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Is the service industry really low-carbon? Energy, jobs and realistic country GHG emissions reductions

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Abstract
In accounting for carbon emissions, the conventional wisdom is that the service industry is ‘emissions light’, but this is not supported when goods and other inputs to services production are included. We examine greenhouse gas emissions in detail for Australia, Germany, Italy, the UK and USA and find similarities for the service industry. Taking the UK as a case study, we apply the 7see system dynamics modelling approach that accounts for both physical capacity limits and empirical data from economic activity. Service emissions are more than doubled when imported inputs are included in a consumption basis, and that UK emissions would reduce only to 42 million tonnes annually by 2050. Tackling service emissions requires additional efficiency measures for energy-use and goods-use and considering the emission intensities of exporting countries for imports. The four key goods underpinning the UK service industry that are continuing to grow are electronic, pharmaceutical, materials and machinery. Energy policy can only deliver net-zero emissions by treating the service industry as a single unified entity, especially important because it provides the majority of employment.

Keywords:; Employment; Greenhouse gas emissions; Input-output analysis. Low-carbon transition; Onshoring emissions; Sustainable consumption.

Abbreviations

agri	agriculture
cnstr	construction
con	final consumption by households
dwlg	dwellings
frgt	freight transport
gas	natural gas
manu	manufacturing
pass	passenger transport
pet_prod	petroleum products
serv	service industry
trans	transport
util	utilities

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Acronyms

CCC	Committee on Climate Change
CCS	carbon capture and storage/sequestration
CF	capital formation
GDP	gross domestic product
GFCF	gross fixed capital formation
GHG	greenhouse gases
GVA	gross value added
IEA	International Energy Agency
LPG	liquefied petroleum gas
MRIO	multi-region input-output
NDC	Nationally Declared Contributions
NIS	National Inventory Submissions
NZE	net-zero emissions
WAM	with additional measures
WEM	with existing measures

Nomenclature

b	proportion of output for intermediate consumption
c	capital formation requirement of the service industry
CF	sum of final expenditure to all capital formation
CF_use	capital formation used by an industry or dwellings
DP(*t*)	domestic proportion of goods
EI, EI(*t*)	emission intensity
ER(*t*)	electricity requirement intensity
f	industry output going to final expenditure destinations
FP(*t*)	fuel proportion of heat
G	emissions
GD	time-series data sourced from national governments
Ga to *Ge*	emissions at steps along reassignment
GR*(t)*	goods-in ratio to service output
h	proportion of final supply for final expenditure destination
HR(*t*)	heat requirement intensity
IEA	time-series energy balance data sourced from the IEA
IG	imported goods
IP(*t*)	imports proportion of goods
j	product index as supplied for intermediate consumption
k	industry index
L	multiplier for rate of measures implementation
M	volume of imports
NIS	time-series emissions data sourced from the NIS
p	output or production of an industry
p'	output or production of an industry net of its contribution to capital formation
r()	function which is the product of time-dependent exogenous relationships
t	time in years
X	final expenditure of exported goods
Y	final expenditure of household consumption
Z	final expenditure of capital formation

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1. Introduction

The Paris Climate Accord [1], leading to the 1.5 ºC target for limiting global temperature rise, is challenging many nations to achieve net-zero-carbon by 2050 [2]–[6] or sooner [7], [8]. Equally important politically is creating employment for growing populations [9], [10]. Low levels of unemployment mitigate psychological and fiscal costs [11]–[14] thus policies boosting economic output are prioritised by Governments [15]–[17].

Actions for decoupling economic growth from emissions have yielded some successes. Total greenhouse gas (GHG) emissions of the EU are level or have fallen while the economy grew [18], with the UK doing well [19] (leading the G20 since 2000) if the analysis is tightly bounded to onshore (direct) emissions only. The UK net-zero emissions target requires a broader set of mitigation measures than those to date [20]. There are no analyses specific to the relationship between employment and its emissions footprint, yet measures are needed to reduce this footprint.

The so-called service industry is often considered as being emissions-light [21], but is that true? This question is important because many, particularly but not exclusively, developed nations are reliant on a growing service industry to provide employment. Desirable environmental trends have been associated with increasing economic activity in the service industry [22]–[25]. Our analysis is not about final consumption, but we note that by considering the household consumption of service industry employees, Greenford et al. [26] contend that the service industry is not light nor that decoupling economic activity and environmental impact is likely to be achieved through shifting to service-oriented activity alone. However, as it is desirable that employment is maintained, household consumption is likely to be independent of the type of industry in which they work. The size and importance of consumption by the service industry is recognised [27] and of its embodied CO_2 emissions [28]. However, this topic is under-researched [28].

For five countries, we contrast (Fig. 1) the two largest employment types of the service industry and manufacturing, where the former comprises retail, hospitality, IT, financial, professional, administrative, public administration, education and health (see Appendix B for their definition). Our country selection (Australia, Germany, Italy, the UK, and USA) includes four in the top 10 by GDP and covers three world regions. The European nations are from both the North and South of the continent. Service industry jobs have been rising continually since 1990, while manufacturing jobs have been level or declining [29], [30]. When we disaggregate employment of the service industry into its parts in Fig. 2, we find that the proportions of job types are similar between countries and stay constant over time with only health for Australia and administration for the UK showing faster rates of increase.

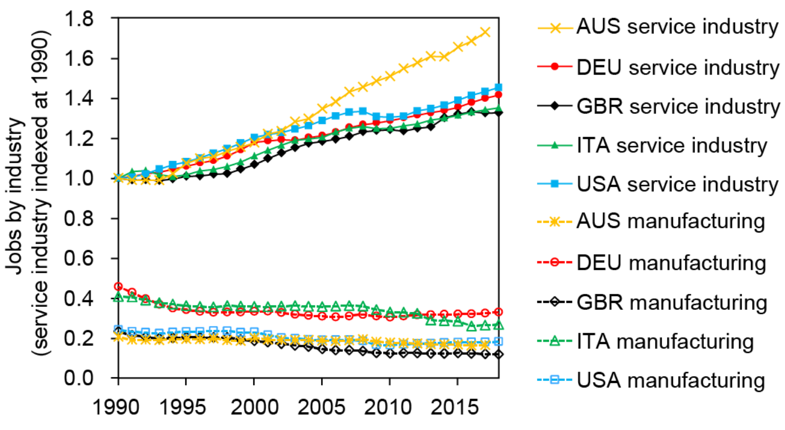

Figure 1. Historical jobs comparison between the service industry and manufacturing for five countries. Service industry jobs are indexed to 1990 with manufacturing jobs to the same index. Time series have been derived by calculation from source data (Appendix A).

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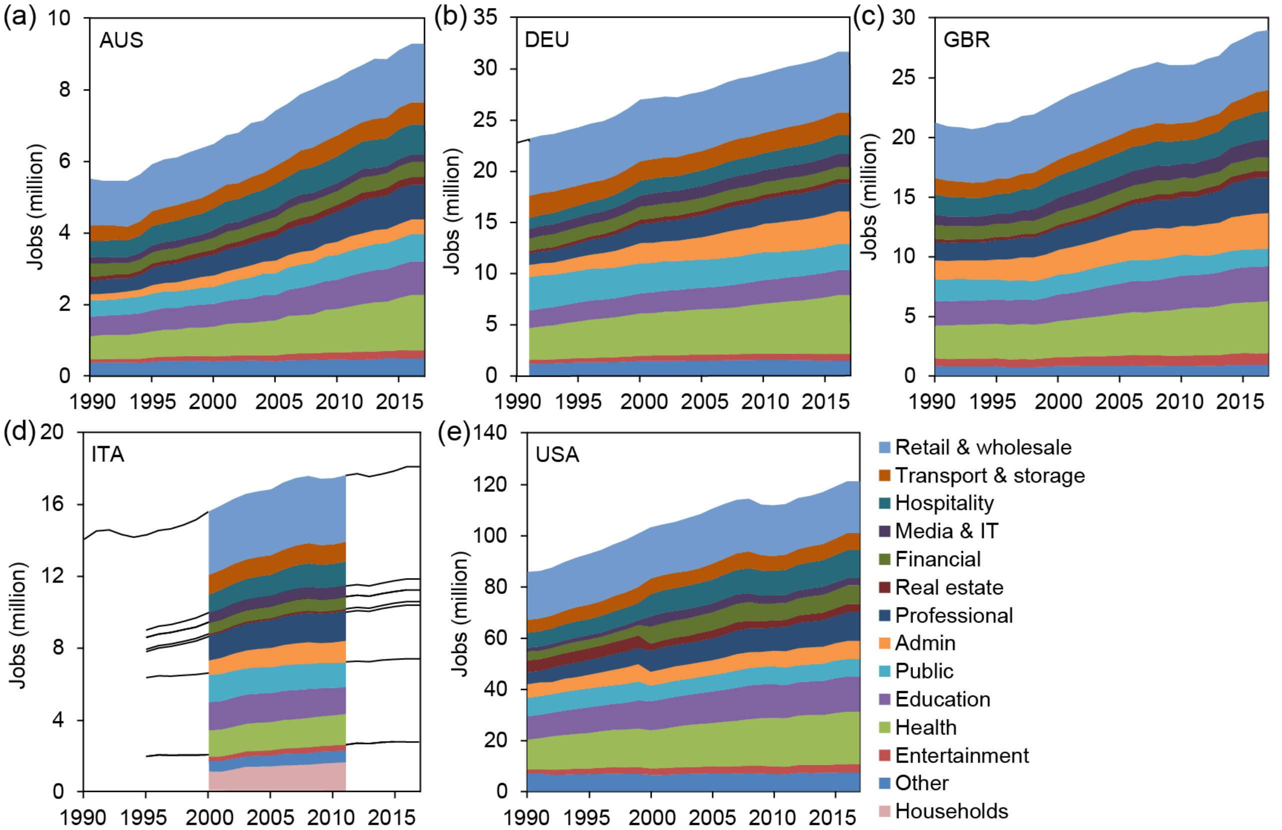

Figure 2. Historical job types within the service industry for various countries. Sub-division of the service industry is according to authors' labelling of SIC2007 categories G-S, as detailed in Table B.1. Time series have been derived by calculation from source data (Appendix A): (a) AUS. (b) DEU. (c) GBR. (d) ITA with amalgamated groups over 1995-1999 and 2012-2017, and including service industry of households (SIC2007 group T). (e) USA.

Despite its importance, the service industry is often omitted from how emissions are analysed and presented which is usually by emissions source [31]–[35] in accordance with the UNFCCC's format of National Inventory Submissions (NIS) [36]. The service industry is regarded as emissions-light because its need for fuel to heat buildings is only about 5% of total emissions across the EU [37]. Explicit emission reduction measures for the service industry are notably absent in contrast to developed measures that target electricity generation, transport, manufacturing and buildings (mostly housing [38]). This lack of attention to the way the service industry is integrated within the whole economy can hamper emissions reduction policy development, and societies will likely reject changes if rising unemployment results. We examine the full emissions footprint of the service industry beyond the direct use of fuel alone to its use of electricity, its need for goods, and the inputs for construction of its buildings.

To understand the extent of international applicability we compare the historical data for five representative developed nations (Fig. 1) for common features related to emissions and the service industry. For our multi-country comparison, we reassign GHG emissions from categorised according to point of source to categorised by end user of which the service industry is taken as one of these. We also compare historical time-series for service industry requirements for energy and goods, and the proportion of goods imported.

We continue with a detailed analysis of one country, the UK, as a case study for scenarios to 2050. The UK was chosen from our country set for its good availability of data. Using the 7see system dynamics model [39]–[42] we exploit historical data for each link of the emissions footprint chain for all inputs to the service industry, including imported goods. We identify the footprint supply chains responsible for most emissions in 2050 and examine these in detail for potential reductions based on state-of-the-art measures at moderate and rapid implementation rates.

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2. Comparing service industry emissions across nations

To learn from a case study, we need to ascertain whether the UK service industry is comparable to those of similarly developed nations. The first section describes the procedure required for each nation of obtaining the emissions footprint of its service industry and other end users when starting with point-of-source emissions data across the economy. The second section describes our findings from this analysis.

2.1 Reassigning emissions from sources to end users

To obtain the full CO_2 emissions footprint for the service industry, we take emissions from its own use of fossil fuels and add emissions of those activities upstream in the supply chain upon which it depends. Our starting point for emissions data across all industries is the NIS [36] in which emissions are all stated according to point of source. From this we identify emissions of upstream activities and reassign these to the service industry. For example, NIS has source emissions at the point of generation which we reassign to the service industry as an end user in proportion to its consumption of electricity. In addition to our interest in the service industry, we reassign the CO_2 parts according to use in a range of categories which relate to policy approaches. Our method uses data for energy balance, transport, national accounts and use of capital formation (gross fixed capital formation, GFCF) by industry and for dwellings. All these data are from government and other public sources, and openly available. We follow the 7see framework for using data from national accounts [39]. We apply reassignment to CO_2 emissions from the following NIS categories[1]:

- 1A Fuel Combustion Activities
  - 1A1 Energy industries
  - 1A2 Manufacturing industries and construction
  - 1A3 Transport
  - 1A4 Other sectors: commercial/institutional; residential; agriculture/forestry/fishing/fish farms
  - 1A5 Other (not specified elsewhere)
- 1B Fugitive emissions from fuels
- 2 Industrial processes and product use

In Fig. 3 we show schematically the steps required to reassign CO_2 emissions from NIS in order to arrive at emissions by end-use. We reassign in the following sequence of steps and denote scope of emissions at each stage of the reassignment by *Ga, Gb, Gc, Gd, Ge*:

a. Disaggregate three NIS categories, '1A2' to '1A4', to seven finer categories. This is for *Ga* emissions from own fuel combustion and including industrial processes of NIS '2'.
b. Reassign electricity from energy industries to where used. This is for *Gb* emissions from own fuel combustion and use of electricity.
c. Start a separate category, capital formation (investment activity of constructing buildings and other long-term assets), by reassigning where supplied from various industries. This is for *Gc* industry emissions less their contributions to capital formation.
d. Assign capital formation to users. This is for *Gd* emissions including their use of capital formation.
e. Reassign goods from agriculture and manufacturing to users. This is for *Ge* emissions including use of goods.

[1] We exclude NIS '1C CO_2 transport and storage' (CCS) and '4. Land use, land-use change and forestry' (LULUCF) since we are considering only releases of CO_2 emissions. We leave off NIS '3 Agriculture' and '5 Waste' since their CO_2 emissions are zero for our country set.

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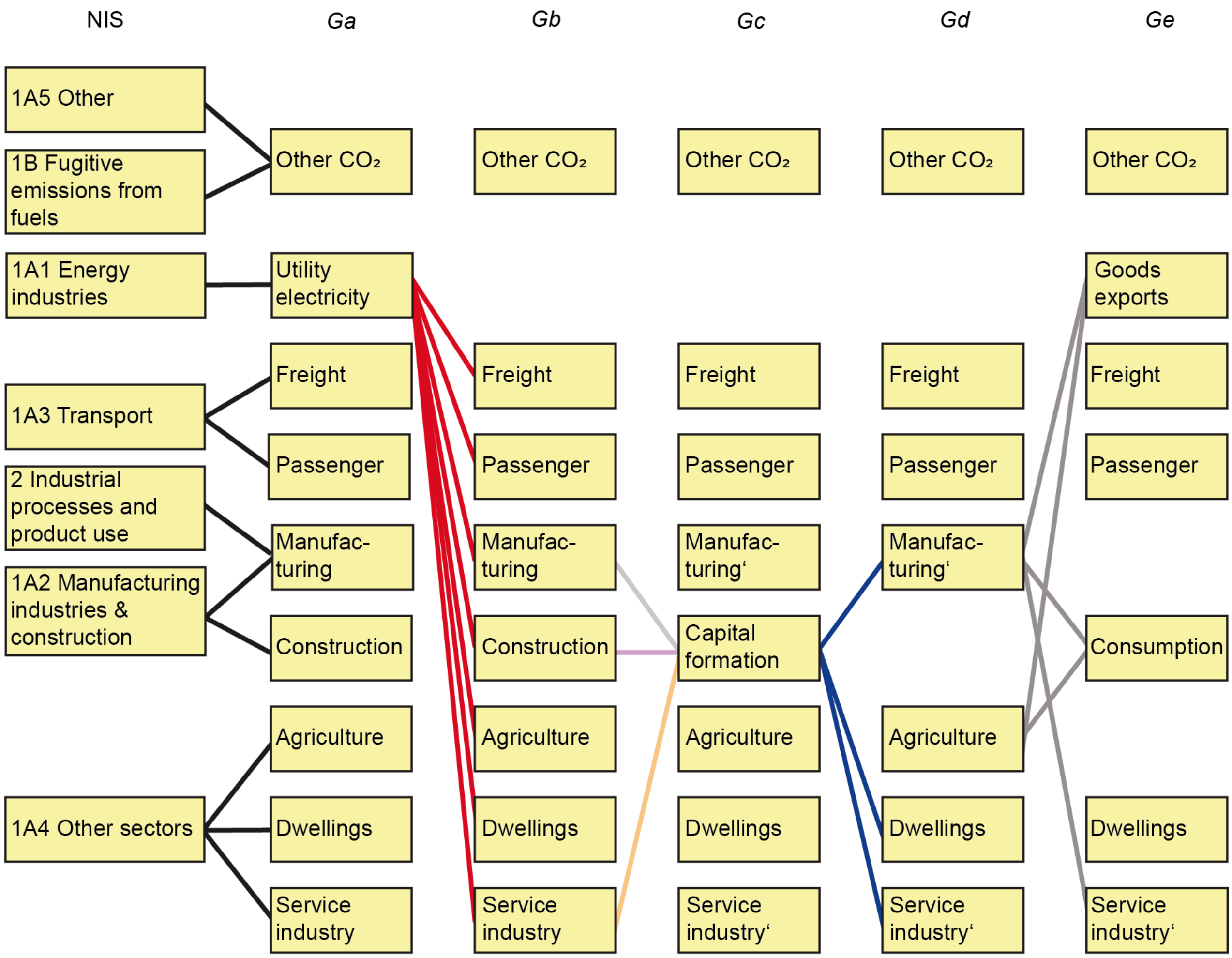

Figure 3. Schematic of steps, from left to right, in reassignment of CO_2 emissions from NIS categories to categories by use. The total of emissions in each column are all equal. Key: ', output net of contribution to capital formation; *G<letter>*, emissions scope at each step of the reassignment.

For emissions of scope *Ga*, we relabel NIS category '1A1' and disaggregate NIS categories '1A2' to '1A4' into the following sectors with our abbreviations and industry numbering in brackets:

- Utility electricity (*util*, 3)
- Manufacturing (*manu*, 4)
- Construction (*cnstr*, 5)
- Freight transport (*frgt*)
- Passenger transport (*pass*)
- Service industry (*serv*, 6)
- Dwellings (*dwlg*)
- Agriculture (*agri*, 1)

We start with IEA energy balance data [43] for each of these and convert to emissions using emission intensities for coal products and petroleum products calibrated from NIS values. We use $IEA_{<sector>,<fuel>}(t)$ to denote time-series energy balance data sourced from the IEA and $NIS_{<category>}(t)$ for time-series emissions data sourced from the NIS.

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We take the emission intensity for natural gas, EI_{gas}, as a fixed value of $MtCO_2$/PJ in 2017 according to the submissions of implied emission factors from each country for overall gaseous fuels.[2] For petroleum products, we derive a country-specific time-dependent emission intensity from '1A3 Transport' after separating LPG,

$$\mathrm{EI}_{pet_{prod}}(t) = \frac{\mathrm{NIS}_{1A3}(t) - \mathrm{IEA}_{trans,LPG}(t) \cdot EI_{gas}}{\mathrm{IEA}_{trans,pet\_prod}(t)} \tag{1}$$

We derive the emission intensity for coal (and its products) from '1A1 Energy industries' after separating natural gas and petroleum products,

$$\mathrm{EI}_{coal}(t) = \frac{\mathrm{NIS}_{1A1}(t) - \mathrm{IEA}_{util,gas}(t) \cdot EI_{gas} - \mathrm{IEA}_{util,pet\_prod}(t) \cdot \mathrm{EI}_{pet\_prod}(t)}{\mathrm{IEA}_{util,coal}(t)} \tag{2}$$

An example of using these emission intensities to derive emissions for one of our groups where for clarity we now omit the time argument is,

$$Ga_{serv} = \left(IEA_{serv,gas} + IEA_{serv,LPG}\right) \cdot EI_{gas} + IEA_{serv,pet\_prod} \cdot EI_{pet\_prod} + IEA_{serv,coal} \cdot EI_{coal} \tag{3}$$

For manufacturing, we include NIS category '2',

$$Ga_{manu} = \left(IEA_{manu,gas} + IEA_{manu,LPG}\right) \cdot EI_{gas} + IEA_{manu,pet_{prod}} \cdot EI_{pet_{prod}} + IEA_{manu,coal} \cdot EI_{coal} + NIS_2 \tag{4}$$

For disaggregating transport emissions between passenger and freight, we use separate fuels in the IEA's extended energy balances and specific transport data on transport modes. IEA fuel types for road are motor gasoline (petrol), diesel and LPG, and for aviation are gasoline and kerosene. We assign all domestic aviation as for passenger. For passenger cars, we include their proportion of petroleum products used and all LPG. Government data in AUS and GBR is available for total energy use for passenger road vehicles, GD_{pass_road,pet_prod}, which we can use directly,

$$Ga_{pass} = GD_{pass\_road,pet\_prod} \cdot EI_{pet\_prod} + IEA_{road,LPG} \cdot EI_{gas} + IEA_{aviation} \cdot EI_{pet\_prod} \tag{5}$$

For other countries we need proxy data to derive a passenger factor of petrol use, *pass_factor_petrol*, either to reduce if also used by commercial vehicles or increase where the car fleet includes diesel engines,

$$Ga_{pass} = IEA_{road,petrol} \cdot pass\_factor\_petrol \cdot EI_{pet\_prod} + IEA_{road,LPG} \cdot EI_{gas} + IEA_{aviation} \cdot EI_{pet\_prod} \tag{6}$$

In USA we take petrol as used by all short wheelbase light duty vehicles and use the proportion of these registered as passenger cars for *pass_factor_petrol*. In DEU and ITA, the car fleet is both petrol and diesel so we use Eurostat data on numbers of vehicles by engine type to derive their *pass_factor_petrol*.
We derive emissions for freight transport as the balance of total transport emissions,

$$Ga_{frgt} = NIS_{1A3} - Ga_{pass} \tag{7}$$

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[2] We find that each countries' average values of emission factors for gaseous fuels are 0.051 $MtCO_2$/PJ for AUS, 0.056 $MtCO_2$/PJ for DEU, 0.058 $MtCO_2$/PJ for GBR, 0.058 $MtCO_2$/PJ for ITA, and 0.050 $MtCO_2$/PJ for USA.

Of the remaining NIS categories for CO_2 emissions, these are '1A5 Other' and '1B Fugitive emissions from fuels', which we put under our category 'Other CO_2' in Fig. 4.

To go from *Ga* emissions of direct fuel alone to *Gb* emissions with electricity use included, we reassign NIS '1A1' emissions between categories of users in proportion to their annual electricity use. For the emission intensity of electricity we use,

$$EI_{elec} = NIS_{1A1} / \left(IEA_{util,coal} + IEA_{util,pet\_prod} + IEA_{util,gas}\right) \quad (8)$$

An example of using the electricity emission intensity for one industry is

$$Gb_{serv} = Ga_{serv} + IEA_{serv,elec} \cdot EI_{elec} \quad (9)$$

Emissions of scope *Gc* are net of capital formation supplied. We use national accounts for proportions to capital formation from construction and other industries at the point of final expenditure, following intermediate consumption. We use the 7see method of apportioning industry inputs and impacts [42] to convert these contributions back up stream to the point of output or gross value added (GVA). Here we denote proportions by *b* for intermediate consumption, *h* for final expenditure destination and *f* for industry output going to final expenditure destination. We use suffices to signify each part of these journeys starting with products at the point of output or value added, via finished products to final expenditure or end use. In 7see we number industries 1 to 6 and use * to denote all industries and X to Z for final expenditure destination. For example, by f_{4*Z} we mean that the proportion of all products 4 (goods) that end up as 'Z' (capital formation), irrespective of which industries, 1-6, they have passed through. For the level of accuracy we require, we find it sufficient to work with just the three larger industries of manufacturing, construction and service industry, numbered 4 to 6. For these three, we derive the proportion of output, *f*, of products *j* whose final expenditure after intermediate consumption is type *Z* of capital formation, f_{j*Z}.

$$\begin{pmatrix} f_{4*Z} \\ f_{5*Z} \\ f_{6*Z} \end{pmatrix} = \begin{pmatrix} b_{44*} & b_{45*} & b_{46*} \\ b_{54*} & b_{55*} & b_{56*} \\ b_{64*} & b_{65*} & b_{66*} \end{pmatrix} \begin{pmatrix} h_{*4Z} \\ h_{*5Z} \\ h_{*6Z} \end{pmatrix} \quad (10)$$

where b_{jk*} is the proportion of output at basic prices plus imports M of products *j* that are supplied for intermediate consumption to industry *k* for the final products *k*, and h_{*kZ} is the proportion of final expenditure for each product *k* in its final form going to final expenditure type Z of capital formation. As an example, for the service industry, we use proportion f_{6*Z} to derive emissions *Gc*, net of contribution to capital formation,

$$Gc_{serv} = Gb_{serv}(1 - f_{6*Z}) \quad (11)$$

The emissions total for capital formation is the sum of contributions supplied by manufacturing and the service industry and all of construction,

$$Gc_{CF} = (Gb_{manu} - Gc_{manu}) + Gb_{cnstr} + (Gb_{serv} - Gc_{serv}) \quad (12)$$

The emission intensity of capital formation is,

$$EI_{CF} = {}^{Gc_{CF}}/_{CF} \quad (13)$$

where *CF* is the sum of final expenditure to all capital formation.

For emissions of scope *Gd*, we assign emissions of capital formation to industries and dwellings in proportion to their investment requirements along with capital formation of power generation in proportion to their use of electricity, for example,

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$$Gd_{serv} = Gc_{serv} + \text{CF\_use}_{serv} \cdot EI_{CF} + \text{CF\_use}_{util} \cdot EI_{CF} \cdot \frac{IEA_{serv,elec}}{IEA_{total,elec}} \quad (14)$$

For emissions of scope *Ge*, we assign of goods to three destinations: service industry, exports and consumption by households. To the service industry, we assign the proportion of manufacturing emissions according to the portion of manufacturing output that goes to intermediate consumption by the service industry,

$$Ge_{serv} = Gd_{serv} + Gd_{manu} \cdot b_{46*} \quad (15)$$

where b_{46*} is the proportion of goods (4) as intermediate consumption to the service industry (6).

With the remaining emissions for goods, these are split between emissions of exported goods (X) and household consumption (Y) according to their proportions of final expenditure of goods for exports, h_{*4X}, and household consumption, h_{*4Y}. For emissions of exported goods,

$$Ge_{goods,export} = Gd_{manu}(1 - b_{46*}) \cdot \frac{h_{*4X}}{(h_{*4X} + h_{*4Y})} \quad (16)$$

Of the remaining emissions of goods, we assign these to final consumption by households (labelled *cons*),

$$Ge_{cons} = \sum_{all\ sectors} Ga_{<sector>} - \left(Ge_{goods,exports} + Ge_{frgt} + Ge_{pass} + Ge_{dwlg} + Ge_{serv}\right) \quad (17)$$

We handle the remainder of NIS categories of non-CO_2 emissions as total GHG emissions less the CO_2 emissions as detailed above,

$$\text{Non-CO}_2 = \text{NIS}_{\text{GHG}} - \sum_{\text{all sectors}} \text{Ga}_{<\text{sector}>} \quad (18)$$

2.2 Multi-country comparison

Applying our reassignment of emissions, we show in Fig. 4(a)-(e) the relative proportions of historical GHG emissions (since 1990) for our country set. These reveal that the service industry for each member of our country set are far from being ‘light’. Comprising 17-24% of total domestic emissions, service industry emissions are comparable in size to emissions of transport and dwellings. Furthermore, the service industry has been a constant proportion over this period independent of absolute emissions (Fig. 4(f)). We draw from these observations that the service industry for all countries needs specific attention for emissions reduction to achieve a net-zero emissions target.

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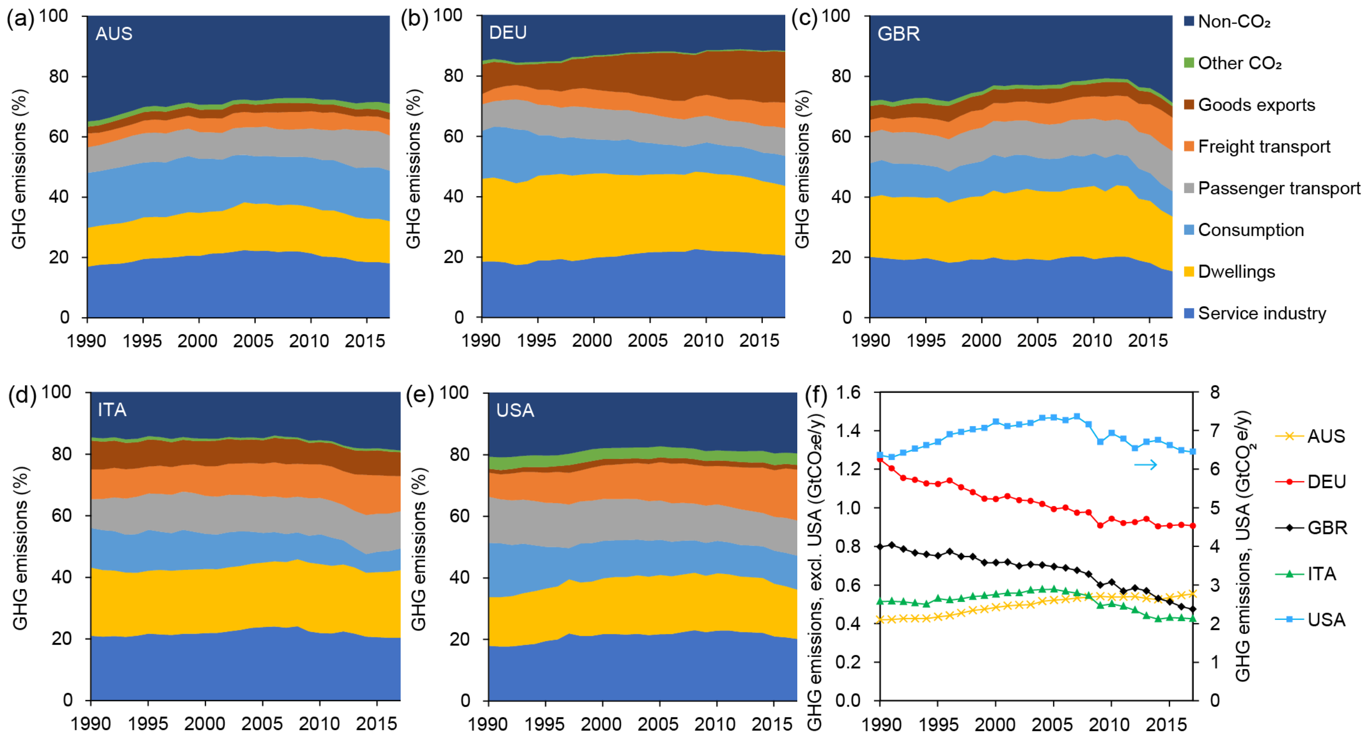

Figure 4. National historical greenhouse gas (GFG) emissions as proportions reassigned according to use. GHG exclude land use change. Time series have been derived by calculation from source data (Appendix A). (a) AUS. (b) DEU. (c) GBR. (d) ITA. (e) USA. (f) Absolute GHG totals.

Focusing on service industry energy requirement intensity, we show in Fig. 5(a) the sum of fuel and electricity as a ratio to service industry output (gross value added or GVA). All countries show a decline, flattening out over the historical period, with Italy's falling since 2005. The decline for Australia is much less apparent. The similar shape of these trends shows that countries in our country set have in common continuous improvements in energy efficiency. The use of goods by the service industry is an often overlooked component contributing to emissions, which we show in Fig. 5(b) as a ratio of goods required to output of services. In contrast to energy requirement, these ratios do not have a falling trajectory but have settled in the range 0.10 to 0.17 for most countries, with only Australia declining in recent years. These flat trajectories point to a problem for the service industry of not reducing their material input, with the consequent emissions footprint.

Most nations state only the emissions within their national boundary, with the exclusion of offshored emissions from national reporting giving a false assessment of progress on emission reductions. The data in Fig. 4 covers only domestic sources of emissions, but the material requirements of the service industry in Fig. 5(b) mean that we need to include emissions of imported goods, referred to as the consumption approach to emissions analysis [44]–[46]. We show in Fig. 5(c) how the proportion of goods imports has evolved over time. We note that all countries apart from Australia show the same behaviour of imports rising until 2010 at which point they plateau. Since our country comparison shows similar trends, we can select one as a representative case study from which to draw conclusions applicable to all.

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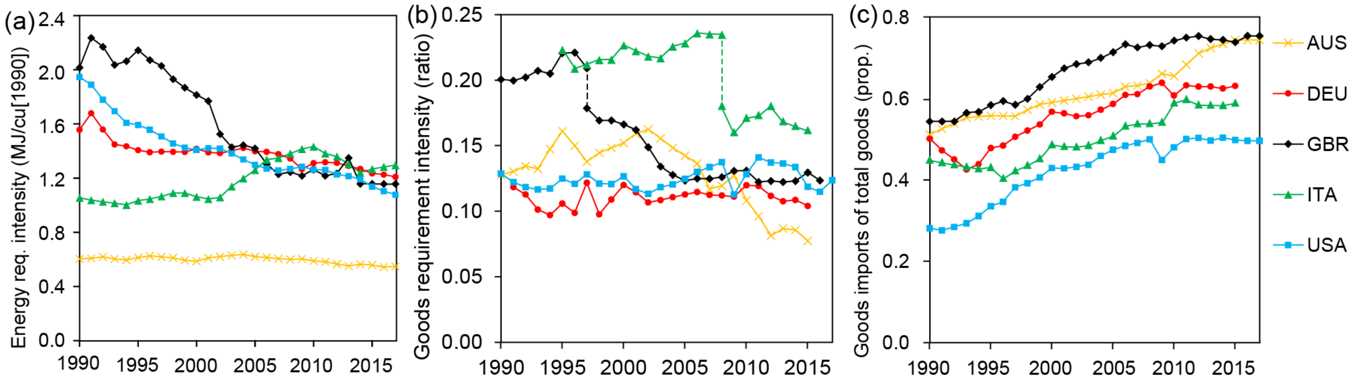

Figure 5. Country comparison for historical behaviour of their service industry requirement for energy and goods and of goods imports. Time series have been derived by calculation from source data (Appendix A). (a) Energy requirement intensity where "cu[1990]" is currency units inflation corrected back to 1990. The graph for AUS is lower because the AU$ has much lower value than currencies of the other countries. (b) Ratio of goods use by the service industry to its output, both in monetary units. (GBR and ITA had changes of industry and product categorisation in 1997 and 2008, respectively, that manifest as a step changes, but their graph trends are essentially level before and after.) (c) Proportion of goods imported to the sum of imported and domestically sourced goods.

3. Case-study modelling

The current emphasis internationally is to reduce emissions to net-zero by 2050 or sooner; our view is that effective polices to achieve this should include offshored emissions. To assess these we apply the 7see modelling approach to generate future scenarios. The whole-economy analytical framework of a 7see model harmonises multiple national accounting procedures [39]. In a modular fashion, the framework curates and maintains disparate accounts (economic stocks and flows, energy use, employment, transport) in parallel, but retains each of their unique measurement unit and accounting requirements. These data are exploited in a system dynamics model that, for example, links energy demand through to final economic consumption [40]. The dynamic aspects assume that supply follows demand but are constrained in the short-term by physical infrastructure. At the same time, capital formation grows the physical infrastructure. Historical behaviour of coefficients [42] manifest the relationships between components of an economy, enabling the 7see computational model to create physically-consistent business-as-usual future scenarios. A complete national 7see model provides a methodology for testing investment requirements for different policy measures [41]. These additional investments increase gross fixed capital formation (GFCF) by the economy while the model ensures that resulting scenarios comply with physical constraints.

The strengths of the 7see approach are that physical capacity limits are accurately accounted for, and the empirical data generated by economic activity is modelled analytically in a system dynamics paradigm. Based on a historic calibration period (1990–2017) and the conventions of the international system of national accounts, 7see implements a rigorous integration of physical, economic and societal data to provide outputs of energy use, emissions and employment. Its credibility is based on relationships calibrated from historical data and meeting physical laws of thermodynamics. The 7see model requires each scenario year to meet the same product balance requirement for National Accounts reconciliation as historical years do for presentation of GDP. These are all features essential for accurate and realistic evaluation of scenarios. To extend this modelling to the emissions footprint embodied in imports, we use historical data of multi-region input-output (MRIO) analysis for historical emissions embodied in imports [47].

To identify components of CO_2 emissions, the 7see approach starts by identifying flows of products (goods and services) through an economy, from raw materials via production infrastructure to their form for consumption or export (see Appendix C, Fig. C.1(a) for this in schematic form). To apportion emissions from the uses of fuel and electricity to the service industry (Fig. C.1(b)), we use economic volume flows, measured in deflator-corrected monetary units. For goods used by the service industry, we weight emissions by comparing the economic volume flow of its intermediate consumption to total availability of goods as the sum of domestic production by manufacturing and imports. In our modelling approach we apply a demand

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perspective, or requirement. The starting point is 'Demand for services'. The relationship between demand for services and actual output is described fully in Roberts et al. [40].

3.1 Emissions for the GBR service industry

Using the UK (GBR) for our case study, we show in Fig. 6(a) emissions for the GBR service industry, both from domestic sources alone (in production accounting terms) and since 1997 these combined with imports of goods they use (in consumption accounting terms). For the future scenario, our base case is 'with existing measures' (WEM) which presumes the emission reduction measures of the fifth carbon budget (5CB) of the UK Committee on Climate Change [48]. For the production approach to emissions, the historical declining trend looks set to continue until about 2030 when it levels out to 49 $MtCO_2$ per year. When we include imports of the consumption approach, this follows a similar declining trend but levels out at 109 $MtCO_2$ per year.

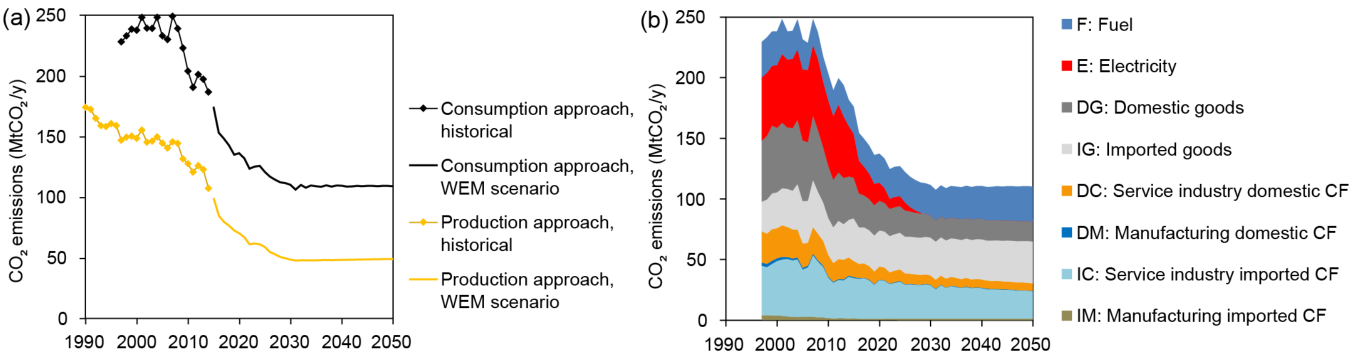

Figure 6. Carbon Dioxide emission footprints for the GBR service industry of historical data and WEM (with existing measures) scenario. CF: capital formation. See Appendix A for data sources. (a) Approaches of production (without imported goods or imported CF) and consumption (including imports). (b) The consumption approach decomposed into 8 sources. Time series have been derived by calculation from data: [43], [49], [50]. See Fig. C.1(b) for a schematic of these sources.

It is helpful to decompose the consumption approach into eight emission sources (Fig. 6(b) and (Fig. C.1(b)). For example, emissions from electricity are responsible for 50 $MtCO_2$/y in 1990 which fall to negligible levels by 2030. We note four of these emission sources show no decline and are responsible for 95% of emissions in 2050. We list these in order of decreasing impact:

1. Emissions from imported goods (IG)
2. Emissions from fuel (F)
3. Emissions from service industry imported capital formation (IC)
4. Emissions from domestic goods (DG)

As these sources of emissions present a risk to reaching a net-zero carbon future, we examine each by disaggregating into the chain of their constituent links in order to understand their dependencies and opportunities for reduction.

3.2 Emissions from imported goods (IG)

Starting with emissions from imported goods, we compute its whole-chain emissions from the product of the first factor of service industry output with one or more time-dependent exogenous factors. For the links in this chain, the factors are goods requirement intensity, the proportion of these imported and the emission intensity of imported goods (see the path from 'Service industry' to 'IG' in Fig. C.1(b)).

For service industry output (also known as the economic volume output), we denote by p the total output less rental [39]. This follows historical data from 1990 and for the future is generated from the 7see model. We use output net of its contribution to capital formation, p', to avoid double counting since we account for emissions from use of capital formation separately. The amount to capital formation is equivalent to emissions reassignment in equation (11),

$$p' = p(1 - f_{6*Z}) \quad (19)$$

Emissions from imported goods used by the service industry, G_{IG}, is dependent on output of the service industry as follows:

$$G_{IG} = r_{IG}(p') \quad (20)$$

where the function $r_{IG}()$ is the product of time-dependent exogenous relationships: goods-in ratio to service output, GR(t); imports proportion of goods, IP(t); emission intensity of imported goods, $\mathrm{EI}_{IG}(t)$. Thus:

$$G_{IG} = p' \cdot \mathrm{GR}(t) \cdot \mathrm{IP}(t) \cdot \mathrm{EI}_{IG}(t) \quad (21)$$

For the rate of implementation of 'with additional measures' (WAM), we apply an S-shaped curve based on the logistic equation. We need to derive from this a multiplier, L, for a rate of measures implementation. We use the equation for a logistic curve where y transitions from 0 to 1.

$$y = f(x) = \frac{1}{1 + \exp(-x)} \quad (22)$$

A feature of this form is that the slope is steepest about x=0 with 23% change from x=-1 to x=0 and from x=0 to x=1. For our chosen values of *centre_year* and *width* for policy implementation, we substitute for x to put y in terms of year, t,

$$y = f\big(s(t)\big) \quad (23)$$

$$s(t) = \frac{t - centre\_year}{width} \quad (24)$$

We constrain the period to 2020 to 2050 for a scaled output of 0 at the start and 1 at the end,

$$L = \frac{f\big(s(2050)\big) - f\big(s(t)\big)}{f\big(s(2050)\big) - f\big(s(2020)\big)} \quad (25)$$

We choose values of *centre_year* and *width* by trial in order to achieve required values of L at selected intermediate years.

For emissions from imported goods, we show these four factors in Fig. 7 for historical data and to 2050 for our WEM scenario and WAM policy scenarios at two rates. Output by the service industry in Fig. 7(a) has risen historically in line with jobs (Fig. 1) and continues to rise in our scenarios. This follows from input to the 7see model of increasing size of the economically active population and model configuration for low levels of unemployment [41], [42]. For the exogenous factors in Fig. 7(b) to (d), their base scenario is from trending their historical data together with implementing WEM where appropriate [42]. To explore the most potential for emissions reduction by 2050, we identify a target reduction for each separate footprint link. We mitigate uncertainty in the uptake rates towards these targets by implementing a band of transition rates between a pair of S-profile logistic curve transitions over time [51]–[53]. These start in 2020 with a fast rate corresponding to achieving 90% of agreed Nationally Declared Contributions (NDC) by 2030 (WAM-fast) [54][3], and a slower transition corresponding to following carbon budget targets of the CCC (WAM-slow)[4].

[3] The S-shaped curve parameters for our fast rate are *centre_year* of 2027 and *width* of 1.7 years.

[4] The S-shaped curve parameters for our slower transition are *centre_year* of 2050 and *width* of 3.0 years.

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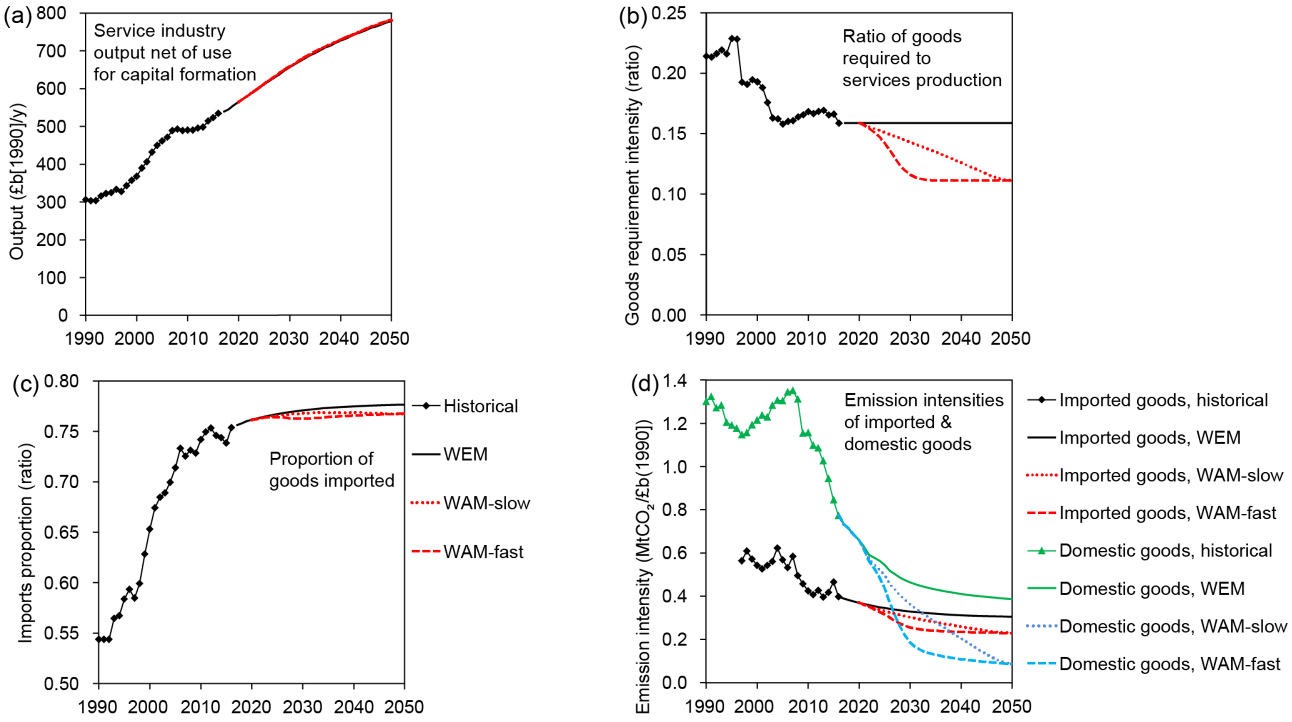

Figure 7. Factors in emissions for imported goods used by the service industry and domestic-manufactured goods for GBR. These relate to equations (21) and (31). They are shown for historic data and future scenarios of WEM (with existing measures), WAM-slow (with additional measures) and WAM-fast. Historical time series have been derived by calculation from source data: [43], [49], [50] (a) Service industry output, net of contribution to capital formation. (b) Goods requirement intensity. (c) Imports proportion for goods. (d) Emission intensities of imported goods and domestic manufactured goods.

For the second factor of emissions from imports goods, we need to consider how the goods requirement intensity (Fig. 7(b)) can be reduced [55]. We use a target reduction of 30% by 2050 which we have estimated from product-specific measures based on an assessment of the possible resource use efficiency gains for a range of product types used by the service industry. For goods used by the service industry we disaggregate into 11 types (Tables B.2 and B.3) and show their time series in Fig. 8. From this disaggregation, we note that the largest six are food and drink, electronic, pharmaceutical, print, materials and machinery.

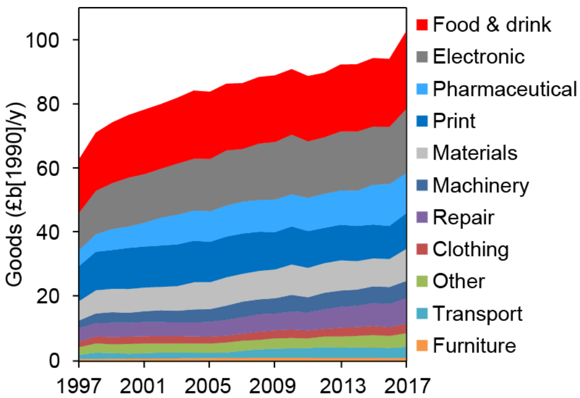

Figure 8. Detailed breakdown of all goods as intermediate consumption (IC) by the service industry for GBR. See Appendix B for mapping of categories. For pharmaceutical, this is the sum of both IC and final expenditure by government. Goods of IC are in order of their decreasing economic volume flow. For the atypical rise in 2017, this is a consequence of a major transformational programme by the ONS introduced for that year for the processing of SUTs data [50].

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In Fig. 9 we detail these by use according to 13 industries (Table B.1) comprising the service industry. The overall picture is of level (food and drink) or upward trends (electronic, pharmaceutical, materials and machinery), with only print having dropped 10% over the 20-year historical period. We incorporate proposals for reducing the impacts of these categories. For food and drink (Fig. 9(a)), a half to two thirds of food waste could have been eaten [56], [57] and measures are proposed to minimise these [57]. For electronic (Fig. 9(b)) and machinery (Fig. 9(f)), there is potential to extend lifetimes by tackling perceived obsolescence [58]–[60], cascading devices [61], and enabling repair [62], [63]. For pharmaceutical use (Fig. 9(c)), NHS England estimate 4% of prescribed medicines are wasted [64] while the WHO estimates that more than half of all medicines are prescribed, dispensed or sold inappropriately [65] and Busfield [66], [67] notes the industry's driving forces for expansion beyond meeting health needs. For print (Fig. 9(d)), we noted in Fig. 5(b) the exceptional decline of goods intensity for Australia. Their greatest reduction is for their use of print running at 5.6% per year [68] with most decline for newsprint and communication. For materials (Fig. 9(e)), half of plastic goes to waste and the issue of marine pollution has focused attention on eliminating unnecessary and single-use plastic packaging [69]–[71].

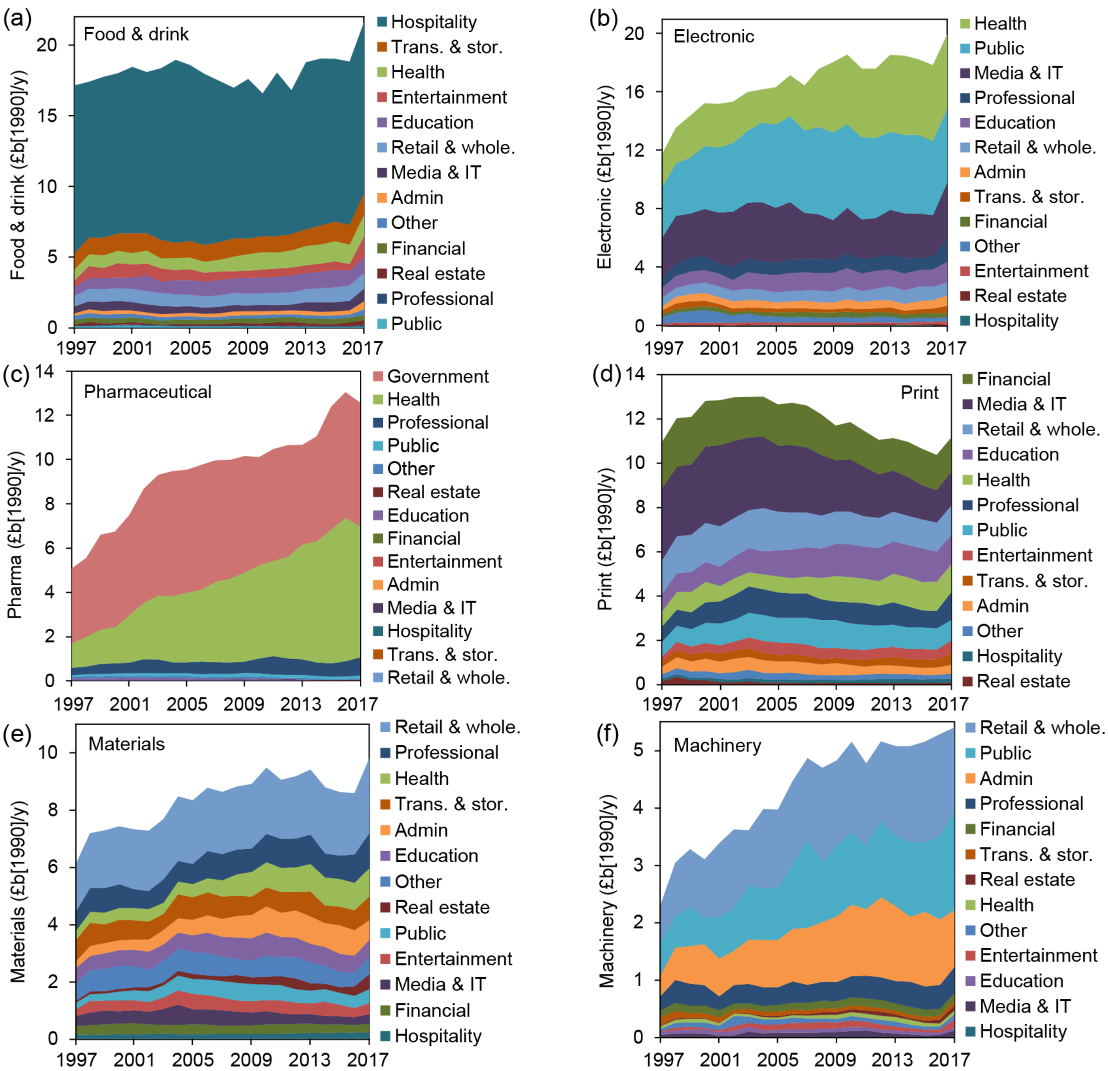

Figure 9. Historical behaviour of specific goods as inputs to 13 industries that comprise the service industry for GBR. See Appendix B for mapping of these industries and product categories. Industries are arranged in decreasing order of usage in the last year for each type of goods. Time series have been derived by calculation from source data: [50], [72]. (a) Food and drink (excluding duty). (b) Electronic. (c) Pharmaceutical. (d) Print. (e) Materials (excluding tyres). (f) Machinery.

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The third link in the emissions footprint chain is the imports proportion for goods (Fig. 7(c)). The direction of change necessary to reduce emissions depends on comparing manufacturing emission intensities of domestic goods and imports. We show in Fig. 7(d) that imports will have a higher intensity in the long term so reducing imports would be beneficial for emissions. Governments usually incentivise reshoring [73], [74] to increase employment [75], [76]. However, there are limitations [77] with more work needed to understand the impacts on environmental sustainability [78], therefore we target only a 5% reduction by 2050 of the volume ratio of imports to domestic goods.

The last link is the emission intensity of goods imports in Fig. 7(d). One policy for reducing this is to bias imports away from the highest emitting exporters. In Fig. 10 we derive a composite emission intensity from the main exporters to the UK based on weighting their economy wide emission intensities by volume of imports. The composite emission intensity drops by 25% if cutting out imports from the highest intensity emitter (China).

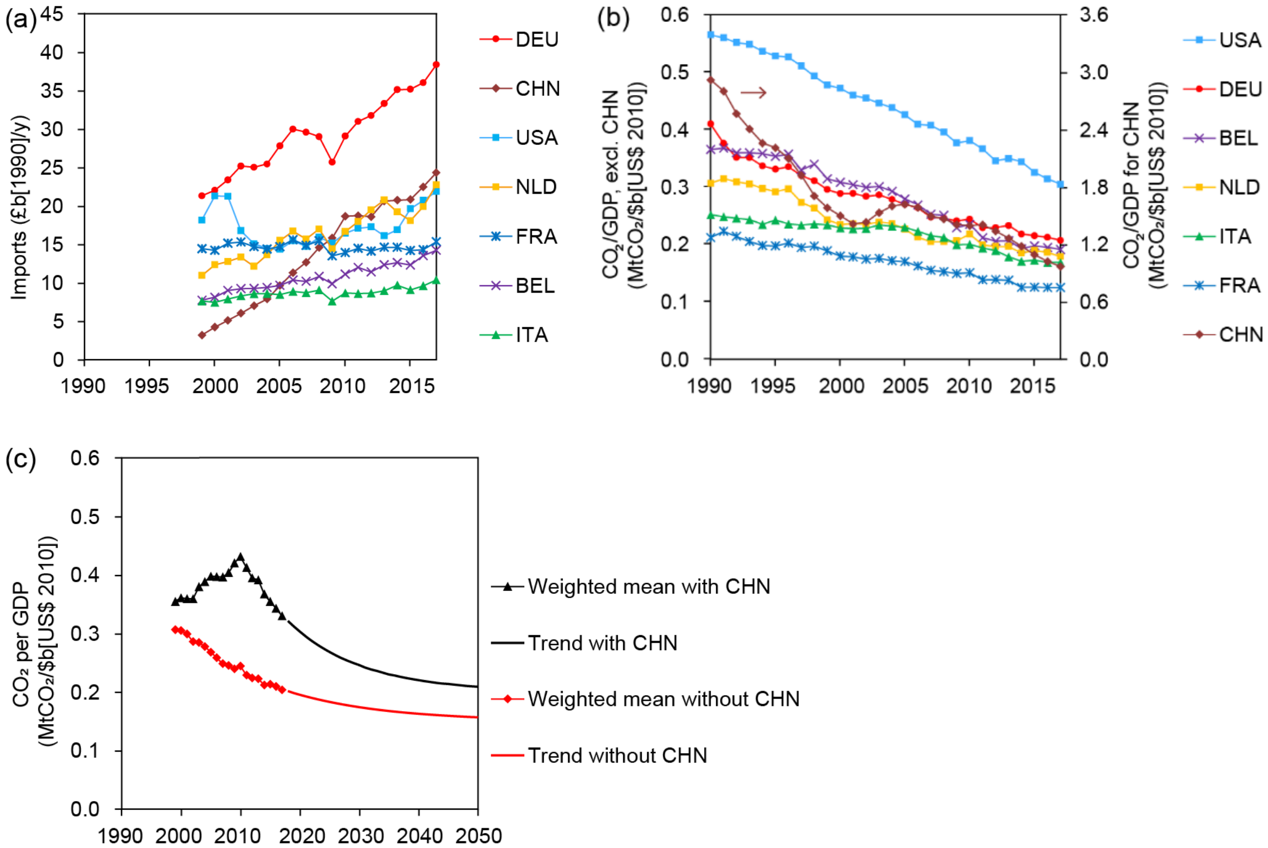

Figure 10. Analysis of goods imports by GBR by volume and emission intensity for the top seven exporting countries. Historical time series have been derived by calculation from source data: [79]–[81] (a) Volume of goods imports. (b) Economic-wide CO_2 emission intensity of the exporter countries. (c) Mean of emission intensities weighted by volume of imports for exporters, with and without CHN.

3.3 Emissions from fuel (F)

We apply a similar approach to the other three sources of emissions (from fuel, F; from service industry imported capital formation, IC; from domestic goods, DG) which will still be high by 2050. For emissions from fuel, we have implemented the measures suggested by the CCC [31]. These include improvements in the thermal efficiency of buildings, heat from heat pumps and heat networks.

We use the CCC net-zero emissions (NZE) analysis [20], [82] for some of the measures that we apply for our scenario 'with additional measures' (WAM), which build on our scenario 'with existing measures' (WEM) based on the fifth carbon budget [48].

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The NZE analysis proposes ‘core’ options for non-residential buildings as proportions and at absolute levels. These include energy efficiency 25% (28 TWh), low-carbon heat networks 46% (41 TWh) and heat pumps 54% (49 TWh). From the NZE values for energy efficiency, these imply total heat demand of 112 TWh/y or 403 PJ/y. Our value from the 7see model agrees with this for 2018, which confirms that 7see and NZE share the same scenario starting point.

To use measures of NZE as a basis for WAM scenarios, we must consider whether to apply as proportions or absolute values. The NZE values for low carbon heat networks and heat pumps sum to 100% and a heat demand of 90 TWh/y or 324 PJ/y. If we assume this is after application of the NZE value for energy efficiency of 75%, this corresponds to a total heat demand before efficiency measures of 432 PJ/y. The equivalent value from 7see modelling, which includes the service industry growing, is higher at 551 PJ/y. Rather than assuming all of this can be met by the combination of low carbon heat networks and heat pumps, we use the absolute values for 2050 from the NZE analysis on the basis that the capacity for these has been substantiated.

For manufacturing, the NZE analysis proposes 'core' emission reductions to 56 $MtCO_2e$ by 2050, which include:

- energy efficiency of 5 $MtCO_2e$ abatement;
- resource efficiency of 5 $MtCO_2e$ abatement;
- CCS on processing of 6 $MtCO_2e$ abatement;
- low temperature heating by electrical heat pumps of 1 $MtCO_2e$ abatement.

The NZE analysis goes on to propose 'further ambition' emission reductions to 10 $MtCO_2e$ by 2050, which includes hydrogen and electrification for stationary heat or combustion of 19 $MtCO_2e$ abatement and off-road mobile machinery of 4 $MtCO_2e$ abatement.

In considering how to select and apply various measures from the NZE analysis for our WAM scenarios, we check for comparability of coverage for ‘manufacturing’ since this sector can have divergent definitions between data sources. We find that our 7see model for this sector has lower values for emissions in 2018 than the NZE analysis, which we attribute to our use of energy data from the International Energy Agency [43] and emissions data from the UNFCCC [36]. This means we need to adapt measures from the NZE analysis for our WAM scenarios. The values we use are:

- thermal efficiency improvement of 20%;
- heat from heat pumps of 50 PJ/y;
- use of hydrogen of 50 PJ/y;
- application of CCS for 24 $MtCO_2$/y abatement.

For emissions from fuel use, G_F, these are dependent on output of the service industry net of contribution to capital formation, p', as follows,

$$G_F = r_F(p') \tag{26}$$

where $r_F()$ is based on the time-dependent exogenous relationships. These relationships are: heat requirement intensity with respect to service output, HR(t); fuel proportion of heat, FP(t); emission intensity of fuel used by the service industry, $\mathrm{EI}_F(t)$. Thus:

$$G_F = p' \cdot \mathrm{HR}(t) \cdot \mathrm{FP}(t) \cdot \mathrm{EI}_F(t) \tag{27}$$

We show the separate time behaviour of these factors in Fig. 7(a) for p' and Fig. 11.

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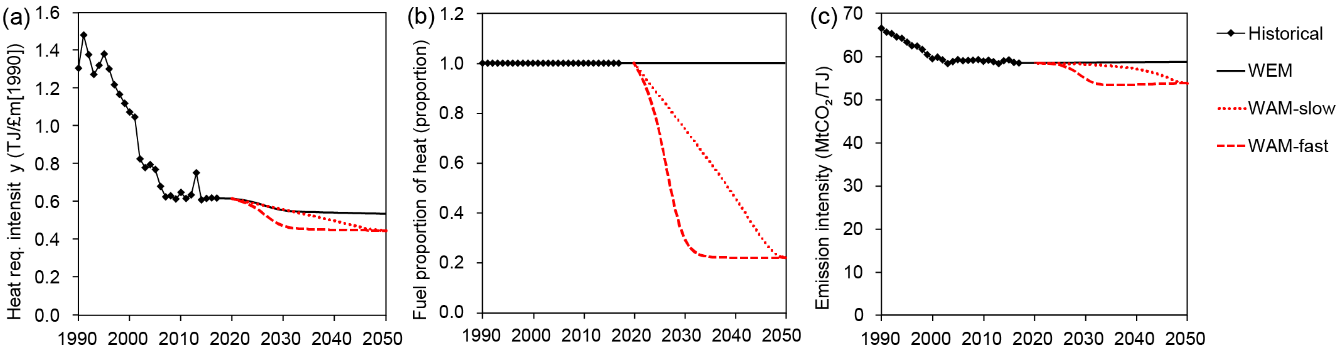

Figure 11. Factors in emissions for direct fuel use by the service industry for GBR. These relate to equation (27). These are shown for historic data and future scenarios of WEM, WAM-slow and WAM-fast. Historical time series have been derived by calculation from source data: [43], [50] (a) Heat requirement intensity of the service industry of heat. (b) Proportion of heat provided by fuel. (c) Emission intensity of fuel used by the service industry.

For the heat requirement intensity of the service industry in Fig. 11(a), this concerns the requirement for heat according to output of the service industry. The historical behaviour shows a decline but only to 2007 when the level stays almost constant. Given that the denominator is output whereas this heat requirement relates to the buildings, we need to check variation of the output intensity with respect to fixed capital, the measure we use of the physical building stock. In Fig. 12 this intensity averaged £0.47m/y per £m of fixed capital over the 1990s and since 2000 has averaged 0.52±0.02, so service industry output, *p'*, appears to track fixed capital. For the WEM scenario, we apply a 10% reduction following measures in the fifth carbon budget [48]. We apply a further 15% reduction for our WAM scenarios according to the CCC net-zero emissions (NZE) analysis [20], [82].

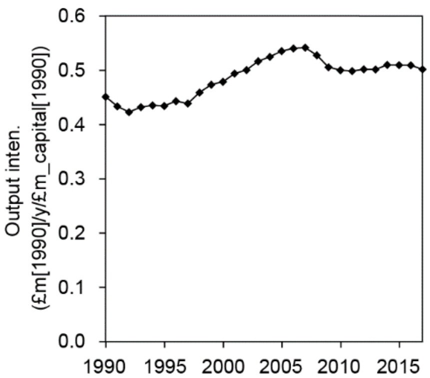

Figure 12. For the GBR service industry, historical output intensity to fixed capital of the building stock. Historical time series have been derived by calculation from source data: [43], [49].

The proportion of heat provided by fuel (Fig. 11(b)) has stayed close to 100% historically, which we have continued for our WEM scenario. For the WAM scenarios, we implement measures from the NZE analysis of offsetting fuel use to a level of 324 PJ/y by 2050 as split 46% from low-carbon heat networks and 54% from heat pumps. With our heat requirement estimate by 2050 of 410 PJ/y, this corresponds to a proportion of 0.21 still from fuel.

The average emission intensity across the mix of fuels used for heating (Fig. 11(c)) has settled historically at 59 $MtCO_2$/TJ, following phasing out of solid fossil fuel through the 1990s. For the WAM scenarios we implement substitution of heating oil by natural gas.

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3.4 Emissions from service industry imported capital formation (IC)

For emissions from capital formation imports, G_{IC}, we compute these emissions, based on the variable of capital formation requirement of the service industry, c, as a function of time. This follows historical data from 1990 and for the future is generated from our 7see model. The emissions are dependent on c as follows,

$$G_{IC} = r_{IC}(c) \tag{28}$$

where the function $r_{IC}()$ simply consists of the time-dependent exogenous emission intensity of imported capital formation, $\mathrm{EI}_{IC}(t)$. Thus:

$$G_{IC} = c \cdot \mathrm{EI}_{IC}(t) \tag{29}$$

We base historical values of $\mathrm{EI}_{IC}(t)$ on historical data of multi-region input-output (MRIO) analysis [47], [83] and volume of imports. We show the separate time behaviour of these factors in Fig. 13.

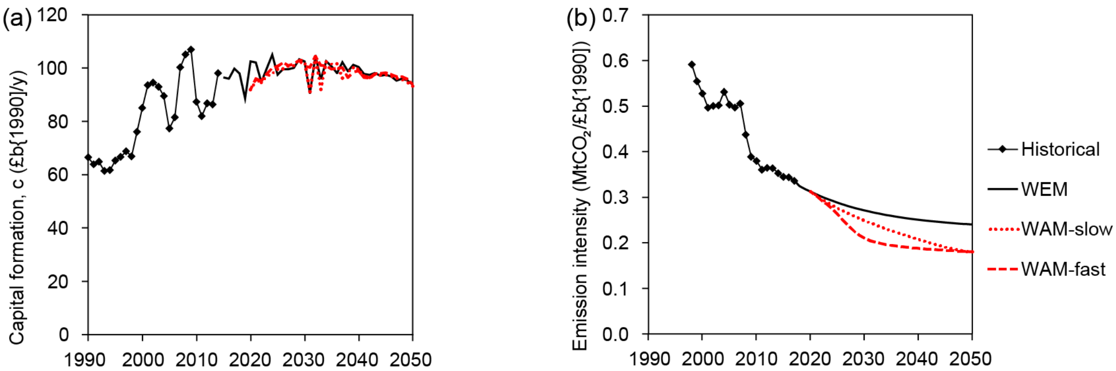

Figure 13. Factors in emissions for imported capital formation of the service industry for GBR. These relate to equation (29). These are shown for historic data and future scenarios of WEM, WAM-slow and WAM-fast. (a) Capital formation requirement, c, of the service industry. (b) Emission intensity of imported capital formation. Historical time series have been derived by calculation from source data: [50], [83].

Capital formation for the service industry rose steadily over the 1990s and reached a peak in 2008 just before the financial crisis. The scenario behaviour to 2050 is as a result of systematic interactions across our 7see model. According to our scenarios we see the level of capital formation staying at a high level as a consequence of the service industry growing.

For the emission intensity of imported capital formation (Fig. 13(b)), the historical trend is falling. Under our WEM scenario, we continue this as a best-fit exponential decay curve whose asymptote is 0.23 $MtCO_2$/£b[1990]. One policy for reducing these emissions is to bias imports away from the highest emitting exporters. In Fig. 10 we derived a composite emission intensity from the main exporters to the UK based on weighting their economy wide emission intensities by volume of imports. For the emissions from imported materials that go to capital formation, we apply the same target reduction in Fig. 7(d) of 25% for our WAM scenarios.

3.5 Emissions from domestic goods (DG)

For emissions from domestic goods, G_{DG}, these are dependent on output of the service industry as follows:

$$G_{DG} = r_{DG}(p') \tag{30}$$

where function $r_{DG}()$ is made up of time-dependent exogenous relationships: goods-in ratio to service output, $\mathrm{GR}(t)$; domestic proportion of goods, $\mathrm{DP}(t)$; emission intensity of domestic goods manufacture, $\mathrm{EI}_{DG}(t)$. Thus:

$$G_{DG} = p' \cdot \mathrm{GR}(t) \cdot \mathrm{DP}(t) \cdot \mathrm{EI}_{\mathrm{DG}}(t) \tag{31}$$

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We show the separate time behaviour of factors in equation (31) in Fig. 7(a), (b) and (d) and in Fig. 14. We show the emission intensity of manufacturing in Fig. 7(d) where measures applied include higher energy efficiency, heat from heat pumps, and hydrogen from reforming of natural gas and CCS.

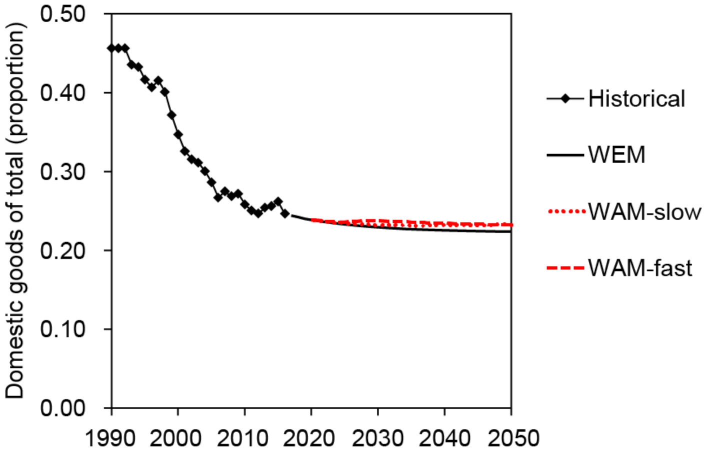

Figure 14. Domestic proportion of goods for GBR. Historical time series have been derived by calculation from source data: [50].

In our analysis of emissions from imported goods (Fig. 7), our WEM scenarios reduced the volume ratio of imports to domestic goods by 5%. When this is expressed as domestic proportion of all goods (Fig. 14), the domestic proportion increases from 22.5% to 23.3% corresponding to an increase of 3%.

For the emission intensity in Fig. 7(d) from use of fuel and electricity, the WEM scenario to 2050 is a combination of measures for fuel and electricity. For the electricity part, the emission intensity of electricity generation reaches zero by 2045. The flattening out of the scenario towards 0.25 $MtCO_2$ per £b[1990] in 2050 is for the fuel component, representing diminishing returns of implementing energy efficiency of existing measures. For the WAM scenarios, we implement measures from the CCC NZE analysis. These are 20% reduction in heat requirement intensity, provision of 100 PJ/y of zero-emission heat and application of 24 MtCO2/y emission reduction from carbon capture and storage (CCS) for some of the remaining use fossil fuel. For the zero-emission heat, this is from using renewable electricity generation to derive 50 PJ/y of hydrogen and power 50 PJ/y of heat pumps.

3.6 Measures combined

In Fig. 15(a) we show the result of combining the measures we have outlined for all the sources of emissions (in Fig. 6(b)). For domestic emissions (only) in the production approach, the zero target is missed by 7 $MtCO_2$/y. This is because the policies of the CCC have not allowed for a growing service industry, so its level of policy implementation falls short. Taking the consumption approach, emissions in 2050 are 42 $MtCO_2$/y. In terms of long-term climate impacts, it is the cumulative CO_2 that is important. The benefit of rapid implementation of reductions is clear (Fig. 15(b)) with a 22% reduction in accumulated emissions at the faster implementation rate. The difference between the WAM-slow and WAM-fast scenarios in production accounting method is 300 million tonnes (total) CO_2, and 500 million tonnes (total) CO_2 for the consumption approach to 2050.

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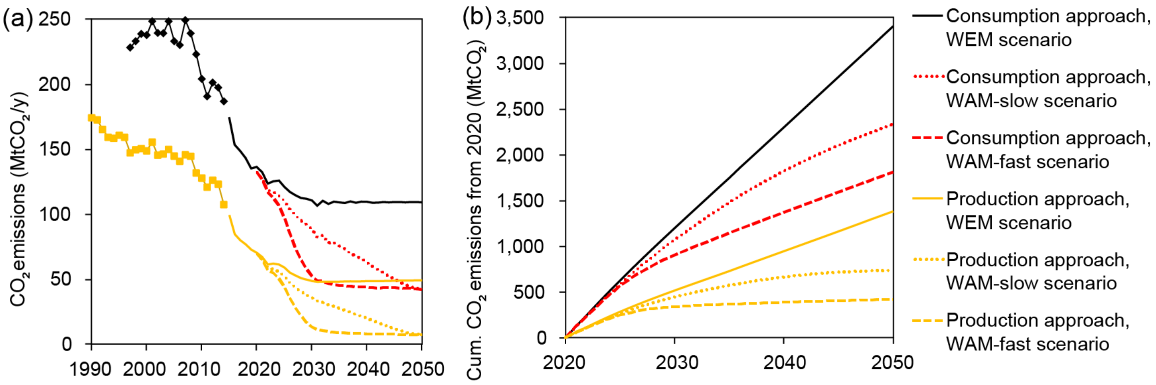

Figure 15. Consequence of measures for emissions for GBR according to approaches of production and consumption. (a) Annual emissions. (b) Cumulative emissions from 2020.

4. Conclusions

In the five modern economies assessed, the service industry drives GDP and employment, yet their energy and emissions policies do not address the full emissions impact of this industry. The service industry needs to be treated as a coherent single entity because of the volume of employment it generates. Policy for emissions reductions for intersecting areas, such has buildings and use of goods, may not be sufficiently coherent to have the effect required by a net-zero target.

In production accounting terms (excluding imports), the service industry is responsible for 17-24% of GHG emissions for the assessed countries since 1990, contrary to its perception as ‘emissions light’. This is because part of the service industry emissions footprint is from manufactured goods. We find for the UK that of six key goods inputs, four continue to grow, namely: electronic, pharmaceutical, materials and machinery. All goods inputs must be constrained and then reduced to meet emissions goals. We detail clear reduction measures but note minimal implementation to date. Since we have shown similarities of key features in our country set, the policy recommendations apply to all developed economies.

The emissions arising from offshored manufactured inputs are excluded from national GHG inventories, giving a misleading impression of progress towards stated or legislated targets. Our analysis shows that for the UK, these imported emissions represent 35 million tonnes omitted from the 2050 net-zero emissions target. We suggest that a goods import policy for the service industry must favour selecting low-emissions producers, possibly avoiding China altogether. Taking the consumption approach implies that members of our country set and similarly developed nations will miss their emissions targets unless the full emissions of their service industry is transparently included in their GHG emissions inventories.

Frequently, emissions reduction targets are stated without the intermediate steps or details of implementation. We show for the consumption approach how modelling the rate of introducing measures is as important as defining a target since it is the accumulation of CO_2 in the atmosphere that leads to the climate impact. Implementation of mitigation measures must be aggressive because although both the WAM-slow and WAM-fast scenarios reach the same end point in annual CO_2 emissions, in cumulative terms the difference between them leads to 500 million tonnes (total) CO_2 extra to 2050. Over the next 30 years, energy and emissions policy must reconcile GDP and jobs with rates of energy-provision transformation and dematerialisation.

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Appendix A. Date sources for Figures 1-2 and 4-5

Figures 1 and 2

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Appendix B. Detailed categorisation of the service industry and goods products

For categorisation of industry, we refer to the standard industrial classification of economic activities [84] used for GB national accounts [50], which is consistent with the EU standard [85]. Following convention, we define the service industry as G-S according to first level alphabetical code and as 45-96 according to second level two-digit numerical code (Table B.1).

For categorising products of goods from manufacturing for intermediate consumption by the service industry, we refer to the classification of products by activities [86]. Thus we define the goods from manufacturing as products 10.1-33OTHER, which we list in Table B.2 along with authors' aggregation into 11 groups. Since for emissions in Fig. 4 we handle transport and energy use separately, we exclude certain products from our analysis of intermediate consumption by the service industry (Table B.3).

Table B.1 Definition of service industries according to SIC2007 and authors' industry labelling.

Authors' industry labelling	SIC2007 first level	SIC2007 second level	SIC2007 industry description
Retail & wholesale	G	45	Wholesale And Retail Trade And Repair Of Motor Vehicles And Motorcycles
		46	Wholesale Trade, Except Of Motor Vehicles And Motorcycles
		47	Retail Trade, Except Of Motor Vehicles And Motorcycles
Transport & storage	H	49.1-2	Rail transport
		49.3-5	Land transport services and transport services via pipelines, excluding rail transport
		50	Water Transport
		51	Air Transport
		52	Warehousing And Support Activities For Transportation
		53	Postal And Courier Activities
Hospitality	I	55	Accommodation
		56	Food And Beverage Service Activities
Media & IT	J	58	Publishing Activities
		59 & 60	Motion Picture, Video & TV Programme Production, Sound Recording & Music Publishing Activities & Programming And Broadcasting Activities
		61	Telecommunications
		62	Computer Programming, Consultancy And Related Activities
		63	Information Service Activities
Financial	K	64	Financial Service Activities, Except Insurance And Pension Funding
		65.1-2 & 65.3	Insurance and reinsurance, except compulsory social security & Pension funding
		66	Activities Auxiliary To Financial Services And Insurance Activities
Real estate	L	68.1-2	Buying and selling, renting and operating of own or leased real estate, excluding imputed rent
		68.2IMP	Owner-Occupiers' Housing
		68.3	Real estate activities on a fee or contract basis

Professional	M	69.1	Legal activities
		69.2	Accounting, bookkeeping and auditing activities; tax consultancy
		70	Activities Of Head Offices; Management Consultancy Activities
		71	Architectural And Engineering Activities; Technical Testing And Analysis
		72	Scientific Research And Development
		73	Advertising And Market Research
		74	Other Professional, Scientific And Technical Activities
		75	Veterinary Activities
Admin	N	77	Rental And Leasing Activities
		78	Employment Activities
		79	Travel Agency, Tour Operator And Other Reservation Service And Related Activities
		80	Security And Investigation Activities
		81	Services To Buildings And Landscape Activities
		82	Office Administrative, Office Support And Other Business Support Activities
Public	O	84	Public Administration And Defence; Compulsory Social Security
Education	P	85	Education
Health †	Q	86	Human Health Activities
		87 & 88	Residential Care & Social Work Activities
Entertainment	R	90	Creative, Arts And Entertainment Activities
		91	Libraries, Archives, Museums And Other Cultural Activities
		92	Gambling And Betting Activities
		93	Sports Activities And Amusement And Recreation Activities
Other	S	94	Activities Of Membership Organisations
		95	Repair Of Computers And Personal And Household Goods
		96	Other Personal Service Activities

[†]Supplemented by final expenditure by Government.

Table B.2 For goods as input to the service industry, their definition according to CPA2008 and authors' aggregation. Since we cover fuel use and transportation separately from goods input here, we detail in Table B.3 those that we exclude from goods input. For quantification of goods input, we exclude duty on alcohol and tobacco so that their economic volume measure is in line with that of other food products.

Authors' product grouping	**CPA2008 code**	**CPA2008 product description**
Food & drink	10.1	Preserved meat and meat products
	10.2-3	Processed and preserved fish, crustaceans, molluscs, fruit and vegetables
	10.4	Vegetable and animal oils and fats
	10.5	Dairy products
	10.6	Grain mill products, starches and starch products
	10.7	Bakery and farinaceous products
	10.8	Other food products
	10.9	Prepared animal feeds
	11.01-6 & 12 [†]	Alcoholic beverages & Tobacco products
	11.07	Soft drinks

Clothing	13	Textiles
	14	Wearing apparel
	15	Leather and related products
Materials 1	16	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials
Print	17	Paper and paper products
	18	Printing and recording services
Materials 2	20.3	Paints, varnishes and similar coatings, printing ink and mastics
	20.4	Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
	20.5	Other chemical products
	20A	Industrial gases, inorganics and fertilisers (all inorganic chemicals) - 20.11/13/15
	20B	Petrochemicals - 20.14/16/17/60
	20C	Dyestuffs, agro-chemicals - 20.12/20
Pharmaceutical	21	Basic pharmaceutical products and pharmaceutical preparations
Materials 3	22 ‡	Rubber and plastic products [except where to 45]
	23.5-6	Manufacture of cement, lime, plaster and articles of concrete, cement and plaster
	23OTHER	Glass, refractory, clay, other porcelain and ceramic, stone and abrasive products - 23.1-4/7-9
	24.1-3	Basic iron and steel
	24.4-5	Other basic metals and casting
Machinery 1	25.4	Weapons and ammunition
	25OTHER	Fabricated metal products, excl. machinery and equipment and weapons & ammunition - 25.1-3/25.5-9
Electronic	26	Computer, electronic and optical products
	27	Electrical equipment
Machinery 2	28	Machinery and equipment n.e.c.
Furniture	31	Furniture
Other	32	Other manufactured goods
Repair	33.15	Repair and maintenance of ships and boats
	33.16	Repair and maintenance of aircraft and spacecraft
	33OTHER	Rest of repair; Installation - 33.11-14/17/19/20

† Excluding duty on alcohol and tobacco.
‡ Excluding tyres (by excluding supply to industry 45 of Motor Vehicles)

Table B.3 Products of fuel use and transportation we exclude from goods as input to the service industry.

CPA2008 code	CPA2008 product description
19	Coke and refined petroleum products
22 (where to industry 45) †	Rubber and plastic products
29	Motor vehicles, trailers and semi-trailers
30.1	Ships and boats
30.3	Air and spacecraft and related machinery
30OTHER	Other transport equipment - 30.2/4/9

† Predominantly tyres.

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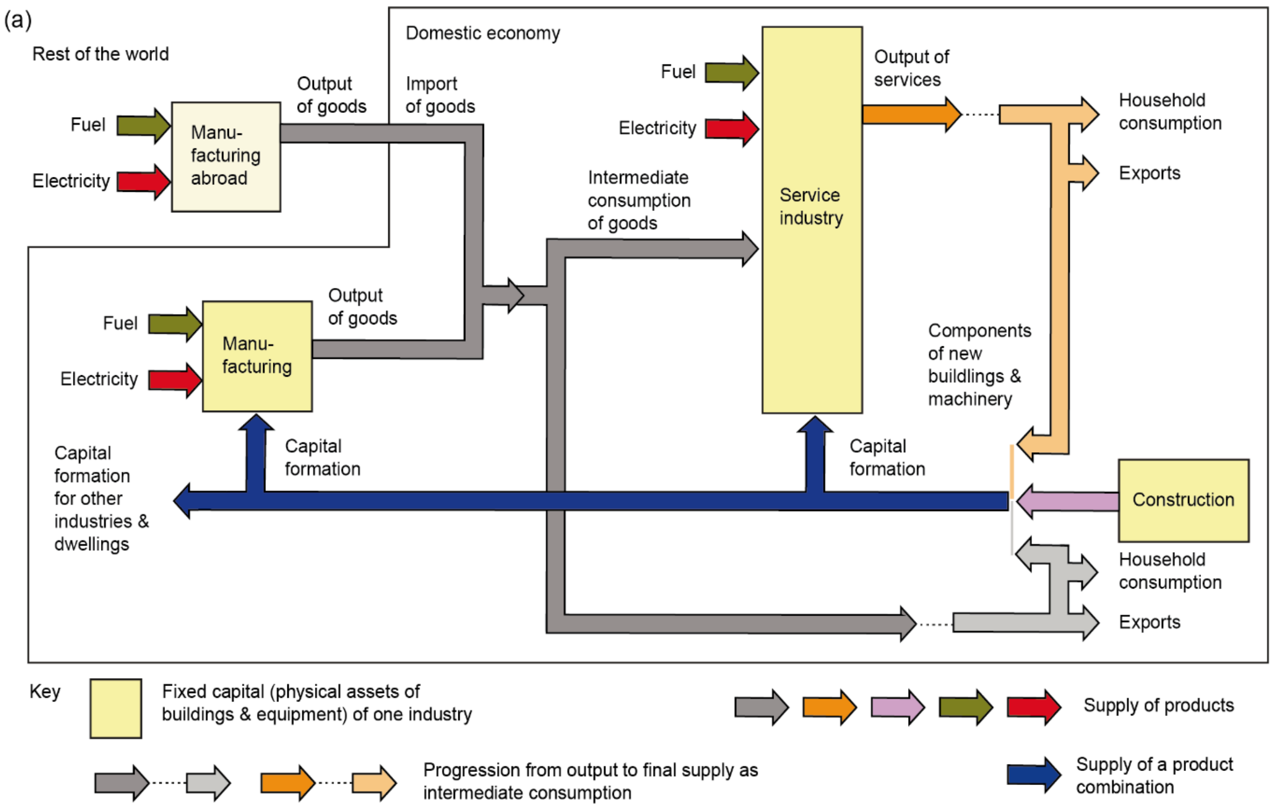
Appendix C. Types of flows in a 7see model

We show in Fig. C.1(a) flows of several products according to: their source where arrows leave boxes and their use where arrows terminate at boxes. The boxes represent the infrastructure of industry for domestic service industry and manufacturing, and manufacturers of goods imported to the domestic economy. The sources of CO_2 emissions associated specifically with activity of (production by) the service industry are based on fuel and electricity emissions used at three points of production. These are emissions: by the service industry itself, intermediate consumption by the service industry of goods from domestic manufacturing and intermediate consumption of goods from imports of manufacturing in the rest of the world.

Fig. C.1(a), also shows the draw of (gross fixed) capital formation (GFCF) each industry needs to maintain and grow the fixed capital of its infrastructure. Capital formation is made up of a combination of products from the service industry, manufacturing and construction. We ensure that emissions associated with capital formation are weighted appropriately and not double-counted. We exclude fuel and electricity use by construction since it is negligible in this analysis.

To assign emissions from the uses of fuel and electricity to the service industry, we use economic volume flows, measured in deflator-corrected monetary units. For goods used by the service industry, we weight emissions by comparing the economic volume flow of its intermediate consumption to total availability of goods as the sum of domestic production by manufacturing and imports.

In Fig. C.1(b) we swap to a demand perspective, or requirement, by reversing the arrow directions. The starting point is on the right of 'Demand for services'. By dashed lines and bowtie symbols we include dependencies which the 7see model uses to set the levels of demand. The relationship between demand for services and actual output is described fully in [40].



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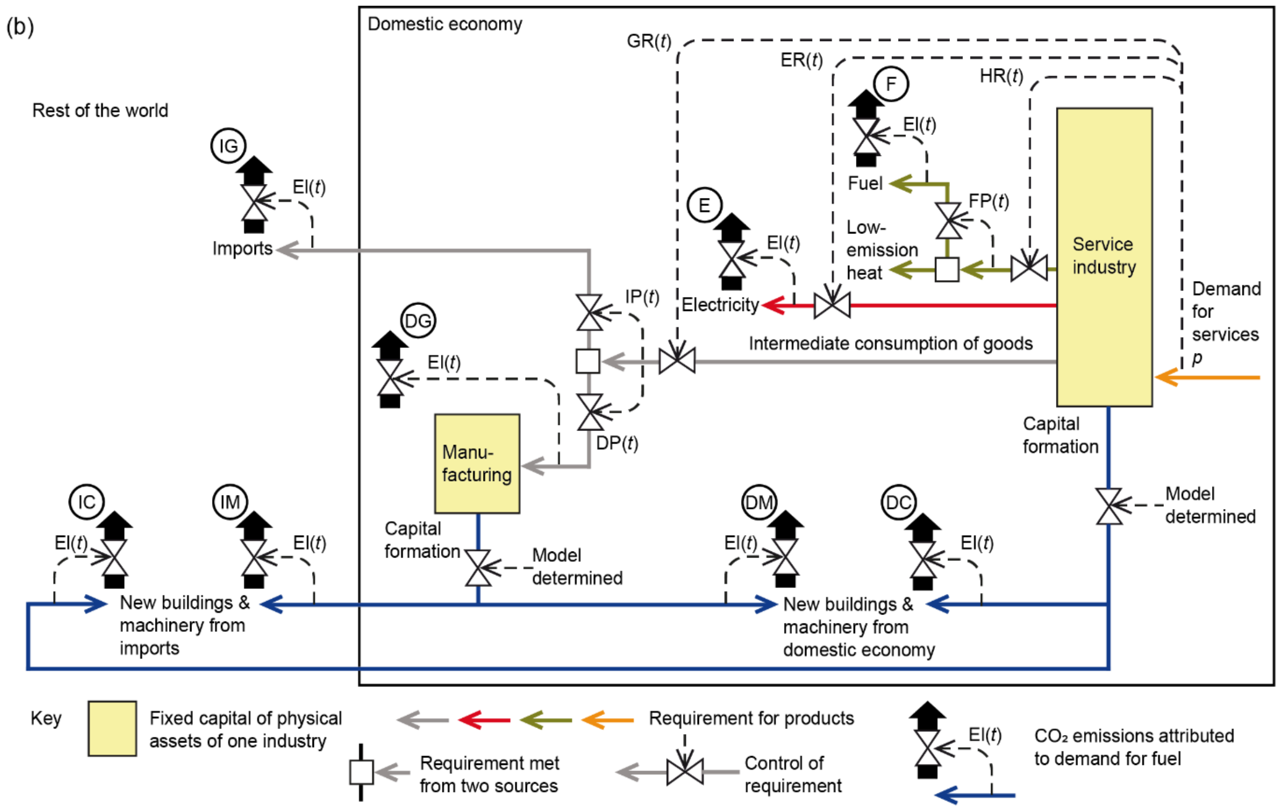

Figure C.1. Schematics of flows in a 7see model as they relate to the service industry, manufacturing and imported goods. (a) Supply flows of energy forms (fuel and electricity), goods, services and capital formation (new buildings and machinery). (b) Demand (thin arrows) for energy forms, goods, services and capital formation. Dashed lines show how demand is interrelated leading to emission of CO_2. Circled letters reference the types of emissions in Fig. 7(b): DC, domestic capital formation; DG, domestic goods; DM, domestic capital formation of manufacturing; E, electricity; F, fuel; IC, imported capital formation; IG, imported goods; IM, imported capital formation of manufacturing. Abbreviations: DP(t), domestic proportion; EI(t), emission intensity; ER(t) electricity requirement intensity; FP(t), fuel proportion; GR(t), goods requirement intensity; HR(t), heating requirement intensity; IP(t), imports proportion; p, output.