by the proportional matrix where the total of the whole matrix is one (rather than the total of the rows or the total of the columns).

Final demand from the UK tables includes the final demand of imported goods so we need to use the analytical tables again to make a domestic proportion table. Final demand of UK products by the RoW is taken from the UK trade blocks of the **full EXIOBASE** database and multiplied by an exchange rate currency conversion factor to get the data in the right unit[16].

5.2.7 TRADE BETWEEN THE REST OF WORLD REGIONS AND BALANCING THE WHOLE TABLE

We use the **106 sector manipulated version of the EXIOBASE model** to provide:

- foreign domestic use tables
- foreign supply tables
- Trade between each of the 15 regions
- foreign value added
- Final demand of foreign products by the total rest of world (all but UK) and the UK

Each of these tables are also multiplied the currency exchange rate conversion factor. In addition, the final demands are re-proportioned to ensure that the total final demand is equal to the total value added.

All the data is then combined with the UK SUT and the intermediate demands to and from the UK to form the first estimate of the MRIO table. The table now needs to be balanced to ensure that total imports equal total output – in other words the row and column sums should be the same. The technique known as RAS iteratively re-proportions the table making adjustments to ensure first that the column sums are correct then the column. The process is repeated until a desired level of accuracy is acquired.

16 Clearly this introduces some uncertainty into the model because we use the same conversion factor for each region and sector, when in reality it is likely that the conversion factors should be sector and country specific

To determine the true row and column sum vectors we use the fact that there are certain row and column totals that are set because the sum of the supply tables are fixed. Figure x below explains how the row and column sums are determined.

		UK supply table				A
			supply table			B
UK dom use table	int dem from UK			UK FD of UK	All RoW FD of UK	C’
UK int dem from	use dom table			UK FD of	All RoW FD of EU	D’
UK VA	VA					
A	B’	C	D			

Figure 18: *Pre-balanced MRIO table*

To balance the table, we know that:

- A’ = A (the row sum of the UK supply table)
- B’ = B (the row sum of the RoW supply table)
- C’ = C (the column sum of the UK supply table)
- D’ = D (the row sum of the RoW supply table)

The RAS balancing procedure is then used to re-proportion this section to ensure that the MRIO table balances

6 APPENDIX II: ACCURACY, UNCERTAINTY AND COMPARISONS WITH OTHER DATABASES

6.1 THE EVOLUTION OF THE UK CARBON FOOTPRINT DATASET

Calculating consumption-based emissions accounts, which accurately cover emissions embodied in imports, has only been possible in the last decade and the datasets and techniques are continually improving. Figure 18 shows the evolution of the UK's carbon footprint as calculated by the UKMRIO database. In the last three years the results are very similar implying that we are approaching a stable methodology for footprint calculation. The overall pattern is also very similar throughout the model versions.

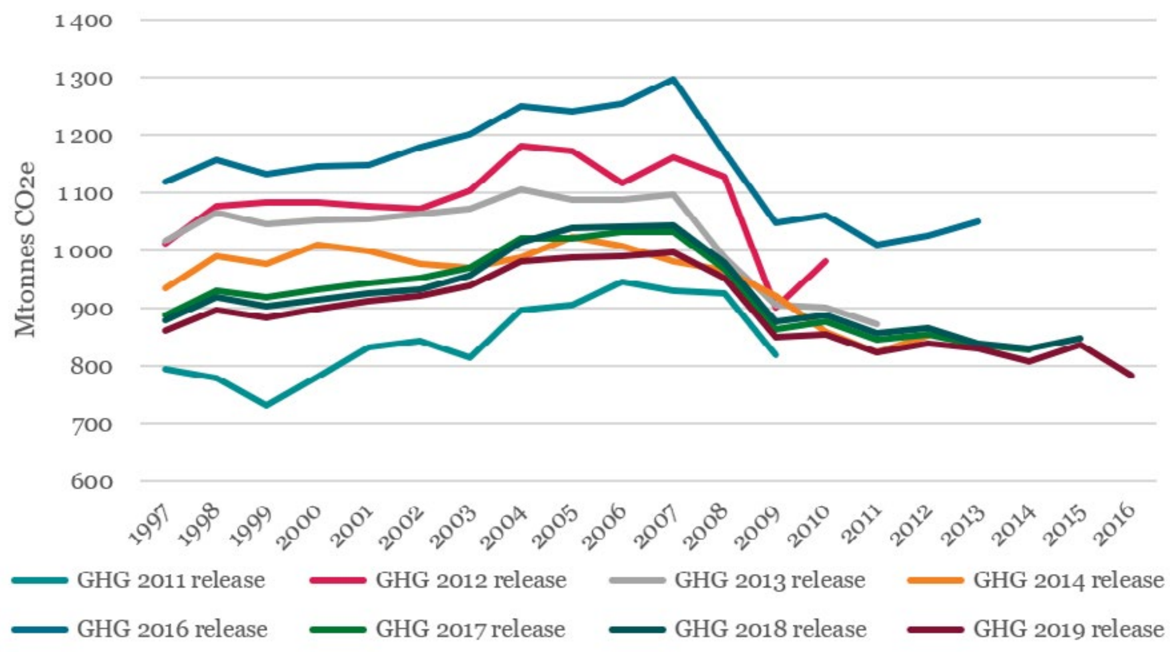


Figure 19: *UK MRIO carbon footprint results from 2011 release to 2019 release*

6.2 UNCERTAINTIES INVOLVED IN EXTENDING THE DATABASE BACK TO 1990

The UK carbon footprint results start in 1997 because this is the earliest year that there exists a consistent set of national account data for the UK. For this project we use data from the National Archives to extend the dataset back to 1990. This involves using data that is not consistent with the UKMRIO database used to provide the carbon footprint for UK government. Sometimes the data uses a different classification system for the sectors and has to be transformed to the 106 sectors used in the national accounts. In other cases, data does not exist for a particular year and assumptions have to be made using proxy data – for example using data from a different year and adjusting the totals to match known changes in GDP.

Figure 20 uses a traffic light system to indicate the reliability of the source data used in the MRIO database construction. The most accurate footprint estimates will be for the years 2010 and 2013-2015. For the newly estimated years, 1995-1996 are reasonable estimates of the footprint. 1992-1994 do not have accurate information on the character of trade into the UK. 1990-1991 are the least accurate estimates and use previous years tables as a large part of the model construction.

<table>
<tr><th></th><th>UK EMISSIONS DATA</th><th>OTHER NATION'S EMISSIONS DATA</th><th>UK ANALYTICAL TABLES - USED TO CONSTRUCT IMPORTS RATIOS</th><th>UK SUPPLY, USE AND FINAL DEMAND TABLES</th><th>EXIOBASE MRIO DATA - PROVIDES TRADE STRUCTURE TO & FROM UK & OTHER NATIONS SUPPLY, USE & FD</th></tr>
<tr><td>1990</td><td rowspan="12">UK emissions data is reported from 1990-2016 by sectors that map directly to the 106 UK sectors</td><td rowspan="3">Take 1995 data and multiply by year-on-year global emissions change</td><td>Convert 1990 from 123 sectors to 106</td><td rowspan="2">Use 1992 data and multiply by year-on-year UK GDP change</td><td rowspan="3">Take 1995 data and multiply by year-on-year global GDP change</td></tr>
<tr><td>1991</td><td rowspan="2">Linear interpolation of trade from 1990-1995</td></tr>
<tr><td>1992-1994</td><td rowspan="3">UK supply column reported for 1992-1996 at 123 sectors. Use 1997 structure and convert to 106 sectors. Use tables and final demand tables at 123 sectors, convert to 106</td></tr>
<tr><td>1995</td><td rowspan="9">Taken from EXIOBASE, converted from 163 to 106 sectors</td><td>Convert 1995 from 123 sectors to 106</td><td rowspan="9">Taken from EXIOBASE, converted from 163 to 106 sectors</td></tr>
<tr><td>1996</td><td rowspan="2">Linear interpolation of trade from 1995-2005</td></tr>
<tr><td>1997-2004</td><td rowspan="7">UK supply, use and final demand tables reported at 106 sectors for 1997-2016</td></tr>
<tr><td>2005</td><td>Convert 2005 from 123 sectors to 106</td></tr>
<tr><td>2006-2009</td><td>Linear interpolation of trade from 2005-2010</td></tr>
<tr><td>2010</td><td>Table for 2010 in 106 sectors</td></tr>
<tr><td>2011-2012</td><td>Linear interpolation of trade from 2010-2013</td></tr>
<tr><td>2013-2015</td><td>Tables for 2013-2015 in 106 sectors</td></tr>
<tr><td>2016</td><td>Use 2015 table</td></tr>
</table>

Figure 20: *Accuracy of source data used in constructing the UK MRIO database*

6.3 COMPARING UK RESULTS WITH OTHER MRIO DATABASES

Prior macro-level analyses of the UK carbon footprint are available using various global MRIO databases. Examples include (Barrett et al., 2013; Hertwich & Peters, 2009; Moran & Wood, 2014; Steen-Olsen et al., 2012; Tukker et al., 2014; Wood et al., 2018). Other studies have employed other UK-MRIO models, e.g. (Druckman & Jackson, 2009; Wiedmann et al., 2010). Figure 21 summarises the UK carbon footprint data provided by the most used global MRIO databases communicated in the reviewed studies. Please note that the data is carbon dioxide only to allow for comparison with models where the additional greenhouse gas data is unavailable. The WWF-UKMRIO model (shown in red) sits in the middle of the results from 1993-2014 and estimates slightly higher for the earlier and later years in the time frame. It must be noted that there are fewer models available for comparison at the extreme ends of the time frame.

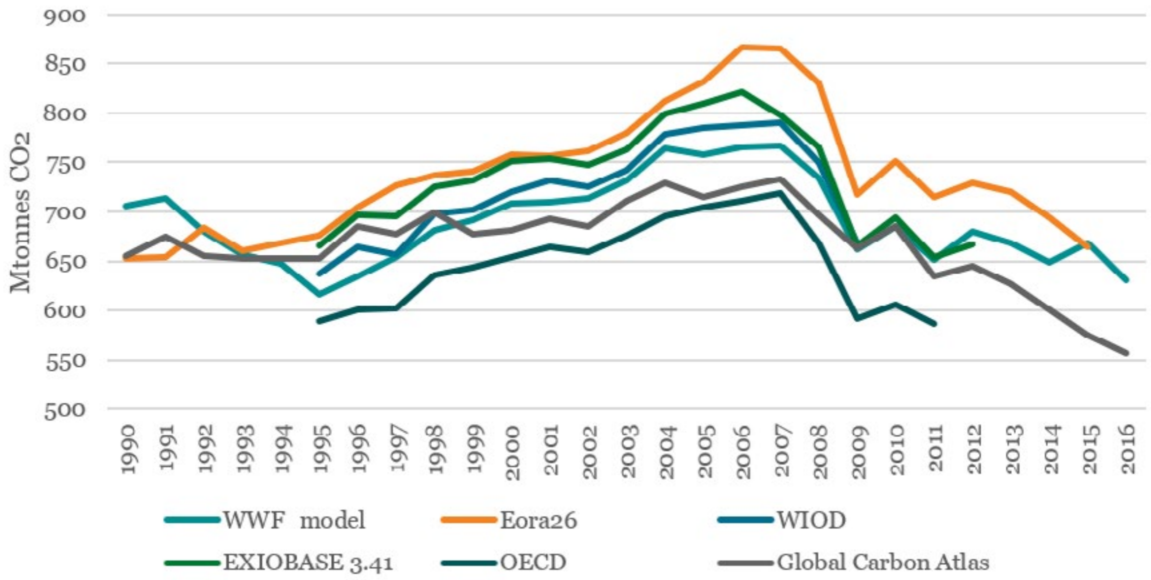
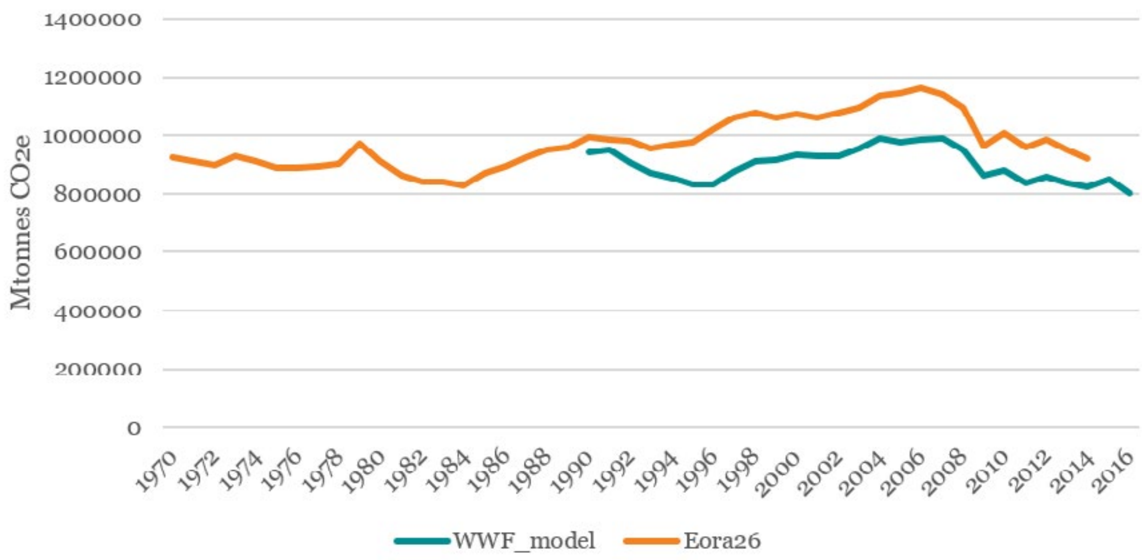


Figure 21: *UK carbon footprint calculated by the WWF-UKMRIO database and the five other global MRIO databases*

7 APPENDIX III: A NOTE ON EXTENDING BACK TO 1970

For this project we were able to extend the UKMRIO database back to 1990 using data that is close to being consistent with the data used to calculate the official UK carbon footprint. We also explored the potential for extending the footprint further back in time to 1970. One of the other global MRIO databases (Eora26) has generated tables for the time series 1970-2015. The philosophy behind Eora's construction is to work from a single base year table and update elements of the table when new data is found. Eora's base year is 2000. To generate the table for the year 2001, new data such as production structures, value added data by industry and country and final demand volume and structure are found. This new data acts as a constraint to a new table and the 2000 table gets updated to satisfy these constraints. The more data that is found, the more accurate the new table will be. For very early years, very little data is available beyond GDP by country. This means that the carbon footprints are likely to be quite unreliable.

Figure 21 compares the results from the WWF-UKMRIO database with Eora26 for both CO_2 emissions and all GHG emissions. Eora consistently measures the UK's carbon footprint to be higher than other model estimates. The shape of the emissions pattern is similar from 1992 to the end of the time series and the GHG emissions appear to pick up some reduction around 1990-1994. From the Eora26 estimates might be possible to conjecture that emissions prior to 1990 were not as quite as high as those seen in 2004-2007 but we are very wary about using this data because of the inconsistency with other models and the estimates made in the model construction.



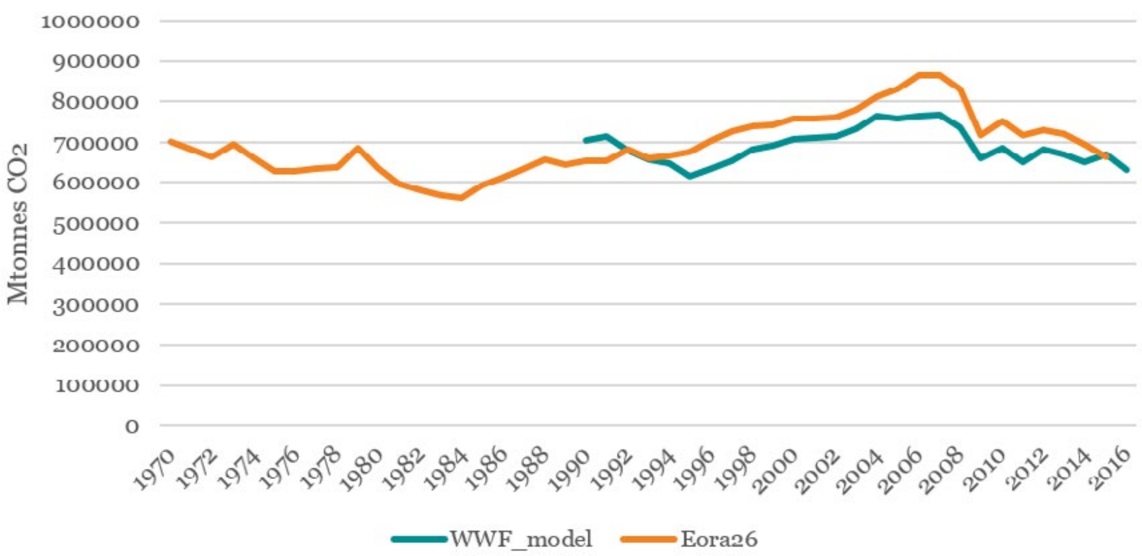


Figure 22: *Comparing Eora 26 with WWF-UKMRIO database for CO_2 emissions (bottom) and all GHG emissions (top)*

8 APPENDIX IV: FURTHER TABLES FROM THE ANALYSIS

		% consumption contribution, 2016	**2016-level compared to 1990-level**	% Production emissions in 2016	**2016-level compared to 1990-level**	Correlation: production and consumption (as final demand) of non-UK origin
1	Products of agriculture, hunting and related services	6.6%	116%	8.4%	86%	-0.63
2	Products of forestry, logging and related services	0.0%	256%	0.0%	207%	0.35
3	Fish and other fishing products; aquaculture products; support services to fishing	0.1%	503%	0.1%	83%	-0.57
4	Coal and lignite	0.2%	40%	0.2%	4%	-0.55
5	Extraction Of Crude Petroleum And Natural Gas & Mining Of Metal Ores	0.5%	167%	3.4%	98%	-0.62
6	Other mining and quarrying products	0.1%	733%	0.2%	46%	-0.80
7	Mining support services	0.0%	309%	0.1%	22%	0.88
8	Preserved meat and meat products	1.6%	87%	0.2%	118%	-0.14
9	Processed and preserved fish, crustaceans, molluscs, fruit and vegetables	0.4%	45%	0.2%	138%	-0.64
10	Vegetable and animal oils and fats	0.0%	30%	0.0%	16%	0.82
11	Dairy products	0.8%	52%	0.2%	74%	0.32
12	Grain mill products, starches and starch products	0.1%	91%	0.1%	117%	0.30
13	Bakery and farinaceous products	0.9%	81%	0.2%	112%	0.55
14	Other food products	1.1%	53%	0.3%	81%	0.65
15	Prepared animal feeds	0.4%	69%	0.1%	71%	0.00
16	Alcoholic beverages	0.2%	21%	0.2%	72%	0.84
17	Soft drinks	0.1%	45%	0.0%	74%	0.58
18	Tobacco products	0.1%	18%	0.0%	40%	0.60
19	Textiles	0.9%	61%	0.2%	55%	0.69
20	Wearing apparel	0.9%	105%	0.1%	54%	-0.66
21	Leather and related products	0.5%	242%	0.0%	27%	-0.85
22	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	0.2%	74%	0.4%	90%	-0.24
23	Paper and paper products	0.2%	57%	0.5%	64%	0.35

24	Printing and recording services	0.3%	89%	0.1%	70%	0.06
25	Coke and refined petroleum products	2.5%	51%	2.7%	74%	0.16
26	Paints, varnishes and similar coatings, printing ink and mastics	0.1%	21%	0.0%	50%	0.49
27	Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	0.6%	50%	0.1%	59%	0.25
28	Other chemical products	0.2%	44%	0.1%	64%	0.69
29	Industrial gases, inorganics and fertilisers (all inorganic chemicals) - 20.11/13/15	0.1%	55%	0.5%	101%	0.33
30	Petrochemicals - 20.14/16/17/60	0.3%	43%	1.1%	14%	0.08
31	Dyestuffs, agro-chemicals - 20.12/20	0.1%	53%	0.2%	62%	0.59
32	Basic pharmaceutical products and pharmaceutical preparations	1.3%	258%	0.1%	69%	0.20
33	Rubber and plastic products	0.3%	30%	0.6%	60%	0.33
34	Cement, lime, plaster and articles of concrete, cement and plaster	0.0%	1%	1.7%	58%	0.51
35	Glass, refractory, clay, other porcelain and ceramic, stone and abrasive products - 23.1-4/7-9	0.5%	96%	0.5%	48%	-0.58
36	Basic iron and steel	0.1%	71%	2.1%	49%	0.54
37	Other basic metals and casting	0.0%	6%	0.2%	14%	0.59
38	Weapons and ammunition	0.1%	382%	0.0%	42%	-0.25
39	Fabricated metal products, excl. machinery and equipment and weapons & ammunition - 25.1-3/25.5-9	0.6%	42%	0.4%	50%	0.26
40	Computer, electronic and optical products	2.1%	71%	0.1%	63%	0.05
41	Electrical equipment	0.4%	50%	0.1%	52%	0.30
42	Machinery and equipment n.e.c.	1.5%	64%	0.3%	52%	0.46
43	Motor vehicles, trailers and semi-trailers	2.1%	60%	0.3%	97%	0.35
44	Ships and boats	0.1%	179%	0.1%	121%	0.27
45	Air and spacecraft and related machinery	0.7%	308%	0.1%	58%	-0.58
46	Other transport equipment - 30.2/4/9	0.1%	121%	0.0%	56%	-0.32
47	Furniture	1.4%	152%	0.1%	28%	-0.81
48	Other manufactured goods	1.3%	118%	0.1%	58%	-0.28
49	Repair and maintenance of ships and boats	0.0%	139%	0.0%	113%	0.08
50	Repair and maintenance of aircraft and spacecraft	0.1%	253%	0.0%	127%	0.45

51	Rest of repair; Installation - 33.11-14/17/19/20	0.0%	0%	0.1%	121%	-0.57
52	Electricity, transmission and distribution	8.0%	51%	17.5%	49%	0.01
53	Gas; distribution of gaseous fuels through mains; steam and air conditioning supply	1.6%	72%	1.1%	51%	0.08
54	Natural water; water treatment and supply services	0.2%	92%	0.1%	202%	0.41
55	Sewerage services; sewage sludge	0.7%	118%	0.7%	84%	-0.20
56	Waste collection, treatment and disposal services; materials recovery services	1.2%	25%	3.1%	29%	0.76
57	Remediation services and other waste management services	0.0%	215%	0.0%	267%	-0.66
58	Construction	6.7%	111%	2.2%	138%	0.73
59	Wholesale and retail trade and repair services of motor vehicles and motorcycles	0.9%	79%	0.4%	104%	0.01
60	Wholesale trade services, except of motor vehicles and motorcycles	0.0%	39%	1.2%	106%	0.20
61	Retail trade services, except of motor vehicles and motorcycles	0.0%	0%	1.4%	231%	0.17
62	Rail transport services	0.6%	106%	0.4%	145%	0.90
63	Land transport services and transport services via pipelines, excluding rail transport	1.5%	112%	3.5%	94%	-0.67
64	Water transport services	2.6%	232%	3.0%	90%	-0.11
65	Air transport services	5.9%	244%	7.1%	202%	0.77
66	Warehousing and support services for transportation	0.1%	299%	0.4%	184%	0.97
67	Postal and courier services	0.0%	89%	0.3%	170%	0.67
68	Accommodation services	0.9%	127%	0.2%	127%	0.19
69	Food and beverage serving services	2.6%	93%	0.4%	123%	0.11
70	Publishing services	0.2%	70%	0.0%	45%	-0.39
71	Motion Picture, Video & TV Programme Production, Sound Recording & Music Publishing Activities & Programming And Broadcasting Activities	0.4%	202%	0.0%	200%	0.86
72	Telecommunications services	0.7%	223%	0.1%	81%	-0.91
73	Computer programming, consultancy and related services	0.5%	398%	0.1%	279%	-0.87
74	Information services	0.0%	41%	0.0%	218%	0.29
75	Financial services, except insurance and pension funding	0.6%	294%	0.0%	93%	-0.24
76	Insurance and reinsurance, except compulsory social security & Pension funding	0.6%	72%	0.0%	893%	0.00

77	Services auxiliary to financial services and insurance services	0.1%	91%	0.0%	995%	0.00
78	Real estate services, excluding on a fee or contract basis and imputed rent	0.4%	2988%	0.1%	131%	0.24
79	Owner-Occupiers' Housing Services	1.0%	97%	0.1%	131%	0.32
80	Real estate services on a fee or contract basis	0.0%	174%	0.0%	92%	-0.82
81	Legal services	0.1%	89%	0.0%	71%	-0.48
82	Accounting, bookkeeping and auditing services; tax consulting services	0.0%	98%	0.0%	100%	0.20
83	Services of head offices; management consulting services	0.0%	50%	0.1%	74%	-0.31
84	Architectural and engineering services; technical testing and analysis services	0.1%	60%	0.1%	111%	-0.06
85	Scientific research and development services	0.8%	2256%	0.0%	53%	-0.73
86	Advertising and market research services	0.0%	30%	0.0%	132%	-0.46
87	Other professional, scientific and technical services	0.0%	178%	0.0%	178%	0.84
88	Veterinary services	0.1%	1315%	0.0%	172%	0.89
89	Rental and leasing services	0.3%	35%	0.2%	135%	-0.77
90	Employment services	0.0%	13%	0.0%	79%	0.54
91	Travel agency, tour operator and other reservation services and related services	0.0%	118%	0.0%	74%	-0.88
92	Security and investigation services	0.0%	74%	0.1%	276%	0.47
93	Services to buildings and landscape	0.0%	28%	0.1%	108%	-0.05
94	Office administrative, office support and other business support services	0.0%	114%	0.1%	226%	0.78
95	Public administration and defence services; compulsory social security services	2.8%	60%	0.9%	42%	0.39
96	Education services	1.2%	74%	0.5%	55%	-0.75
97	Human health services	2.9%	135%	0.7%	115%	-0.23
98	Residential Care & Social Work Activities	1.0%	148%	0.3%	121%	0.14
99	Creative, arts and entertainment services	0.2%	207%	0.0%	86%	-0.84
100	Libraries, archives, museums and other cultural services	0.1%	782%	0.0%	32%	-0.87
101	Gambling and betting services	0.3%	26%	0.0%	47%	0.84
102	Sports services and amusement and recreation services	0.2%	87%	0.2%	76%	-0.65

103	Services furnished by membership organisations	0.2%	88%	0.1%	95%	-0.83
104	Repair services of computers and personal and household goods	0.0%	181%	0.0%	93%	0.50
105	Other personal services	0.3%	91%	0.2%	131%	0.48
106	Services of households as employers of domestic personnel	0.0%	0%	0.0%	93%	-0.35
107	Direct emissions non-travel	9.7%	96%	13.5%	96%	-
108	Direct emissions travel	8.6%	113%	12.0%	113%	-

Table 14: *Product classification in the UKMRIO database, contribution to the consumption and production emissions in 2016, and correlations.*

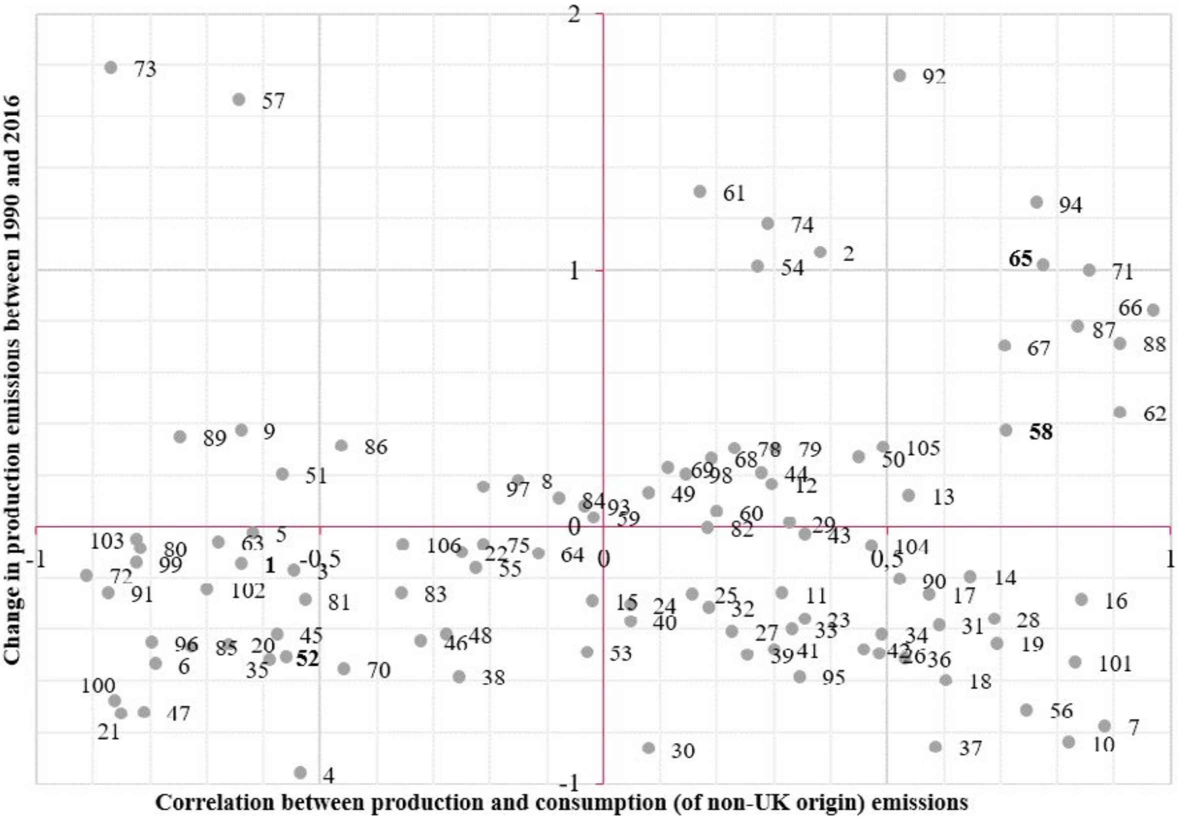


Figure 22: *Change in production emissions by sector (positive values show the % increase in emissions relative to 1990, and negative values – the % decrease in emissions relative to 1990) and correlation between production and consumption emissions of non-UK origin (positive correlations show a common trend in the development of production and consumption emissions, and negative correlations – diverging trends). Figure 11 reflects on some of the products that have been most affected by offshoring between 1990 and 2016 – associated with a decrease in production emissions and an increase in consumption emissions originating abroad. The graph excludes sectors 77 and 76 due to their extreme change in production emissions between 1990 and 2016 (>700%). Both sectors are associated with a positive correlation between production and consumption (outsourced) emissions, meaning that their consumption emissions reduced substantially in the same period as well. Bold values represent the sectors with the highest carbon footprint depicted on Figure 8*

For a future where people and nature thrive | wwf.org.uk