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What structural change is needed for a post-growth economy: A framework of analysis and empirical evidence

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ABSTRACT

In order to avoid environmental catastrophe we need to move to a post-growth economy that can deliver rapid reductions in environmental impacts and improve well-being, independent of GDP growth. Such a move will entail considerable structural change in the economy, implying different goals and strategies for different economic sectors. So far there are no systematic approaches for identifying the desired shape of structural change and sectoral goals in terms of output, demand and employment. We present a novel analysis that addresses this gap by classifying economic sectors into groups with similar structural change goals. Our framework for the classification considers sectoral characteristics along three dimensions, which are (a) the final energy intensity, (b) the potential and desirability for labour productivity growth and (c) the relationship between labour productivity and the energy-labour ratio. We present empirical evidence on the three framework dimensions for economic sectors in the UK and Germany and derive structural change goals for the four sector groups representing particular combinations of the sector characteristics. Our analysis allows us to discuss the specific role of different economic sectors in the structural change envisioned in the post-growth transition and the most important challenges they might be facing.

1. Introduction

To avoid serious environmental crises, global society needs to drastically reduce resource use and eliminate global greenhouse gas (GHG) emissions in a few decades (IPCC, 2018; UNEP, 2016). Up to now, growing GHG emissions and resource use have been closely coupled to growing economic activity, as measured by GDP (Csereklyei et al., 2016; Wiedmann et al., 2015). As long as global GDP continues to grow, achieving the necessary reductions in GHG emissions and resource would require rates of decoupling that are much higher than any rates achieved in the past (Haberl et al., 2020; Hickel and Kallis, 2019; Parrique et al., 2019; Wiedenhofer et al., 2020). Achieving the necessary reductions in GHG emissions and resource use will therefore likely (but not certainly) lead to reductions in GDP growth rates and even in GDP levels in high-income countries (Kallis, 2018, p. 112). Without a radical economic transformation, such reductions in GDP growth rates or levels will have detrimental social impacts (Jackson, 2017, pp. 82–83).

High-income countries therefore face the challenge of transforming their economies to simultaneously increase human well-being and deliver the necessary reductions in GHG emissions and resource use, independent of whether GDP grows or contracts. Fortunately, GDP is not a good measure of human well-being, so the challenge is difficult but not impossible (Costanza et al., 2014; Stiglitz et al., 2010). We refer to an economy that meets this challenge as a 'post-growth economy' following Jackson and Victor (2011) and Jackson (2017, p. 160). The literature features other, similar approaches under the terms of degrowth (D'Alisa et al., 2015; Kallis, 2018) or steady-state economics (Daly, 2008; Dietz and O'Neill, 2013). For the purpose of our article the commonalities of these approaches are more important than their differences and we will refer to them collectively as the 'post-growth literature'.

The transformation to a post-growth economy will not affect all sectors of the economy equally. Production and consumption will have to be reduced in some sectors but expanded in others, leading to changes in the sectoral composition of output, demand and

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employment (Kallis, 2011). For the purpose of our study we refer to such changes in the sectoral composition as 'structural change', although structural change in a wider sense can also refer to other aspects, such as institutions, industrial organisation or technology (Ciarli and Savona, 2019).

Even though structural change is recognised as an important feature of the post-growth transition, the post-growth literature does not yet provide a systematic discussion of the structural change that is desired and of how it can be achieved. Scattered references identify sectors considered harmful to the post-growth transition, such as marketing (Dietz and O'Neill, 2013, p. 96), speculative finance (Daly, 2008) or resource extraction (Sekulova et al., 2013). A somewhat more comprehensive discussion is provided of the sectors that are desired. This discussion focuses especially on the provision of labour-intensive services to create meaningful employment (Jackson, 2017, pp. 147–149; Jackson and Victor, 2011).

Such discussions of specific sectors are a useful starting point for a post-growth structural change analysis, but they have not been integrated into a comprehensive framework that systematically identifies sector goals and strategies. Without such a framework the post-growth literature leaves many open questions on structural change, for example: Which sectors specifically need to expand or shrink in terms of their output or employment share? And what does that mean for sector-specific goals, for example with regard to labour productivity or energy intensity?

Developing a framework that can answer such questions would advance the post-growth agenda in three ways. Firstly, given that structural change will inevitably be part of the post-growth transition, the development of effective strategies to achieve the transition will require a clear picture of the structural change needed, including sector-specific goals and strategies. Secondly, such a framework helps to make the often abstract vision of the post-growth economy more concrete, because it describes a vision for specific sectors, while still maintaining a comprehensive view of the whole economy. Thirdly, having such a concrete vision can help with the communication of post-growth ideas to policy-makers and businesses. Policy makers and businesses are familiar with using sectoral approaches, even if the goals they pursue are different from the objectives of a post-growth economy. For example the UK government has developed sector roadmaps for energy efficiency (e.g. DECC, 2015) and includes "sector deals" in its industrial strategy (HM Government, 2017). Similarly, the German Council of Economic Experts (2019) suggests that "there could be justification for a vertical policy intervention that is tailored to individual sectors or technologies".

To address this gap in the post-growth literature we present a novel framework to systematically define the structural change required for a post-growth economy. We use the framework to classify economic sectors in the UK and Germany into groups and define the sectoral goals for each group with regard to the sectoral share in output, final demand and employment as well as with regard to sectoral labour productivity growth. Sectors are allocated into groups based on their characteristics along three dimensions, derived from the overarching structural change objectives for a post-growth economy. The three dimensions are (a) the sectoral final energy intensity, (b) the potential and desirability of labour productivity growth and (c) the relationship between the growth in labour productivity and the growth in the energy-labour ratio. For each sector in the UK and Germany we present empirical evidence on each of the three dimensions from both a direct and an embodied perspective.

We build on the analysis presented in Hardt et al. (2020) but go beyond its results to present a new and complementary analysis as well as new results. Firstly, Hardt et al. (2020) focus specifically on labour-intensive services. The analysis we present here covers the whole economy outlining sector goals and discussing challenges for all parts of the economy. Secondly, Hardt et al. (2020) only investigate the embodied energy intensity and embodied labour productivity growth rates. The analysis we present here adds new results regarding an important third dimension, namely the relationship between labour productivity and the energy-labour ratio. Thirdly, Hardt et al. (2020) consider only sectoral characteristics from an embodied perspective. The analysis we present here compare the sectoral characteristics from a direct and embodied perspective.

Based on the analysis and discussion we highlight important gaps in current research on the post-growth transition and identify where more research and democratic discussion is needed to determine sector goals and policies to achieve them. Our analysis is intended as a first demonstration of our framework as applied to the economy as a whole. It therefore faces limitations in terms of the level of sectoral detail and depth of discussion in each sector. We envision our framework to be further developed and applied across different scales in the future, for example to guide the development of more fine-grained strategies for different sectors in different countries.

2. Analytical approach

2.1. Definition of economic sectors

We are concerned with structural change in terms of the sectoral composition of the economy, which requires a classification of economic sectors. We use the sectoral classification from the system of national accounts, because it allows us to use the available data on sectoral gross value added (GVA), final demand and employment.

Within the framework of national accounts, economic sectors can be represented from two perspectives. We refer to the first as the direct perspective, because it defines economic sectors by similar activities. From a direct perspective the Transport Equipment sector includes all businesses producing transport equipment. Sectoral data are conventionally presented from a direct perspective in the national accounts. We refer to the second perspective as the embodied perspective, because it defines economic sectors based on the supply chain inputs of a product or unit of final demand. From an embodied perspective the Transport Equipment sector includes not only the assembly of the equipment itself but also all the intermediate inputs used in the production process, such as steel, computer software or electricity. Embodied sectors can be derived from the input-output tables published as part the national accounts. An embodied perspective has been employed for structural change analysis (Pasinetti, 1993; Pasinetti, 1981) as well as for the analysis of emissions or energy use embodied in trade (e.g. Barrett et al., 2013; Lan et al., 2016).

The direct and embodied perspectives are complementary and we present empirical results and discuss sectoral strategies from both perspectives. The direct perspective is important because it can be related to real businesses and therefore allows the development of targeted policies for different processes. However, the direct perspective does not take into account the interconnections between different sectors. The embodied perspective captures the interconnectedness of economic supply chains and therefore helps to assess whether changes in direct sectors are consistent with overarching objectives. However, embodied sectors are more difficult to relate to real businesses as businesses are often part of the supply chains of many final demand sectors.

2.2. A framework for structural change

The post-growth literature does not feature a systematic discussion of structural change. But we can identify the goals post-growth economists want to achieve from structural change by analysing the references to sectors that are desired or not. Three overarching objectives stand out (Fig. 1). Firstly, increasing the share of sectors with lower environmental impact will reduce the overall environmental impact of economic production (Cosme et al., 2017). Here we focus on final energy use as one important element of environmental impact. Secondly,

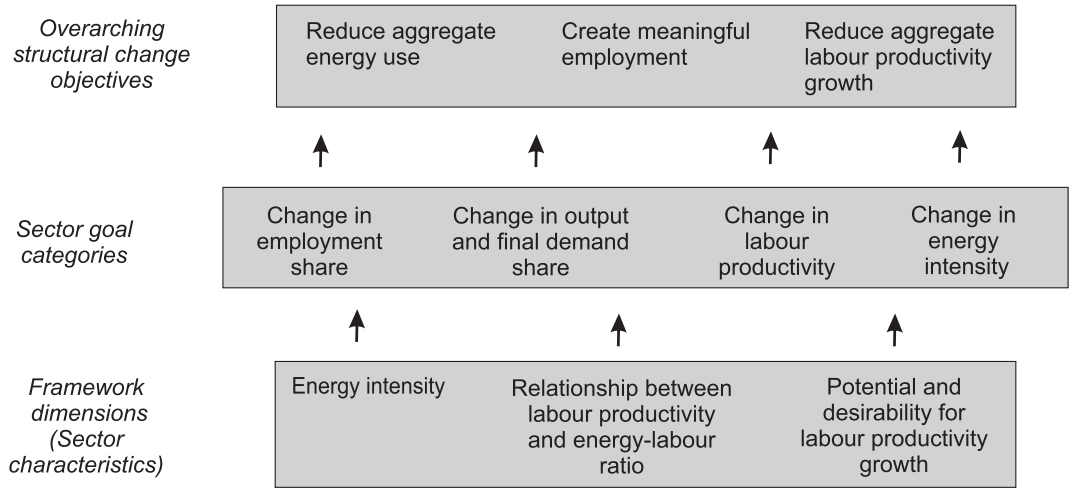

Fig. 1. Framework for determining individual sector goals.

increasing the share of labour-intensive sectors can provide meaningful employment and offset job losses from reduced production or increased labour productivity in other sectors (Jackson, 2015). Thirdly, increasing the share of sectors with low labour productivity growth can reduce harmful economic growth in two ways. It reduces aggregate labour productivity growth (Jackson, 2017, p. 149; Jackson and Victor, 2011), and it redirects the expenditure of economic surplus towards activities that do not increase productive capacity (Kallis, 2018, p. 123).

The purpose of our framework is to translate the three overarching objectives into goals for specific sectors. We specifically identify sector goals in four categories (Fig. 1). The first category is the change in the sector share in output and final demand, where the goal could be an increase or a decrease in the sector share. The second category is the change in the sectoral employment share. The two categories effectively break down the structural change in the economy into its sector-specific components. But it is difficult to determine the goals in the in the first two categories without knowing the desired changes to sectoral labour productivity and energy intensity. We therefore add a third category, which is the change in labour productivity, and a fourth category, which is the change in energy intensity. Applying the framework produces for each economic sector a set of goals, describing whether the sector share in output, final demand, and employment is expected to increase or decrease and whether labour productivity and energy intensity are expected to increase or decrease.

How the three overarching objectives are translated into sector-specific goals is determined by the inherent characteristics of different sectors. For example the output share of energy-intensive steel production needs to be reduced to achieve the overarching objective of reducing aggregate energy use. While the sectoral goals might seem obvious for some sectors, difficulties arise where there are trade-offs between the different goals. For example, taken on their own, energy intensity reductions are desirable in all sectors. But in some sectors reductions in energy intensity might clash with the goal of labour productivity growth. To strike a balance between comprehensiveness and ease of application we determine sector goals based on sector characteristics in three dimensions. The three dimensions are the energy intensity, the potential and desirability for future labour productivity growth and the relationship between labour productivity and the energy-labour ratio (Fig. 1).

The three dimensions omit any assessment of the ability of a sector to contribute to the provision of basic human needs and well-being. Arguably, such an ability is a key determinant for the sector goals in the transition to a post-growth economy. We omit such a dimension in our framework because it cannot be assessed based on economic statistics alone and requires democratic discussion. Our framework can therefore give indications about the directions of the sector goals but not necessarily the desired magnitude of change. For example we identify sectors in which final demand should be reduced. But in order to determine by how much it should be reduced, further assessment of the contribution of such sectors to human well-being is necessary.

2.2.1. *Dimension 1: final energy intensity*

The first dimension describes the final energy intensity of a sector. We include final energy intensity in the framework because it determines how much a change in the sector share in output or final demand can contribute to the overarching objective of reducing aggregate energy use. It also determines the importance of further energy intensity reductions in the sector in comparison with other goals.

For the purpose of our analysis we focus on final energy intensity at the expense of other measures of environmental impact, such as GHG emissions or resource use. We do so for two reasons. Firstly, final energy use is closely related to other environmental impacts, such as carbon emissions and nitrogen pollution (Owen et al., 2017). Secondly, final energy use features a prominent role in the post-growth literature because it is related to labour productivity growth (see Section 2.1.3). Further research that extends our framework to include other measures of environmental impact would be a useful addition to the post-growth literature.

We define the direct energy intensity of a sector as the direct final energy consumption per Euro of gross value added in constant prices, as is commonly done in the literature (Hammond and Norman, 2012). We define the embodied energy intensity for each sector as the embodied final energy consumption per Euro of final demand in constant prices. We restrict the analysis to the domestic components of final demand, as price deflators for non-domestic components are not readily available.

For the purpose of allocating economic sectors into groups we distinguish two types of sectors, namely sectors of high energy intensity and those of low energy intensity. We will refer to sectors of high energy intensity as energy-intensive sectors and to sectors with low energy intensity as energy-light sectors.

2.2.2. *Dimension 2: potential and desirability of labour productivity growth*

The second dimension describes the potential and desirability of labour productivity growth in a sector. We include the dimension in the framework because it determines how changes in the employment and output share of a sector can contribute to the overarching objectives of creating meaningful employment and reducing aggregate labour productivity growth. By definition the dimension also determines how desirable changes in the labour productivity are for a sector. The desirability of and potential for labour productivity growth are two

separate but related aspects and could therefore be treated as two separate dimensions. We combine the two aspects into one dimension to keep the application of the framework simpler.

Because the dimension combines two aspects, it can refer to different kinds of sectors. Some sectors have a very low potential for increasing labour productivity. In such sectors the value of the output is mostly determined by the labour time invested. Any reductions in labour inputs would reduce the quality of the output (e.g. care services). While such sectors are often seen as desirable for creating employment in a post-growth economy, they do not necessarily provide high-quality work (Druckman and Mair, 2019). In other sectors it is possible to increase labour productivity but it might be undesirable. The post-growth literature offers several potential reasons for the undesirability of labour productivity growth in a sector. Labour productivity growth can eliminate meaningful jobs, for example if highly skilled craft work is replaced by repetitive factory work (Mair et al., 2020; Nørgård, 2013). Labour productivity growth can harm the well-being of workers if it increases job demands or job insecurity (Isham et al., 2020). Labour productivity growth can also come at the cost of worsening environmental impacts. Factory workers might be replaced by energy-intensive machines or farm workers by bee-harming pesticides. Indirectly, labour productivity growth may increase environmental impacts if it makes environmentally-damaging products cheaper than environmentally-friendly ones (Baumol, 2012, pp. 71–73).

To classify economic sectors in our framework we distinguish only two potential values for the dimension. We refer to labour-light sectors as those sectors that have a high potential for labour productivity growth and a high desirability to realise such potential. We refer to labour-intensive sectors as those sectors that have either a low potential for labour productivity growth or a low desirability of labour productivity growth.

Assessing the dimension empirically presents a challenge. In our empirical analysis we assess only the potential for labour productivity growth but not its desirability. To assess the desirability of labour productivity growth we would need to analyse of the potential of a sector to provide meaningful work. While such an analysis is possible, it lies beyond the time and resource constraints of our research project. The lack of such an analysis is an important limitation of our study and of the wider post-growth literature. More empirical research into the desirability of labour productivity growth in different sectors is vital for the development of a post-growth strategy.

In order to assess the potential of future sectoral labour productivity growth we use the historic rates of labour productivity growth as an indicator. Using historic rates has the advantage that they can be calculated easily and consistently across economic sectors from existing data. But there are also large uncertainties in how far historic rates of labour productivity growth will be similar to future rates. For example past labour productivity growth might have exhausted the potential for further growth in some sectors, or the development of new technologies might redistribute the potential for labour productivity growth between sectors (Frey and Osborne, 2017).

We define the direct sectoral labour productivity as the sectoral GVA in constant prices divided by the hours of direct labour inputs. We define the embodied labour productivity as the amount of final demand in constant prices per embodied hour worked. We obtain the annual compound rate of growth in direct and embodied labour productivity in each sector by fitting a log-linear regression model over the whole time period (Gujarati, 1995, pp. 169–171). High and low values for potential labour productivity growth are assigned based on absolute rates, with growth rates above 1% per year being considered high and growth rates below 1% per year being considered low.

2.2.3. Dimension 3: relationship between labour productivity and the energy-labour ratio

The third dimension in our framework describes the relationship between the growth in labour productivity and the growth in the energy-labour ratio in different sectors. We include the dimension in the framework because it is important for assessing the potential trade-offs between sector goals. The previous two dimensions treat energy intensity and labour productivity separately and do not consider potential trade-offs between different goals. To explore such trade-offs, it is useful to decompose the growth in energy intensity into the growth of the energy-labour ratio and the growth of labour productivity (Semieniuk, 2015). The relative size of the growth rates of these two variables then determines the change in energy intensity. The energy-labour ratio describes the energy used per unit of work and can give an indication whether increases in labour productivity have been achieved by increasing the energy utilised by workers.

Empirical evidence indicates that historical growth in aggregate labour productivity has been associated with a growing energy-labour ratio (Kander et al., 2013; Semieniuk, 2015). On a sectoral level the evidence on the relationship between labour productivity and the energy-labour ratio is limited. Two studies by Mulder and de Groot (2004) and Witt and Gross (2019) suggest that there might be a correlation between growth in labour productivity and in the energy-labour ratio in the manufacturing and transport sectors, but not in the service sectors.

To classify economic sectors in our framework we divide sectors into two groups, depending on whether the changes in the energy-labour ratio and labour productivity are positively or negatively correlated. It is also possible that they are uncorrelated. The implications of 'no correlation' for the sector goals are either the same as for 'positive correlation' or the same as for 'negative correlation', depending on the results for the other framework dimensions. Sectors without a correlation will therefore be attributed to one of the two groups accordingly.

For our empirical analysis, we calculate the rates of change in the direct and embodied energy-labour ratio. The direct energy-labour ratio is the direct final energy consumption divided by the hours of direct labour inputs. The embodied energy-labour ratio is the embodied final energy consumption divided by the embodied amount of hours worked. We assess the relationship between the change in the energy-labour ratio and labour productivity growth by examining the sign and relative magnitude of the average growth rates in both variables. We do not perform a statistical assessment of the formal correlation between the variables in each sector. Doing so would require the implementation of several statistical tests for each sector, the description and discussion of which is beyond the scope of this article. In the future, however, it would be useful to explore the relationship between the energy-labour ratio and labour productivity at a sectoral level using more sophisticated econometric methods.

2.3. Sector goals

Based on the sector characteristics in the three framework dimensions, we identify the sector goals in each sector. For the purpose of our study, sectors can only be assigned one of two possible values in each of the three dimensions, for example they are either energy-intensive or energy-light. Two values in three dimensions gives eight possible combinations of sector characteristics. Each of the eight combinations represents a group of sectors with its own set of goals, derived from their specific characteristics. Table 1 provides an overview of those sectors goals for the different groups. To increase the clarity of presentation and discussion, we group the eight possible combinations into four overarching groups based on the first two dimensions. Each of these four groups has then 2 subgroups according to the characteristic in the third dimension.

The goals outlined in Table 1 are derived purely from theoretical considerations. In summary, the need to reduce the overall energy use in the economy suggests that output and energy use associated with sectors of high energy intensity should be reduced relative to other sectors. In addition labour productivity growth in the labour-light sectors should be supported. However, the share of the labour-light sectors in economic output, demand and employment should be

Table 1
Overview of proposed framework dimensions and sector-specific policy goals for a post-growth economy.

Sector group	Framework dimension (sector characteristics)			Sector goals			
	Dimension 1: Energy intensity	Dimension 2: Potential and desirability of labour productivity growth	Dimension 3: Relationship between labour productivity and energy-labour ratio	Sector share in output and final demand	Sector share in employment	Labour productivity	Energy intensity
Group 1	High	High potential and desirability	Positive correlation	Reduce	Reduce	Increase, but balance with increasing energy intensity	Reduce, but balance with increasing labour productivity
			Negative correlation or uncorrelated	Reduce	Reduce	Increase	Reduce
Group 2	High	Low desirability or potential	Positive correlation or uncorrelated	Reduce	Unclear, depends on balance between changes in output and labour productivity	Maintain or reduce, especially if it reduces the energy-labour ratio and energy intensity	Reduce, but balance with reductions in labour productivity if desirable
			Negative correlation	Reduce	Will probably be reduced	Maintain or increase in order to avoid increasing energy intensity	Reduce
Group 3	Low	Low desirability or potential	Positive correlation or uncorrelated	Increase	Increase	Maintain or reduce	Will be reduced unless labour productivity falls faster than energy-labour ratio
			Negative correlation	Increase	Increase	Maintain in order to avoid increasing energy intensity	Reduce
Group 4	Low	High potential and desirability	Positive correlation	Unclear, depends on necessity	Will likely fall	Increase, but balance with increasing energy intensity	Reduce, but balance with increasing labour productivity
			Negative correlation or uncorrelated	Unclear, depends on necessity	Will likely fall	Increase	Reduce

reduced relative to the labour-intensive sectors, in order to reduce aggregate labour productivity growth and create meaningful employment. Energy intensity should also be reduced throughout the economy, but there might be trade-offs with labour productivity goals, depending on the relationship between labour productivity and the energy-labour ratio. The resolution of these trade-offs depends on the other characteristics in each sector.

In practice, some combination of sector characteristics are likely to be more prevalent than others and some might not exist at all. We therefore discuss the sector goals in more detail in Section 4 in the context of our empirical results.

2.4. Empirical data

We demonstrate the application of our framework by providing empirical estimates for the three framework dimensions and for different economic sectors. We calculate sectoral values for final energy intensity, the rate of change in labour productivity and the rate of change in the energy-labour ratio, both from a direct and embodied perspective. Our empirical evidence covers sectors in the UK and Germany between 1995 and 2011.

Our empirical results build on the work of Hardt et al. (2020) and we utilise their estimates of embodied final energy intensity and the rate of change in embodied labour productivity. We extend the analysis by calculating the rate of change in the embodied energy-labour ratio as well as presenting direct measures for all three dimensions.

Our analysis draws on the EXIOBASE V3.4 database, which provides data on the global economy from 1995 to 2011 (Stadler et al., 2018). EXIOBASE disaggregates the economy into 163 sectors based on the NACE rev. 1.1 classification. For our analysis we aggregate all the data to a level of 70 sectors. For presentation, the results are further aggregated into 21 sectors (Table A1, Appendix). By definition, energy-producing sectors, such as coal mining, oil refining or electricity production, do not feature a final energy consumption. Energy-producing sectors are therefore not included in the 21 sectors for which results are presented. In addition we exclude the Real Estate sector from the empirical analysis, because the large fraction of real and imputed rents in the sector makes it difficult to calculate meaningful values of labour productivity.

From EXIOBASE we obtain (a) symmetrical input-output tables indicating the flows of intermediate demands between all sectors in all countries, (b) the final demand for products from different sectors in the UK and Germany, (c) the sectoral gross value added (GVA) for sectors in the UK and Germany and (d) the labour inputs for each sector in the global economy in terms of total hours worked. EXIOBASE provides all monetary data in current prices only. We convert the data on GVA and final demand to constant 2010 prices using GVA deflators obtained from the Eurostat database (Eurostat, 2018).

To calculate the direct and embodied final energy use for each economic sector we use the energy extension vector calculated by Hardt et al. (2020). The extension vector is based on data from the IEA World Energy Balances (IEA, 2018), with additional detail for the UK and Germany obtained from country-specific sources. For brevity we will use the term 'energy' to describe final energy inputs in the reminder of this article. More details on the method for calculating the direct and embodied energy measures can be found in Hardt et al. (2020).

3. Empirical sector classification

3.1. Group 1: energy-intensive and labour-light sectors

Group 1 includes sectors that are energy intensive and have a high potential and desirability for labour productivity growth. In the empirical classification we present here, we only consider the potential of labour productivity growth, as indicated by past rates, but not the desirability of labour productivity growth. We allocate the manufacturing

Table 2
Energy intensity and annual rates of change in labour productivity and energy-labour ratio for sectors in the UK.

UK	Direct measures			Embodied measures		
Sector	Energy intensity (MJ/EUR)	Labour productivity change (%)	Energy- labour ratio change (%)	Energy intensity (MJ/EUR)	Labour productivity change (%)	Energy- labour ratio change (%)
Group 1						
Agriculture, Forestry, Fishing	3.5	4.1	−0.5	3.7	3.3	−1.5
Food, Beverages and Tobacco	7.1	3.7	0.9	5.5	1.7	−0.8
Textiles, Clothes, Leather	4.8	4.8	6.6	4.5	3.0	3.0
Paper, Printing, Publishing	5.1	3.0	2.0	5.2	2.3	0.4
Chemicals	8.5	6.4	0.2	6.5	3.3	−1.7
Metals and Fabricated Metal Products	8.9	3.1	−3.5	6.1	1.9	−1.7
Machinery, Electrical Equipment, Computers	1.8	5.6	2.2	4.5	3.3	−1.1
Transport Equipment	3.3	5.4	0.8	6.6	3.4	−1.4
Other manufacturing	11.6	3.2	4.8	9.5	1.6	2.3
Transport	13.6	3.0	0.8	13.6	1.6	−0.8
Group 2						
Mineral Products	3.8	−1.2	3.1	4.1	−2.7	−1.2
Construction	0.6	−0.2	−3.1	1.9	−1.0	−1.2
Group 3						
Hotels and Restaurants	1.1	1.0	−1.1	1.3	0.0	−1.4
Public Administration	1.2	−0.6	−4.4	1.7	−0.5	−2.0
Health	1.4	−2.8	−5.0	1.7	−2.5	−3.3
Education	0.8	1.1	−2.9	1.7	0.6	−0.1
Other Services	2.0	0.8	−0.1	2.2	0.0	−0.7
Group 4						
Wholesale and Retail Trade	1.8	2.6	0.6	2.0	2.6	0.5
Finance and Insurance	0.2	6.6	2.4	1.4	3.5	−1.2
IT and Communication	0.7	7.9	1.4	1.7	6.9	0.0
Business Services	0.7	3.7	0.8	1.4	2.6	−1.3
Real Estate	–	–	–	–	–	–

sectors (with the exception of Mineral Products) as well as the Agriculture, Forestry, Fishing sector and the Transport sector to Group 1.

All of the Group 1 sectors have a direct and embodied energy intensity of more than 3 MJ/EUR, which compares to direct and embodied energy intensities between 0.2 and 2.3 MJ/EUR for the sectors in Group 3 and Group 4 (Tables 2 and 3). The only exceptions are the Machinery, Electrical, Equipment, Computers sector and the Transport Equipment sector which values of direct energy intensity that are lower than 3 MJ/EUR and in the same range as the service sectors. While these sectors could therefore be considered energy-light, they feature considerably higher values for embodied energy intensity, indicating that they rely on energy-intensive inputs in the supply chain.

Group 1 sectors also exceed 2% annual growth in direct labour productivity in both countries. The exception is the Food, Beverages and Tobacco sector which only achieves such rates in the UK (Tables 2 and 3). Our estimates are in line with results in the literature that have estimated high rates of direct labour productivity growth for the manufacturing, agriculture and transport sectors across different high-income countries and time periods (Baumol et al., 1985; Maroto and Rubalcaba, 2008; Mulder and de Groot, 2004). Growth in embodied labour productivity, however, is generally lower than growth in direct labour productivity in Group 1 sectors (Tables 2 and 3). In the UK, embodied labour productivity growth in all Group 1 sectors still exceeds 1.5% per year. In contrast, embodied labour productivity growth in most of Germany's Group 1 sectors is well below 1% or even negative. It seems that the growth in direct labour productivity in Germany's Group 1 sectors has been offset by lower labour productivity growth in other parts of the supply chain. Given the short time frame of our analysis we cannot say whether the pattern of low embodied labour-productivity growth in Germany's Group 1 sectors presents a long-term trend.

The third dimension of the framework asks whether labour productivity growth in Group 1 sectors has been associated with growth in the energy-labour ratio. Most, but not all, Group 1 sectors show a positive growth rate in the direct energy-labour ratio in combination with growth in direct labour productivity (Fig. 2). Generally, the growth rate of the direct energy-labour ratio is below the growth rate of direct labour productivity, leading to a decline in direct energy intensity. In contrast, the embodied energy-labour ratio declines in most Group 1 sectors in both countries, sometimes in combination with increasing embodied labour productivity and sometimes in combination with decreasing embodied labour productivity.

3.2. Group 2: energy-intensive and labour-intensive sectors

In our empirical classification Group 2 includes sectors with high energy intensity but low rates of labour productivity growth. We allocate the Mineral Products and Construction sectors to Group 2.

The Mineral Products sector is the only sector that mostly fits these characteristics. Its direct and embodied energy intensity exceeds 3.8 MJ/EUR in both countries (Tables 2 and 3). It also features a declining direct and embodied labour productivity in the UK and only a growth of 0.3% in embodied labour productivity in Germany. Only the direct labour productivity growth in Germany defies the pattern with a 3.3% annual rate of growth.

We also allocate the Construction sector to Group 2, because it shows low rates of direct and embodied labour productivity growth. The Construction sector does not strictly fit the characteristics of Group 2 because its energy intensity is low, with values of 1 MJ/EUR or below for direct energy intensity and values below 3 MJ/EUR for embodied energy intensity. We still consider it useful to allocate the sector to Group 2 because it shows large environmental impacts in other aspects, particularly a high material intensity (Giesekam et al., 2014).

The relationship between labour productivity and the energy-labour ratio varies between the two sectors. In the Construction sector, the two variables consistently change in the same direction, in both countries and both from a direct and embodied perspective. For the Mineral

Table 3
Sectoral energy intensity and rates of change in labour productivity and energy-labour ratio for sectors in Germany.

Germany (DE)	Direct measures			Embodied measures		
Sector	Energy intensity (MJ/EUR)	Labour productivity change (%)	Energy- labour ratio change (%)	Energy intensity (MJ/EUR)	Labour productivity change (%)	Energy- labour ratio change (%)
Group 1						
Agriculture, Forestry, Fishing	9.6	4.3	1.7	7.1	2.4	−1.0
Food, Beverages and Tobacco	5.8	−1.3	−0.4	4.6	−2.0	−2.1
Textiles, Clothes, Leather	6.5	3.7	1.9	5.3	−0.2	−2.1
Paper, Printing, Publishing	7.6	6.4	5.1	4.1	3.0	1.0
Chemicals	7.7	2.1	2.5	6.9	0.1	−0.3
Metals and Fabricated Metal Products	11.0	2.0	0.1	5.9	0.5	−1.9
Machinery, Electrical Equipment, Computers	0.6	4.2	0.5	3.1	0.6	−2.0
Transport Equipment	1.5	3.3	0.9	4.0	−0.6	−2.1
Other manufacturing	3.4	2.5	2.6	3.7	0.1	0.7
Transport	12.6	4.6	2.6	10.3	0.4	0.5
Group 2						
Mineral Products	10.6	3.3	2.0	7.9	0.3	−0.4
Construction	1.0	0.1	0.8	2.8	−0.7	−0.4
Group 3						
Hotels and Restaurants	2.1	1.9	0.7	2.2	0.9	0.0
Public Administration	1.1	1.7	−1.8	1.9	0.8	−1.3
Health	1.1	−1.7	−2.7	1.5	−1.3	−2.2
Education	0.9	1.0	−2.1	1.6	0.1	−0.9
Other Services	1.6	0.2	−1.6	2.1	−0.3	−1.3
Group 4						
Wholesale and Retail Trade	2.1	2.0	−0.9	2.3	2.8	−1.1
Finance and Insurance	0.4	−0.6	−0.5	1.0	−5.2	0.5
IT and Communication	0.9	4.1	−0.5	1.6	3.8	1.1
Business Services	1.1	−2.2	−1.7	1.8	−1.3	−1.5
Real Estate	–	–	–	–	–	–

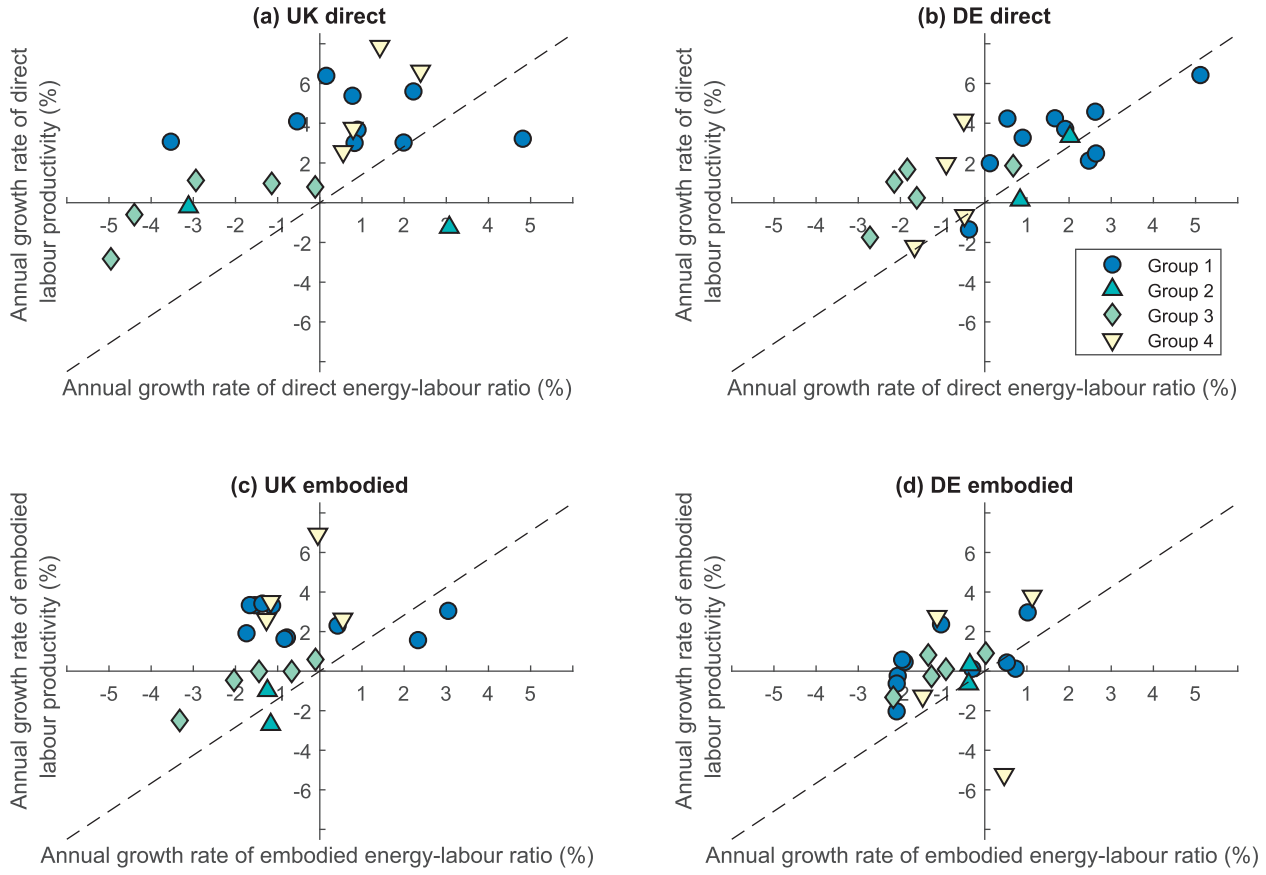

Fig. 2. Relationship between the average growth rates in embodied labour productivity and the embodied energy-labour ratio between 1995 and 2011 for different economic sectors.

Products sector the relationship between the two variables shows a diverse pattern. The two variables both grow in Germany from a direct perspective and both decline in the UK from an embodied perspective. The growth in the two variables show opposite signs in Germany from an embodied perspective and in the UK from a direct perspective.

3.3. Group 3: energy-light and labour-intensive sectors

In our empirical classification Group 3 includes sectors that show low energy intensity and low rates of labour productivity growth. We allocate five sectors to this group, namely the sectors Hotels & Restaurants, Public Administration, Health, Education and Other Services (Tables 2 and 3). Note that in our conceptual framework Group 3 also includes sectors with a low desirability for labour productivity growth. The five sectors we allocate to Group 3 are the same sectors identified as labour-intensive services in Hardt et al. (2020), who only draw on embodied measures. Here we add results from a direct perspective which confirms the allocation of the five sectors to Group 3.

The direct energy intensities of all five Group 3 sectors range from 0.8 MJ/EUR to 2.1 MJ/EUR, while the embodied energy intensities range from 1.3 MJ/EUR to 2.2 MJ/EUR. Such values are considerably lower than the ones recorded for Group 1 sectors.

The five sectors also show growth rates in direct or embodied labour productivity at or below 1% per year. Exceptions are the growth rates in direct labour productivity in the Hotels & Restaurants and Public Administration sectors in Germany, which measure 1.9% and 1.7% respectively. Such rates are still below the growth rates of direct labour productivity growth in Group 1 sectors.

Almost all of the sectors in Group 3 show reductions in the direct and embodied energy-labour ratio, independent of whether they have positive or negative embodied or direct labour-productivity growth. The only exception is the direct energy-labour ratio in the Hotels & Restaurants sector in Germany, which grew at 1.7% per year on average. All Group 3 sectors lie above the 45° line in Fig. 2, indicating reductions in energy intensity, for both countries and both direct and embodied measures.

3.4. Group 4: energy-light and labour-light sectors

In our empirical classification, Group 4 contains sectors of low energy intensity but high rates of labour productivity growth. We allocate the sectors of Wholesale and Retail Trade, Finance and Insurance, IT and Communications and Business Services to this group.

The direct energy intensities of Group 4 sectors range from 0.2 MJ/EUR to 2.1 MJ/EUR, while the embodied energy intensities range from 1 MJ/EUR to 2.3 MJ/EUR. Such values are very similar to the ones in Group 3.

Only the IT and Communications sector and the Wholesale and Retail Trade sector show consistently high rates of labour productivity growth, exceeding 2% per year from both a direct and an embodied perspective and in both countries. For the Finance and Insurance sector and the Business Services sector, the growth rates of labour productivity show very different values in the two countries. In the UK direct and embodied labour productivity grew by more than 2.6% per year in both sectors. In Germany direct and embodied labour productivity fell in both sectors. Such divergent results can also be found in the literature where different studies come to different conclusions on labour productivity growth in the two sectors for different countries and time periods (Baumol et al., 1985; Maroto and Rubalcaba, 2008). We decided to allocate the two sectors to Group 4 because the high rates of labour productivity growth in the UK seem to indicate that the two sectors have a potential for labour productivity growth, even if it was not realised in Germany.

The relationship between the energy-labour ratio and labour productivity for Group 4 sectors varies between countries and between the direct and embodied perspective. In the UK the direct energy-labour ratio is growing in combination with growing direct labour productivity in all Group 4 sectors (Fig. 2a). But the embodied energy-labour ratio is falling in three out of four sectors, despite growth in embodied labour-productivity (Fig. 2c). In Germany the direct energy-labour ratio is falling in all Group 4 sectors independent of whether direct labour productivity is increasing or declining (Fig. 2b). From an embodied perspective the four German sectors in this group show all four possible combinations of growing or declining embodied energy-labour ratio and embodied labour productivity (Fig. 2d).

3.5. Group comparison

After allocating economic sectors into the four groups, we can compare the structure of GVA, final demand, energy use and employment with regard to the four groups (Fig. 3). A key feature that is consistent across countries is the high share of Group 1 in energy use and energy footprint. The share of Group 1 in energy use and energy footprint is much higher than the group's share in GVA and final demand, which follows from the higher direct and embodied energy intensity of Group 1 sectors. The main difference between the two

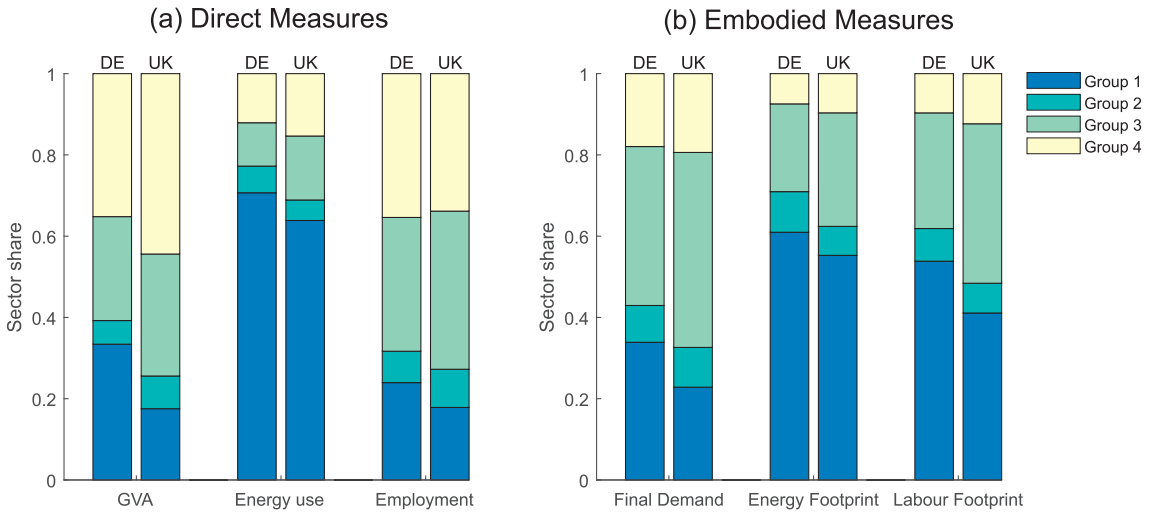

Fig. 3. Sector shares in 2011 in (a) GVA, direct energy use and direct employment and (b) final demand, energy footprint and labour footprint. GVA and final demand are in current prices. Energy use for private transport and residential purposes is excluded.

countries is a larger share for Group 1 in Germany across all direct and embodied measures.

Two differences stand out between the direct and embodied perspectives. Firstly, the share of employment of Group 1 sectors is much smaller for direct employment than for the labour footprint. The difference highlights that the demand for industrial and agricultural products in high-income countries is now strongly dependent on labour abroad (Sakai et al., 2017; Simas et al., 2015). Secondly, the share of Group 4 is of similar size as the share of Group 3 for the direct measures, but the share of Group 4 is much smaller for the embodied measures. The difference highlights that the output of Group 4 sectors is mostly used as intermediate input into other sectors rather than directly bought as final demand.

4. Sector goals and challenges

In Section 2 we identify theoretical structural change goals for different sector groups based on different combinations of characteristics in our three framework dimensions (Table 1). In Section 3 we allocate real sectors from the UK and Germany to the sector groups based on empirical data (Tables 2 and 3). The empirical analysis is not comprehensive because we do not assess the desirability of labour productivity growth in different sectors. Still, combining the insights presented in Sections 2 and 3, we can now provide a first discussion of what structural change for a post-growth economy might look like.

4.1. Group 1: energy-intensive and labour-light sectors

We allocate to Group 1 the sectors producing agricultural goods, transport services, and manufactured goods (with the exception of mineral products). Our allocation is based only on historic rates of labour productivity growth. For some sectors allocated to the group labour productivity growth might not be desirable from a post-growth perspective. Such sectors would then fall under the discussion of Group 2.

An important structural change goal for the post-growth transition is to reduce the share of Group 1 sectors in output and final demand. Such a reduction is important to reduce aggregate energy intensity and energy use, given that Group 1 sectors are responsible for the majority of domestic commercial energy use and the majority of the energy footprint in both Germany and the UK (Fig. 3). But there are limits to the magnitude of reductions in energy intensity and energy use that can be achieved from relative shifts in output and final demand alone (Hardt et al., 2020). A second important goal for the post-growth transition is therefore the reduction of energy intensity within Group 1 sectors. But the magnitude of energy savings that can be achieved from intensity reductions also faces limits from thermodynamic laws and rebound effects (Brockway et al., 2017; van den Bergh, 2011). In light of such limitations, the transition to a post-growth economy might not only need relative, but also absolute, reductions in the output and final demand of Group 1 sectors.

Increasing labour productivity in Group 1 sectors constitutes another goal for the post-growth transition, because, by definition, it is desirable in Group 1 sectors. Given the high energy intensity of Group 1 sectors we suggest that the goal to reduce energy intensity should receive priority over the goal to increase labour productivity. But our empirical results suggest that trade-offs are limited. Group 1 sectors have often achieved both reductions in energy intensity and growth in labour productivity at the same time, both from a direct and an embodied perspective. Still, labour productivity growth in Group 1 sectors might come at the cost of a higher energy-labour ratio. We do not consider such a cost to be a problematic because the share of the labour force employed in Group 1 sectors will likely become quite small, given the combination of growing labour productivity and shrinking output and final demand.

The post-growth and climate change mitigation literature offers a range of policy proposals to achieve the goal of reducing the share of energy-intensive sectors in output and final demand. Some policies aim to reduce demand for energy-intensive goods and services by increasing their relative prices, for example through taxes or cap-and-trade schemes (Cosme et al., 2017; Hardt and O'Neill, 2017). Other proposals promote a shift to business models that sell the services derived from energy-intensive products rather than the products themselves, for example selling washing services rather washing machines (Jackson, 2017, p. 142; Moran et al., 2018).

Equity considerations pose a key challenge to the implementation of any policies that aim to achieve reductions in the final demand and output of Group 1 sectors. Many Group 1 sectors provide essential goods which often makes blanket policies, such as energy or carbon taxes, regressive (Owen and Barrett, 2020). To ensure that reductions in the final demand for Group 1 sectors are perceived as fair, a democratic discussion is needed to determine who should reduce demand, for what kind of products, and by how much. Baumol's cost disease might provide another challenge to the effectiveness of price-based policies aimed at reducing demand for Group 1 sectors. If labour productivity in Group 1 sectors continues to grow relative to other groups, the relative prices Group 1 goods and services might fall, counteracting the effect of price-based policies (Baumol, 2012, pp. 71–73).

Strategies to achieve the goals of reducing energy intensity and increasing labour productivity are not unique to the post-growth transition and are discussed extensively in the wider economics literature. We do not discuss the literature here but we want to point out an important challenge that is unique to the post-growth transition. In the post-growth transition labour productivity growth in Group 1 sectors is aimed to be achieved while simultaneously reducing output and final demand in the sectors. In the mainstream economics literature, labour productivity growth in a sector is considered to be pre-condition or even a driver of output growth (Nordhaus, 2005). Kaldor's growth laws suggest that labour productivity growth in the manufacturing sectors is not only an important driver of output growth in the manufacturing sectors themselves but also in the wider economy (Marconi et al., 2016; Thirlwall, 1983). Achieving labour productivity growth in Group 1 sectors under the conditions of contracting output might therefore pose difficulties. Or, in reverse, the achievement of labour productivity growth in Group 1 sectors might jeopardise the goal of reducing demand and output in such sectors.

4.2. Group 2: energy-intensive and labour-intensive sectors

In our empirical analysis we only allocate the Construction sector and the Mineral Products sector to Group 2 based on potential labour productivity growth. Group 2 also includes energy-intensive sectors where it might be desirable to adopt more labour-intensive production methods to create meaningful jobs, for example by moving to small-scale, artisanal methods (Mair et al., 2020; Nørgård, 2013). In Australia, the rise of artisan bakeries has already been recognised to lower labour productivity growth (Ferguson, 2015). We do not identify such sectors in our empirical analysis, but developing strategies for increasing labour-intensive production methods in sectors where it is desired will be important for the post-growth transition.

As Group 2 sectors are, or could be, labour-intensive, expansion of production and consumption in Group 2 sectors would contribute to the overarching objectives to create meaningful employment and reduce aggregate labour productivity growth. Given the environmental emergencies that society is facing, however, we would suggest that the overarching objective to reduce energy intensity and energy demand should take priority. In that case, the most important goal for Group 2 sectors is to reduce their share in output and final demand, similar to Group 1 sectors.

The sector goals for the remaining production in Group 2 sectors are not clear cut, because there are potential trade-offs between different goals. On the one hand, it might be desirable to reduce labour

productivity in order to create meaningful jobs and reduce aggregate labour productivity growth. On the other hand, such reductions in labour productivity could increase the energy intensity of production. If labour productivity and the energy labour-ratio are negatively correlated, reductions in labour productivity increase the energy-labour ratio and energy intensity. Even in the case of increasing energy intensity, Kallis (2018, p. 134) suggests that the adoption of more labour-intensive production methods could be worthwhile because lower aggregate labour productivity restricts the overall scale of production and environmental impact. Still, there might be better ways to provide meaningful employment and lower aggregate labour productivity without increasing the energy intensity in already energy-intensive sectors. If the labour productivity and the energy-labour ratio are positively correlated or unrelated, the trade-offs are much smaller, especially if the balance between reductions in the energy-labour ratio and labour productivity still allows for reductions in energy intensity.

While the transformation towards labour-intensive production methods is a common theme in the post-growth literature, the literature does not offer a detailed discussion of its implications. No systematic analysis is provided that identifies in which sectors the adoption of more labour-intensive methods would be feasible and desirable. There might be many sectors, such as steel production, in which small-scale, labour-intensive production is not possible or desirable. In the few sectors for which the literature identifies labour-intensive production methods as desirable, there is little analysis of the consequences of a large-scale uptake of such methods. For example, post-growth economists propose small-scale, labour-intensive farming techniques, such as organic and permaculture approaches, on the ground that they are efficient in terms of energy and land use. But the literature offers hardly any scientific assessments of how a large-scale shift towards labour-intensive farming would impact yields, food availability and labour requirements (Infante Amate and González De Molina, 2013). Kostakis et al. (2018) suggest that an approach of “design global, manufacture local” could be useful for many aspects of a degrowth economy. Their approach features local, decentralised production using simple technologies or 3D printing, based on designs developed in a global digital commons. It is not clear whether such an approach would be more or less labour-intensive or energy-intensive than current industrial production.

Once it is clearer in which sectors more labour-intensive production methods are desired for a post-growth economy, achieving the adoption of such methods will require the removal of important barriers. In our current market system, businesses are continuously under pressure to reduce production costs, a key driver of labour productivity growth (Jackson and Victor, 2011; Shaikh, 2016). Except in niche areas, labour-intensive, small-scale manufacturing businesses cannot compete against the low prices of goods mass-produced in energy-intensive factories and by cheap labour abroad. Ecological tax reform that shifts tax burdens from labour to environmental impacts have been proposed to reduce the energy intensity relative to labour intensity (Daly, 2008). But in a system where competition is based on costs and prices, labour-intensive production methods will always struggle, even if price incentives are somewhat shifted in their favour. The adoption of labour-intensive methods in Group 2 sectors requires a system that puts greater value on quality, durability and fair working conditions. Johanisova et al. (2013) propose that an increase in the use of social enterprises, not-for-profit organisations and other “non-market capitals” can play an important part in creating such a system. In order for such organisations to flourish, however, consumers would also need to be willing to shift away from mass consumption to buy fewer, more expensive and high-quality products.

Finally, a special challenge for the post-growth economy is the different treatment of labour productivity growth in different sectors. While labour productivity growth is desired in some sectors (Group 1) it is not desired in others (Group 2). Policies will therefore have to be tailored to achieve opposite outcomes in different parts of the economy.

4.3. Group 3: energy-light and labour-intensive sectors

In our empirical analysis we allocate five sectors to Group 3, namely Hotels & Restaurants, Public Administration, Health Care and Other Services. The five sectors are the same as the labour-intensive services already identified in Hardt et al. (2020). We identified the five sectors based on historic rates of labour productivity growth, but Group 3 would also include energy-light sectors where labour productivity growth is possible but not desirable.

The sectors in Group 3 have a low energy intensity, so that employment-related goals can take priority over energy-related goals. The most important goal for Group 3 sectors is therefore to increase their share in employment, in order to offset employment losses in other sectors and to reduce the growth in aggregate labour productivity. A second important goal in Group 3 sectors is the maintenance or reduction of labour productivity, as labour productivity growth is not possible or desired. It is not completely clear how the pursuit of increased employment in Group 3 sectors will impact the sector shares in output and final demand. Many of the Group 3 sectors constitute non-market services, for which economic output is difficult to define and measure (Eurostat, 2016, pp. 34–38). Increases in employment can manifest either as increases in output or as reductions in labour productivity, depending on how output is measured. For example, adding an additional teacher into each school class could lead to increased output if output is measured as teacher-hours, or to reduced labour productivity if output is measured as number of students taught. Overall it is likely that the share of Group 3 in output and final demand will increase if the employment share increases, at least in current prices.

While Group 3 sectors have a low energy intensity relative to Group 1 and Group 2 sectors, Group 3 sectors still account for a non-negligible fraction of the direct energy use and energy footprint for the UK and Germany (Fig. 3). Any expansion in the employment, output and final demand share of Group 3 sectors therefore needs to be combined with reductions in energy intensity. Reducing energy intensity could clash with the goal to reduce labour productivity, if labour productivity and the energy-labour ratio are negatively correlated (Table 1). Fortunately, our evidence suggests that Group 3 sectors have shown reductions in energy intensity and the energy-labour ratio despite reductions in labour productivity (Fig. 2). There is therefore no evidence for trade-offs between the goals for Group 3.

We already discuss the challenges for achieving an expansion of Group 3 sectors in Hardt et al. (2020) and will only provide a brief summary here. Firstly, Group 3 sectors feature low labour productivity growth and therefore face increasing relative costs compared to sectors with high labour productivity growth (Baumol, 2012; Baumol, 1967; Baumol et al., 1985). Such a cost disadvantage has already pushed several market services that are important for a post-growth economy, such as repair services, into the margins of our economy. Non-market services, such as health care and education, face continuous political discussions about the justification of increasing public expenditure. Secondly, new and existing jobs in Group 3 sectors need to be made high quality. At the moment, many jobs in these sectors are low-paid and associated with difficult working conditions, for example for nurses (Currie and Carr Hill, 2012; Druckman and Mair, 2019) or hospitality workers (Kotera et al., 2018). Lastly, any expansion of Group 3 sectors needs to consider the boundary between paid and unpaid work. Even though our framework focuses only on the formal economy, the development of strategies for the post-growth transition needs to take into account all work performed in society, whether it is paid or not (Sekulova et al., 2013). In the context of a post-growth economy it might be useful to assess where it makes sense that products and services are delivered by the formal economy, especially if other policies reduce the need for monetary income from work (D'Alisa and Cattaneo, 2013; Nørgård, 2013). Such a question is particularly relevant for Group 3 sectors, because many of them already straddle the boundary

between paid and unpaid work, for example in the areas of health care, education or art.

4.4. Group 4: energy-light and labour-light sectors

In our empirical analysis we allocate four sectors to Group 4. The four sectors are Wholesale and Retail Trade, Finance and Insurance, IT and Communications and Business Services. Here, we also discuss the Real Estate sector as part of Group 4, even though we do not present empirical results for it.

It is difficult to determine structural change goals for Group 4 sectors, because they cannot contribute strongly to any of the overarching objectives. Labour productivity growth is possible and desired, indicating that these sectors are not a potential source of meaningful employment. Energy intensity is low, so there is no strong rational for reducing output and final demand from an environmental perspective either. While energy intensity is low, Group 4 sectors still account for a non-negligible fraction of the direct energy use and energy footprint in the UK and Germany (Fig. 3). A post-growth perspective would therefore suggest that output and final demand in Group 4 sectors should be reduced, unless such output and final demand is necessary for meeting basic needs or increasing wellbeing. In effect the structural change goals for Group 4 sectors are therefore similar to those for Group 1: reduce final demand and output where possible, reduce the energy intensity of the remaining production and increase labour productivity (Table 1).

Another reason why it is difficult to define structural change goals for Group 4 sectors, is the fact that Group 4 sectors largely provide intermediate inputs into other sectors rather than final demand. As Fig. 3 shows, the share of Group 4 sectors in value added is much larger than their share in final demand. The group's share in final demand is also dominated by the Real Estate sector, which largely consists of real and imputed rent payments (Table 4). Defining and achieving structural change goals for Group 4 sectors therefore requires an analysis of how production is interconnected with other sector groups.

More than other groups in our framework, Group 4 sectors highlight the limitations of the national accounts and of our framework that relies on national accounts data. For many sectors in Group 4 it is difficult to measure final demand and value added in constant prices. As the services delivered are intangible and heterogeneous, it is difficult to separate any price increases into quality improvements or inflation (Eurostat, 2016, p. 112). Such difficulties are more serious for financial services and business services than for communication services and wholesale and retail trade (Inklaar et al., 2008; Schettkat and Yocarini, 2006). Similar difficulties apply for the non-market services in Group 3. But because the structural change goals for Group 3 sectors are clearly focused on employment, it is less of an issue.

Group 4 sectors do not only highlight measurement difficulties, but also problems with the underlying conventions in the national accounts, defining what counts as a productive activity and what does not. It is a social and political decision which forms of income count as a productive activities and contribute to GDP and which ones are classified as transfer payments distributing the production from other parts of the economy. For some Group 4 sectors it is not clear cut in how far they contribute to the creation of new value. For example, the income of the finance sectors has only recently been included as a productive activity contributing to GDP (Christophers, 2011). It is likely that a considerable part of the income obtained in the sectors of this group, especially in the Finance & Insurance, Real Estate and Communication & IT sectors can be considered as economic rent payments. Such rent payments have important implications for inequality in the post-growth transition (Stratford, 2020). A fully review of this issue is beyond the scope of this paper, but it serves to highlight the difficulties of defining output, demand and value added in many sectors in this group.

The difficulties of defining structural change goals for Group 4 sectors do not mean that the sectors are not important for the post-growth transition. On the contrary, the sectors in this group are very much at the heart of many important challenges that our society is facing. Such challenges include unaffordable land and housing (Kenny, 2019), the impacts of financial speculation (Jackson, 2018), the gig economy facilitated by technological platforms (De Stefano, 2016) or the power of communication companies to exploit personal data and influence democratic processes (Hind, 2019). Group 4 sectors present a very diverse set of challenges that will require specific strategies for reform. Such strategies will undoubtedly affect the output, demand and employment of Group 4 sectors, but it might be less useful to define sector goals in such terms.

Table 4
Sector shares of labour-light services in final demand.

Sector	Demand share in 2011 (%)	
	UK	DE
Share of Group 4 sectors in total final demand	25.7	20.4
Sector shares within group 4		
Wholesale and Retail Trade	18.3	10.0
Finance and Insurance	14.4	16.4
Real Estate	47.4	43.7
IT and Communications	11.2	13.8
Business Services	8.8	16.2

5. Conclusion

In order to avoid environmental catastrophe, the environmental impacts from economic production and consumption in high-income countries have to be reduced rapidly. Given the close coupling of GDP and environmental impacts, achieving the necessary reductions in high-income countries will likely lead to lower GDP growth, or even reductions in GDP. In high-income countries, we therefore need to create a post-growth economy that can simultaneously increase human wellbeing and deliver rapid reductions in environmental impacts, independent of whether GDP is growing or declining.

The transformation to a post-growth economy will require structural change in the sectoral composition of output, final demand and employment as well as strategies tailored to specific sectors. There will be winners and losers, sectors that will expand, and sectors that will contract. Politicians are often not explicit about the necessity of such structural change. They are especially not willing to identify sectors that will lose out in the transition to a sustainable economy. Sometimes not even in obvious cases, such as the oil and gas industry. As post-growth economists, we need to start defining the necessary structural change in order to stimulate a discussion about which sectors need to expand and which sectors need to contract. Providing such a definition is crucial for moving discussions beyond the abstract question of whether reductions in aggregate GDP are desirable and feasible.

Our analysis starts to systematically define the structural change necessary for the transition to a post-growth economy. The framework and evidence presented allows for a consistent vision of structural change to take shape. The production and consumption of energy-intensive goods will be reduced as much as possible. Small-scale, labour-intensive production should be encouraged where feasible, while industrial, efficiency-focused production will only be pursued where it makes sense from a social and environmental perspective. Potential losses of employment will be offset by increasing employment in labour-intensive services with high social value, while making sure that the new and existing jobs in these sectors are of high quality. Finally, the remaining service sectors will have to be scrutinised in how far they can contribute real value to a post-growth economy.

More research is needed to fully utilise the framework and develop sectoral strategies at a more detailed level. Especially information on

the potential and desirability of labour productivity growth in different sectors, and its implications for energy use, is currently lacking in the post-growth literature. More information on such sector characteristics is needed to inform discussions on important normative questions: What production is necessary and desirable? Where could production and consumption be reduced? Where exactly would reductions in labour productivity be desirable and where is further pursuit of labour productivity sensible? These questions tie into current debates about the future of automation. Research from a post-growth perspective can offer something to such debates by investigating the desirability of automation and by putting automation into the context of environmental challenges.

Even if we cannot determine all sector characteristics and structural change goals with certainty yet, the preliminary outline we present already highlights some important challenges for achieving the necessary structural change. The production, employment and consumption of different sectors is not distributed equally across countries and across income groups. Strategies for achieving structural change need to be just and equitable. Some of the sector goals we identify also go against the grain of our current economic system. Business is currently dominated by pressures to reduce costs and grow markets and output. Many of our sector goals would require resistance to such pressures. Achieving the goals might entail increasing costs, reductions in output and the shrinking of markets and supply chains. Can markets be reformed so that they support achieving such objectives? If yes, how? Do we need to find alternative ways of providing some goods and services? The answer to the last question is almost certainly yes. The post-growth literature has already started to develop alternative approaches but more needs to be done. For example Raworth (2017) distinguishes between four domains of provisioning, the market, government, commons and the household. Such a perspective could be linked with our framework to determine which sectors might be best suited to which of the four domains.

Declaration of Competing Interest

None.

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Appendix A

Table A1
Sector classification used for presenting the results.

Sector	NACE codes (rev. 1.1)
Agriculture, Forestry, Fishing	01, 02, 05
Mineral Products	13, 14, 26
Food, Beverages and Tobacco	15, 16
Textiles, Clothes, Leather	17, 18, 19
Paper, Printing, Publishing	21, 22
Chemicals	24
Metals and Fabricated Metal Products	27, 28
Machinery, Electrical Equipment, Computers	29, 30, 31, 32, 33
Transport Equipment	34, 35
Other Manufacturing	20, 25, 36, 37
Construction	45
Wholesale and Retail Trade	50, 51, 52
Hotels and Restaurants	55
Transport	60, 61, 62, 63
Finance and Insurance	65, 66, 67
IT and Communication	64, 72
Professional Services	71, 73, 74
Public Administration	75
Health	85
Education	80
Other Services	41, 90, 91, 92, 93
Sectors not presented in empirical results	
Energy Producers	10, 11, 23, 40
Real Estate Activities	70
Private households with employed persons	95

References

Barrett, J., Peters, G., Wiedmann, T., Scott, K., Lenzen, M., Roelich, K., Le Quéré, C., 2013. Consumption-based GHG emission accounting: a UK case study. Clim. Pol. 13, 451–470. https://doi.org/10.1080/14693062.2013.788858.

Baumol, W.J., 1967. Macroeconomics of unbalanced growth: the anatomy of urban crisis. Am. Econ. Rev. 57, 415–426.

Baumol, W.J., 2012. The Cost Disease: Why Computers Get Cheaper and Health Care doesn't. Yale University Press, New Haven and London.

Baumol, W.J., Batey Blackman, S.A., Wolff, E.N., 1985. Unbalanced growth revisited: asymptotic stagnancy and new evidence. Am. Econ. Rev. 75, 806–817.

Brockway, P.E., Saunders, H., Heun, M.K., Foxon, T.J., Steinberger, J.K., Barrett, J.R., Sorrell, S., 2017. Energy rebound as threat to a low-carbon future: Results and implications from an exergy-based UK-US-China empirical study. Energies 10. https://doi.org/10.3390/en10010051.

Christophers, B., 2011. Making finance productive. Econ. Soc. 40, 112–140. https://doi.org/10.1080/03085147.2011.529337.

Ciarli, T., Savona, M., 2019. Modelling the evolution of economic structure and climate change: a review. Ecol. Econ. 158, 51–64. https://doi.org/10.1016/j.ecolecon.2018.12.008.

Cosme, I., Santos, R., O'Neill, D.W., 2017. Assessing the degrowth discourse: a review and analysis of academic degrowth policy proposals. J. Clean. Prod. 149, 321–334. https://doi.org/10.1016/j.jclepro.2017.02.016.

Costanza, R., Kubiszewski, I., Giovannini, E., Lovins, H., McGlade, J., Pickett, K., Ragnarsdóttir, K.V., Roberts, D., De Vogli, R., Wilkinson, R., 2014. Time to leave GDP behind. Nature 505, 283–285. https://doi.org/10.1038/505283a.

Csereklyei, Z., Rubio-Varas, M.D.M., Stern, D.I., 2016. Energy and economic growth: the stylized facts. Energy J. 37, 223–256.

Currie, E.J., Carr Hill, R.A., 2012. What are the reasons for high turnover in nursing? A

discussion of presumed causal factors and remedies. Int. J. Nurs. Stud. 49, 1180–1189. https://doi.org/10.1016/j.ijnurstu.2012.01.001.
D'Alisa, G., Cattaneo, C., 2013. Household work and energy consumption: a degrowth perspective. Catalonia's case study. J. Clean. Prod. 38, 71–79. https://doi.org/10.1016/j.jclepro.2011.11.058.
D'Alisa, G., Demaria, F., Kallis, G., 2015. Degrowth: A Vocabulary for a a New Era. Routledge, London and New York.
Daly, H.E., 2008. A steady-state economy. Opin. Piece Redefining Prosper. Sustain. Dev. Comm. UK 1–10.
De Stefano, V., 2016. The rise of the just-in-time workforce: on-demand work, crowdwork, and labor protection in the gig-economy. Comp. Labour Law Policy J. 37, 471–504.
DECC, 2015. Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 – Iron and Steel. (London, UK).
Dietz, R., O'Neill, D., 2013. Enough is Enough: Building a Sustainable Economy in a World of Finite Resources. Routledge, London.
Druckman, A., Mair, S., 2019. Wellbeing, care and robots: prospects for good work in the health and social care sector. CUSP Work. Pap. 21.
Eurostat, 2016. Handbook on Prices and Volume Measures in National Accounts.
Eurostat, 2018. Eurostat Database.
Ferguson, P., 2015. Productivity growth as a barrier to a sustainability transition. Environ. Innov. Soc. Transitions 20, 86–88. https://doi.org/10.1016/j.eist.2015.10.003.
Frey, C.B., Osborne, M.A., 2017. The future of employment: how susceptible are jobs to computerisation? Technol. Forecast. Soc. Change 114, 254–280. https://doi.org/10.1016/j.techfore.2016.08.019.
German Council of Economic Experts, 2019. Dealing with Structural Change – Executive Summary, Executive Summary of the Annual Report 2019/2020. https://doi.org/10.1007/978-3-319-43193-2_24.
Giesekam, J., Barrett, J., Taylor, P., Owen, A., 2014. The greenhouse gas emissions and mitigation options for materials used in UK construction. Energy Build. 78, 202–214. https://doi.org/10.1016/j.enbuild.2014.04.035.
Gujarati, D., 1995. Basic Econometrics, 3rd ed. McGraw-Hill, New York.
Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., Fishman, T., Hausknost, D., Krausmann, F., Leon-Gruchalski, B., Mayer, A., Pichler, M., Schaffartzik, A., Sousa, T., Streeck, J., Creutzig, F., 2020. A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights. Environ. Res. Lett. 15, 1–42.
Hammond, G.P., Norman, J.B., 2012. Decomposition analysis of energy-related carbon emissions from UK manufacturing. Energy 41, 220–227. https://doi.org/10.1016/j.energy.2011.06.035.
Hardt, L., O'Neill, D.W., 2017. Ecological macroeconomic models: assessing current developments. Ecol. Econ. 134, 198–211. https://doi.org/10.1016/j.ecolecon.2016.12.027.
Hardt, L., Barrett, J., Taylor, P.G., Foxon, T.J., 2020. Structural change for a post-growth economy: investigating the relationship between embodied energy intensity and labour productivity. Sustainability 12, 1–25.
Hickel, J., Kallis, G., 2019. Is green growth possible? New Polit. Econ. 0, 1–18. https://doi.org/10.1080/13563467.2019.1598964.
Hind, D., 2019. The British Digital. A New Model Public Sector Institution, Cooperative. https://doi.org/10.1017/CBO9781107415324.004.
HM Government, 2017. Industrial Strategy: Building a Britain Fit for the Future.
IEA, 2018. World Energy Statistics 2018 Edition: Database Documentation.
Infante Amate, J., González De Molina, M., 2013. "Sustainable de-growth" in agriculture and food: an agro-ecological perspective on Spain's agri-food system (year 2000). J. Clean. Prod. 38, 27–35. https://doi.org/10.1016/j.jclepro.2011.03.018.
Inklaar, R., Timmer, M.P., van Ark, B., 2008. Market services productivity across Europe and the US. Econ. Policy 139–194.
IPCC, 2018. Summary for policymakers. In: Masson-Delmotte, V., Zha, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R. ... Waterfiel, T. (Eds.), Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change. World Meteorological Organization, Geneva, Switzerland, pp. 32. https://doi.org/10.1017/CBO9781107415324.
Isham, A., Mair, S., Jackson, T., 2020. Wellbeing and productivity. CUSP Work. Pap. No 22.
Jackson, T., 2015. New economy. In: D'Alisa, G., Demaria, F., Kallis, G. (Eds.), Degrowth: A Vocabulary for a New Era. Routledge, New York, London.
Jackson, T., 2017. Prosperity without Growth, 2nd ed. Routledge, Oxon, New York.
Jackson, T., 2018. The post-growth challenge. Cent. Underst. Sustain. Prosper. 39.
Jackson, T., Victor, P.A., 2011. Productivity and work in the 'green economy'. Environ. Innov. Soc. Transitions 1, 101–108. https://doi.org/10.1016/j.eist.2011.04.005.
Johanisova, N., Crabtree, T., Fraňková, E., 2013. Social enterprises and non-market capitals: a path to degrowth? J. Clean. Prod. 38, 7–16. https://doi.org/10.1016/j.jclepro.2012.01.004.
Kallis, G., 2011. In defence of degrowth. Ecol. Econ. 70, 873–880. https://doi.org/10.1016/j.ecolecon.2010.12.007.
Kallis, G., 2018. Degrowth. Agenda Publishing, Newcastle upon Tyne.
Kander, A., Malanima, P., Warde, P., 2013. Power to the People: Energy in Europe over the Last Five Centuries. Princeton University Press, Woodstock, UK.
Kenny, T., 2019. Land for the many and a new politics of land. Plan. Theory Pract. 00, 1–6. https://doi.org/10.1080/14649357.2019.1676564.
Kostakis, V., Latoufis, K., Liarokapis, M., Bauwens, M., 2018. The convergence of digital commons with local manufacturing from a degrowth perspective: two illustrative cases. J. Clean. Prod. 197, 1684–1693. https://doi.org/10.1016/j.jclepro.2016.09.077.
Kotera, Y., Adhikari, P., Van Gordon, W., 2018. Motivation types and mental health of UK hospitality workers. Int. J. Ment. Heal. Addict. 16, 751–763. https://doi.org/10.1007/s11469-018-9874-z.
Lan, J., Malik, A., Lenzen, M., McBain, D., Kanemoto, K., 2016. A structural decomposition analysis of global energy footprints. Appl. Energy 163, 436–451. https://doi.org/10.1016/j.apenergy.2015.10.178.
Mair, S., Druckman, A., Jackson, T., 2020. A tale of two utopias: work in a post-growth world. Ecol. Econ. 173, 106653. https://doi.org/10.1016/j.ecolecon.2020.106653.
Marconi, N., de Reis, C.F.B., de Araújo, E.C., 2016. Manufacturing and economic development: the actuality of Kaldor's first and second laws. Struct. Chang. Econ. Dyn. 37, 75–89. https://doi.org/10.1016/j.strueco.2015.12.002.
Maroto, A., Rubalcaba, L., 2008. Services productivity revisited. Serv. Ind. J. 28, 337–353. https://doi.org/10.1080/02642060701856209.
Moran, D., Wood, R., Hertwich, E., Mattson, K., Rodriguez, J.F.D., Schanes, K., Barrett, J., 2018. Quantifying the potential for consumer-oriented policy to reduce European and foreign carbon emissions. Clim. Pol. 1–11. https://doi.org/10.1080/14693062.2018.1551186.
Mulder, P., de Groot, H.L.F., 2004. International comparisons of sectoral energy- and labour- productivity performance. Tinbergen Inst. Discuss. Pap. 1–29 No 2004-007/3.
Nordhaus, W., 2005. The sources of the productivity rebound and the manufacturing employment puzzle. NBER Work. Pap. Ser. 11354. https://doi.org/10.3386/w11354.
Nørgård, J.S., 2013. Happy degrowth through more amateur economy. J. Clean. Prod. 38, 61–70. https://doi.org/10.1016/j.jclepro.2011.12.006.
Owen, A., Barrett, J., 2020. Reducing inequality resulting from UK low-carbon policy. Clim. Pol. 1–16. https://doi.org/10.1080/14693062.2020.1773754.
Owen, A., Scott, K., Barrett, J., 2017. Identifying critical supply chains and final products: an input-output approach to exploring the energy-water-food nexus. Appl. Energy Press. https://doi.org/10.1016/j.apenergy.2017.09.069.
Parrique, T., Barth, J., Briens, F., Kerschner, C., Kraus-Polk, A., et al., 2019. Decoupling Debunked: Evidence and Arguments Against Green Growth as a Sole Strategy for Sustainabilty.
Pasinetti, L.L., 1981. Structural Change and Economic Growth: A Theoretical Essay on the Dynamics of the Wealth of Nations. Cambridge University Press, Cambridge, UK.
Pasinetti, L.L., 1993. Structural Economic Dynamics: A Theory of the Economic Consequences of Human Learning. Cambridge University Press, Cambridge, UK.
Raworth, K., 2017. See the Big Picture: From Self-Contained Market to Embedded Economy, in: Doughnut Economics: Seven Ways to Think like a 21st Century Economist. Random House Business Books, London, UK.
Sakai, M., Owen, A., Barrett, J., 2017. The UK's emissions and employment footprints: exploring the trade-offs. Sustainability 9. https://doi.org/10.3390/su9071242.
Schettkat, R., Yocarini, L., 2006. The shift to services employment: a review of the literature. Struct. Chang. Econ. Dyn. 17, 127–147. https://doi.org/10.1016/j.strueco.2005.04.002.
Sekulova, F., Kallis, G., Rodríguez-Labajos, B., Schneider, F., 2013. Degrowth: from theory to practice. J. Clean. Prod. 38, 1–6. https://doi.org/10.1016/j.jclepro.2012.06.022.
Semieniuk, G., 2015. Fossil energy in economic growth: a study of the energy direction of technical change, 1950–2012. SPRU Work Pap. Ser. (SWPS) 2016–11, 1–37.
Shaikh, A., 2016. The theory of real competition. In: Capitalism: Competition, Conflict, Crisis. Oxford University Press, New York, pp. 259–326.
Simas, M., Wood, R., Hertwich, E., 2015. Labor embodied in trade: the role of labor and energy productivity and implications for greenhouse gas emissions. J. Ind. Ecol. 19, 343–356. https://doi.org/10.1111/jiec.12187.
Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.J., Simas, M., Schmidt, S., Usubiaga, A., Acosta-Fernández, J., Kuenen, J., Bruckner, M., Giljum, S., Lutter, S., Merciai, S., Schmidt, J.H., Theurl, M.C., Plutzar, C., Kastner, T., Eisenmenger, N., Erb, K.H., de Koning, A., Tukker, A., 2018. EXIOBASE 3: developing a time series of detailed environmentally extended multi-regional input-output tables. J. Ind. Ecol. 22. https://doi.org/10.1111/jiec.12715.
Stiglitz, J., Sen, A., Fitoussie, J., 2010. Mismeasuring our Lives: Why GDP Doesn't Add Up. The New Press, New York.
Stratford, B., 2020. The threat of rent extraction in a resource-constrained future. Ecol. Econ. 169. https://doi.org/10.1016/j.ecolecon.2019.106524.
Thirlwall, A.P., 1983. A plain man's guide to Kaldor's growth laws. J. Post Keynes. Econ. 5, 345–358. https://doi.org/10.1057/9781137409485_15.
UNEP, 2016. Global Material Flows and Resource Productivity: Assessment Report for the UNEP International Resource Panel. (Paris).
van den Bergh, J.C.J.M., 2011. Energy conservation more effective with rebound policy. Environ. Resour. Econ. 48, 43–58. https://doi.org/10.1007/s10640-010-9396-z.
Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Streeck, J., Pichler, M., Mayer, A., Krausmann, F., Brockway, P., Schaffartzik, A., Fishman, T., Hausknost, D., Leon-Gruchalski, B., Sousa, T., Creutzig, F., Haberl, H., 2020. A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part I: bibliometric and conceptual mapping. Environ. Res. Lett. 15, 1–15.
Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., Kanemoto, K., 2015. The material footprint of nations. Proc. Natl. Acad. Sci. 112, 6271–6276. https://doi.org/10.1073/pnas.1220362110.
Witt, U., Gross, C., 2019. The rise of the "service economy" in the second half of the twentieth century and its energetic contingencies. J. Evol. Econ. https://doi.org/10.1007/s00191-019-00649-4.