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Of embodied emissions and inequality: Rethinking energy consumption

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ABSTRACT

This paper situates concepts of energy consumption within the context of growing research on embodied emissions. Using the UK as a case study I unpack the global socio-economic and ecological inequalities inherent in the measurement of greenhouse gas emissions on a territorial basis under the international climate change framework. In so doing, I problematise questions of distribution, allocation and responsibility with regards to the pressing need to reduce global GHG emissions and the consumption that generates them. I challenge the disproportionate emphasis that energy policy places on supply as opposed to demand, as well as its overriding focus on the national scale. Consequently I argue that any low carbon transition, in addition to a technological process, is also a geographical one that will involve the reconfiguration of "current spatial patterns of economic and social activity" (Bridge et al., 2013:331), as well as relationships both within countries and regions and between them.

1. Introduction

In what Bradshaw ([1]:12) refers to as the difference between industrial production and domestic consumption, wealthy countries have to a large extent exported or outsourced their climate and energy crisis to low and middle-income countries, deliberately or otherwise. Broadly speaking, while GHG emissions have stabilised in developed countries, they are growing in developing countries [2]. Bohm [3] describes this phenomenon as 'carbon colonialism' and Oxfam [4] as 'extreme carbon inequality', estimating that half of the world's population, approximately 3.5 billion people, of which the majority in regions most vulnerable to climate change, emit only about 10% of total global emissions attributed to individual consumption. In contrast, approximately 50% of the world's greenhouse gas emissions (GHG) can be attributed to consumption by the world's richest 10 per cent, with the average carbon footprint of the richest one per cent being 175 times higher than that of the poorest 10 per cent ([4]:1). As this paper explores, the nature of this distribution constitutes a case of 'ecologically unequal exchange' [5].

The term 'embodied emissions' [6–8] is used here to refer to the approximately one quarter of global GHG emissions embodied within goods, services and commodities imported and consumed by the world's high-income consumers [9]. Related terms include 'consumption-based emissions', 'embodied energy' and 'embodied carbon'. This paper explores the ecological and socio-economic inequalities inherent within this structural configuration and argues that embodied emissions are a fundamental yet largely overlooked aspect of energy policy and climate change mitigation. Not least, the global commitment made at the UNFCCC conference in Paris in December 2015 is too ambitious to be achieved without addressing them [10]. Secondly, an exploration into consumption-based emissions unearths "large social and political patterns of inequality" [11] within and between nations, and between generations [12].

While energy consumption is generally associated with measureable units for the purposes of electricity, heating and transport, including kWh, joules, gallons, tonnes of oil equivalent and litres, this paper problematises a much less visible and less quantifiable aspect. That is, the embodiment of energy and its associated emissions within goods, services and commodities consumed by industry, commerce, the household and the individual. In particular the paper asks: what key theoretical approaches enable an analysis of the inequalities inherent in embodied emissions? What are the problems inherent in their measurement? How, if at all, are consumption-based emissions accounted for in policy, and what are the challenges in allocating responsibility for them?

Academic research and policy interventions to reduce energy demand has failed to account for the complexity of economic systems (Sorrell 2014:75), including how energy is embodied within circuits of global capital, industrial infrastructures and systems of production and consumption [14,11,15]. With this in mind, I situate consumption-based emissions within the theoretical context of ecologically unequal exchange. Doing so raises questions over how the increasingly popular and ubiquitous concept of the low-carbon or energy 'transition' (which involves a shift away from fossil fuels towards cleaner energy supplies coupled with increased efficiency in use and demand reduction) found within the sphere of academia [16], policy [17], industry [18] and civil society [19] should be conceptualised and implemented.

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This research uses the UK as a poignant example: while it has one of the least energy-intensive economies in the developed world, in part due to the decline of its industrial sector in recent decades, the country has one of the highest net imports of emissions in the world and is among the highest in terms of per capita emissions [20]. Yet there is limited acknowledgement that the bulk of energy consumed by households in the UK is in fact "embodied in non-energy goods and services" ([13]:77). As Bridge [14] argues, the consumption of energy in high-income contexts has been 'dematerialised' not only via electrification or gasification but also the import of consumer goods such as cars and fridges in which energy-intensive intermediate products such as steel, plastics, cement, and aluminium are incorporated and industrial infrastructure such as roads and buildings in which significant amounts of GHG emissions are embodied. In each case, the small-scale and large-scale consumer has been removed from the numerous and significant material inputs and processes, which include not only energy and natural resource extraction but also labour. Consequently, and as this paper concludes, a deeper understanding is needed of how energy and its associated emissions are embodied within "the context of a chain of processes and structures" [21].

The theoretical approach of this paper draws from two main bodies of literature: ecologically unequal exchange (e.g [5,22]), and consumption-based emissions accounting (e.g [23,7]). While the former is relatively theoretical and sits within the overlap of political ecology, ecological economics and Marxist political economy, the latter is statistically-informed and draws from climate science, engineering and emissions modelling. These two bodies of literature come from very different disciplines and are rarely linked directly, with a possible key tension between them being that the latter is evidence-driven and problem-oriented and by implication leans towards a more pragmatic and policy response, while the former is more analytically focussed and concerned with theoretical nuance and historical exploration. In linking these literatures and while accepting inevitable limitations, I hope to enrich both perspectives whilst speaking to audiences on both sides. Not least, both call for a greater understanding of cross border material resource flows and the global distribution of energy consumption and associated emissions. Responding to this call, I further draw on contributions from economic and human geography which emphasise the role of global interdependencies and the need for a more spatial and relational understanding of energy production and consumption [24]. In bringing together such literatures, I advocate for a creative synthesis of various traditions rather than a concise 'reconciliation' between them.

Empirically, the research draws from a desk-based analysis of grey literature, including reports from UK government departments such as the former Departments for Energy and Climate Change (DECC) and Business Innovation and Skills (DBIS), many of whose functions were taken over the Department for Business, Energy and Industrial Strategy (BEIS) established in July 2016, and the Department for Environment, Food and Rural Affairs (DEFRA); parliamentary bodies such as the UK House of Commons Energy and Climate Change Committee; independent bodies such as the Committee on Climate Change (CCC); and think tanks and information services such as *Carbon Brief*, the *Carbon Trust* and *Energy Live News*. The research also includes compilation of statistics, from the World Bank Development indicators' database and the UK Office for National Statistics.

The paper's structure is as follows. Section 2 discusses evolving concepts of energy and theoretical perspectives behind ecologically unequal exchange, including how the notion of consumption-based or embodied emissions sits within this. Section 3 problematises the measurement of GHG emissions on a territorial and/or production basis for its failure to account for the nature of embodied energy consumption. Section 4 examines the example of the UK which is followed in Section 5 with a consideration of the challenges inherent in a more equitable measurement and allocation of responsibility for consumption-based emissions. Section 6 concludes.

2. Rethinking energy and embodied emissions

While the standard scientific and physical definition of the term energy means "the capacity do work: that is, to move an object against a resisting force" (Boyle et al. [90]:6), the term has since become subject to a myriad of interpretations. These include: as a natural resource e.g coal; a technology e.g a solar panel; a networked infrastructure e.g a transmission grid; a commodity that can be bought and sold on the financial markets [27]; and a 'geopolitical object', central to discourses of security and scarcity ([11]:2). Acknowledging such multi-faceted diversity, in this paper I draw from Marxist concepts of energy as a social relation "enmeshed in dense networks of power and socio-ecological change" ([28]:106). Such an approach analyses energy as embedded within broader social, economic and political forces and processes and "a particular historical phenomenon inextricably tied up with unequal exchange" ([15]:102).

As the papers in this special issue demonstrate, concepts of 'spatial' in relation to energy are diverse and wide-ranging. Here, I speak to a spatial concept of energy by examining how the consumption of energy embodied in goods, services and commodities has become thoroughly separated and dislocated from its production. Such a separation illustrates the restructuring of global space in recent decades which, following Smith, includes processes of uneven development and shifting production across borders, particularly in the form of industrialisation in low and middle-income countries and deindustrialisation in high income countries ([29]:122). A spatial examination of energy further includes a consideration of the often under-theorised relationship between energy and labour. Not least, as the global mobility of capital has enabled the relocation of industry and technological production (and by consequence GHG emissions) to other geographical locations ([30]:334) labour has remained 'spatially trapped' ([31]:472).

By adopting such an approach I offer a challenge to the academic literature[1] on the low-carbon transition. While this literature has made valuable contributions to the understanding of socio-technological change, energy policy and innovation, it can also be criticised for its spatial blindness and its implicit overemphasis of "the national level at the expense of other geographical levels" ([32]:3); for its overriding focus on the individual in the residential sector as opposed to large energy-intensive and organisational consumers, which gives us "an unrealistic view into the kinds of transformation of energy consumption patterns that are needed" [11]; and for its heavy focus on energy supply as opposed to energy demand and/or the relationship between the two [32,13].

With this in mind, I now turn to embodied emissions as ecologically unequal exchange.

2.1. Embodied emissions as ecologically unequal exchange

> *"'Dirty' Industries: Just between you and me, shouldn't the World Bank be encouraging MORE migration of the dirty industries to the LDCs [Less Developed Countries]? I can think of three reasons: …"* Excerpt from leaked memo 12 December 1991, by Larry Summers, then World Bank chief economist,[2]

In the above citation, Larry Summers, then chief economist at the World Bank, justified his proposal for the offshoring of 'dirty industries' to less developed countries on the basis of economic arguments. These included: the removal of 'health impairing pollution' to the country with the lowest cost; that poorer countries are 'under-polluted'; and that the demand for a 'clean environment for aesthetic and health reasons' increases with levels of income. I include this citation here because it rationalises an economic growth model based on the export of polluting industries to low and middle-income countries, and the subsequent import of embodied

[1] Including socio-technical transitions [86], sustainability transitions [87] and the energy transition [16].

[2] Available: http://www.whirledbank.org/ourwords/summers.html.

emissions by high-income countries, with blatant disregard for questions of equity or social justice. While this statement, made 25 years ago would no longer be endorsed by the World Bank which now counts sustainable development and climate change among its core priorities, the practice of outsourcing of emissions still continues in practice.

'Ecologically unequal exchange' [5,32–34] merges concepts of economic 'unequal exchange', derived from strands of Marxist political economy, with concerns from political ecology and ecological economics over asymmetric metabolic flows within the capitalist world system. As I now discuss, while the former focusses on flows of monetary exchange and conflicts of *economic* distribution, the latter is more concerned with conflicts of *ecological* distribution [35,36]. Conflicts which in both cases are caused by industrial capitalism [5].

Economic unequal exchange, a broad concept subject to various interpretations and debates (cf [5]), can be summarised as being concerned with: global wage inequality and the labour time embodied in commodities traded between nations; the relationship between labour, capital and surplus value, which sees capitalists in high-income countries exploiting labour in their own country as well as benefitting from the surplus value produced by labour in less developed countries; and unequal terms of trade and purchasing power resulting in the transfer of wealth from less developed to high-income countries. Economic unequal exchange draws from various theories of underdevelopment and uneven development, including dependency theory and world systems theory [37,38], which asserted that national development could only be understood within the context of a global system that involves politically strong 'core' countries and their economically strong corporations, and much weaker and less developed 'periphery' countries ([5]:205). Unequal exchange results from asymmetric flows of surplus value from the 'periphery' to the 'core', a relationship exists *between* as well as *within* countries [37].

Though far from united,[3] the literature on ecologically unequal exchange develops concepts of economically unequal exchange by building on Marxist value theory[4] in order to analyse the exploitation and degradation of natural resources in processes of production and the biophysical limits of capitalism often ignored by orthodox as well as heterodox economics approaches [39]. Ecological awareness has not been systematic within Marxist political economy, which has paid limited attention to the natural and ecological limits to accumulation and the relationship between nature, labour and capital. Indeed, Marxist thought to date has failed to adequately account for the contribution of energy to the capitalist process [11] and the role of energy consumption in processes of production ([30]:Chapter 15). This in addition to the by-products or waste, including GHG emissions from fossil-fuel energy, generated from these processes [40].

In essence, while the surplus extracted from labour and its relationship to capital is central to Marxist value theory, there is limited explicit consideration of the way in which capital exploits and alienates environmental and natural resources from nature [40]. Much of the literature on Marx's value theory has focussed on fixed capital such as machines and infrastructure (in which embodied energy plays a fundamental role but is in this case invisible) and labour power in the means of production, but has underplayed the role of energy and raw materials.

Embodied emissions can therefore be considered a form of ecological, social and economic surplus extraction from low and middle-income countries, through which high-income consumers "are increasingly appropriating both global natural resources and the sink capacity of ecological systems" (Vetöné Mózner, [92]:84). Moreover, embodied energy has essentially replaced "labour in one part of the world with technologies based on imports of natural resources and embodied labour from other parts of the world" ([36]:17). Such a lens throws stark clarity on the inequality inherent in global patterns of consumption and the global "distribution of purchasing power and environmental degradation" ([36]:16).

Of further note is that concepts of ecologically unequal exchange [22] extend far beyond GHG emissions to incorporate other forms of pollution; the depletion of non-renewable energy and mineral resources; deforestation; and land[5] and soil degradation, as well as concepts of carbon and environmental footprint [43,44],[6] global environmental space, and 'environmental load' [45].

Beyond Marxist political economy, ecologically unequal exchange also offers a significant counterpoint to the limits of mainstream and environmental economics and the policy often guided by such approaches, which rarely accounts for the transboundary nature of systems of production and consumption and the energy and emissions embodied within them. For example while the environmental economics approach recognises nature's limits, it nonetheless assumes that environmental problems can be solved by the efficient pricing and regulation of natural resources, technical innovations, market systems and well-defined property rights [46].

A popular tool of environmental economics, the Environmental Kuznets Curve (EKC), though now rather dated, illustrates many of these assumptions. Under the logic of the EKC, poor and largely agriculturally-dependent countries generate limited environmental degradation and pollution which increases as they develop and industrialise but then decreases once they are past a certain level of wealth as a result of the introduction of greater efficiency and technological innovation. However, evidence for the EKC is not only limited ([13]:76) but also fails to recognise that 'growth-based dematerialisation' takes places at the cost of offshoring environmental externalities to poorer countries ([36]:12). Most obviously, if all countries followed the idealised trajectory from an agricultural to an industrial to a high-end manufacturing and service economy, "eventually there would be no further countries to specialise in material-intensive production" ([91:120]).

The failure of climate change policy to recognise the inequality inherent in methods of production-based accounting and consumption-based emissions are now discussed in the following section.

3. Problematising the territorial measurements: inequalities of consumption

The Kyoto framework under the United Nations Framework Convention on Climate Change (UNFCCC) measures emissions on a territorial basis, thereby placing "the burden of emissions reduction on those countries which produce energy-intensive goods, rather than those which consume them" ([47]:213). Under the UNFCCC countries are required to submit national emission inventories (NEI) based on emissions produced within the territorial boundary of the country in question [8].[7] Yet heavy criticism has been levelled at this measurement for its failure to account for emissions embodied within the import of commodities, goods and services from abroad, as detailed studies have shown in

[3] My discussions on this topic are limited to a broad summary. I acknowledge the depth and complexity of thought that has been put into understanding the relationship between biophysics and economics, and interpretations and criticisms of Marx's concern with the 'metabolic rift' between human society and the natural environment. Such thinking includes various attempts, contested and otherwise, to link and/or challenge Marxist economics and ecological economics [88,36], as well as the divisions that can be identified between and within these literatures (see for example [36,89,5]).

[4] Theories of the creation of profit via the exploitation of labour by capital.

[5] The UK is also a net importer of agricultural land, embodied in agricultural products ([45]:54).

[6] Note that the total carbon footprint of the UK includes the six main greenhouse gases: CO2, methane (CH4), nitrous oxide (N2O) and fluorinated compounds. This when compared to the 'carbon dioxide footprint' which relates just to CO2 emissions [44].

[7] Note that though the terms 'territorial-based' emissions and 'production-based' emissions are often used synonymously, they are in fact slightly different as explored by Barrett et al. ([23]:452-3). Notably, while the measurement of territorial emissions is required under the UNFCCC and reported internationally, the measurement of production based emissions, largely carried out by developed countries, is not. In addition, the former does not allocate international aviation and shipping to individual countries whereas the latter allocates such emissions to the country of the relevant vessel's operator.

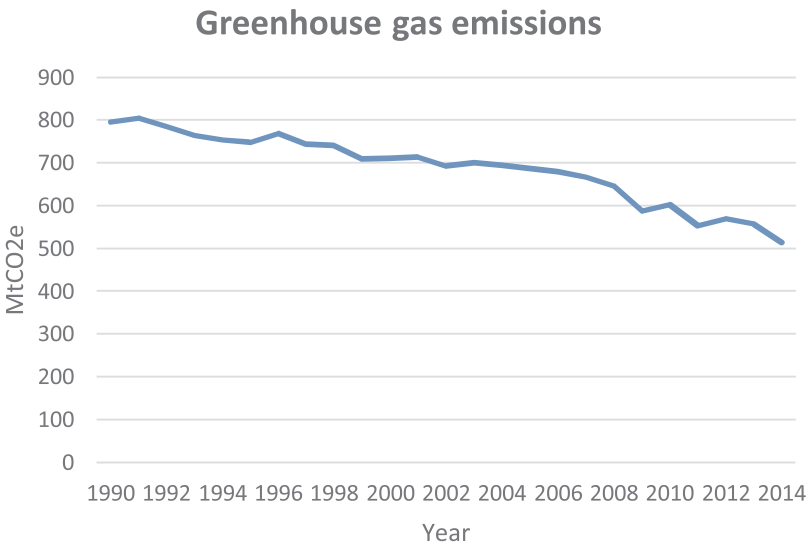

Fig. 1. Greenhouse gas emissions, UK (1990–2014).
Source: ONS [51].

relation to the UK [20,23,7,13]. Moreover the measurement of NEIs does not account for international transportation including aviation and shipping [8]. Consequently, NEIs present a wholly inaccurate portrayal of national impacts and fail to account for the "social, economic and ecological relations that underpin the experience of consumption" ([14]:4). Energy consumption is therefore inaccurately and inequitably portrayed within a 'national scalar frame' ([14]:825), as a result of which the environmental and social origins of GHG emissions embodied within consumer and capital goods go unrecognised [15].

There is therefore a strong case for emissions to be measured on a consumption basis in addition to a production and/or territorial one [23]. As Scott and Barrett ([7] :150) argue, consumption-based emissions accounting offers "underexploited policy interventions and increases the potential to break down barriers that exist between industrialised and emerging economies in international climate policy". However attempts to measure and integrate consumption-based emissions accounting into international negotiations have been largely unsuccessful and were barely mentioned at the UNFCCC conference in Paris [10].

How consumption-based emissions should be calculated and applied is a relatively new and evolving area in both policy [48] and academic research [8,23], and the measurements that do exist are rarely treated as 'official statistics' (Barrett et al. [23]:453). There are complex methodological challenges for this calculation, including the reallocation of emissions from technologies to sectors and imports. While work on this issue is growing, there is significant variation in the calculation of consumption-based emissions as compared to that of production-based emissions (Vetöné Mózner, [92]). In summary, methodological challenges include: the complexity of being able to attribute and measure embodied carbon within international supply chains, time lags in data availability, an absence of adequate time series data, a lack of publicly available data in some countries and/or regions, and differing opinions over where the boundaries for measurement should lie [49,20]. Consequently there is significant scope for uncertainty [8] and estimates vary depending on methodology and data availability, which so far makes it difficult to undertake cross country comparisons. In the absence of an agreed international standard, significant differences exist across countries in terms of the quality, sectors and time frames represented and in the ability to match emissions data with economic sectors (cf [20]:15). However, the multi-regional input-output [8] model of emissions (MRIO) in global trade, supported by emissions data from the Global Trade Analysis Project (GTAP) [6,8,43], despite the limitations posed by its complexity and lack of transparency.

There is also a point of contention in identifying who the polluter actually is [50]. For example "in the case of the construction of a factory, who should be attributed emissions from the initial construction of the building? The ultimate consumers of the goods produced by the factory? Or the owners of that factory?" ([42]:21).

A further challenge is the inadequacy of data to measure inequality of consumption and emissions *within* countries ([42]:20). This, in addition to how emissions embodied in financial investments including bonds, sovereign wealth funds and pension funds should be accounted for if those investments are in turn channelled into carbon-intensive activities.

These dynamics are now discussed in relation to the UK in the following section.

4. Consumption-based emissions: the case of the UK

In the UK, industrial direct GHG emissions have halved since 1990 (CCC 2016:120) and the country is now one of the world's least energy-intensive economies. The UK's territorial GHG emissions have declined significantly in recent decades and by 35 per cent since 1990 ([51], see Fig. 1).

Key reasons for this include a shift from coal to gas and increased renewable energy generation in the electricity sector (CCC 2016); energy efficiency in the transport and domestic sectors; fuel switching and increased energy efficiency in the industrial sector; a shift towards less carbon-intensive manufacturing; and an overall decline in industrial

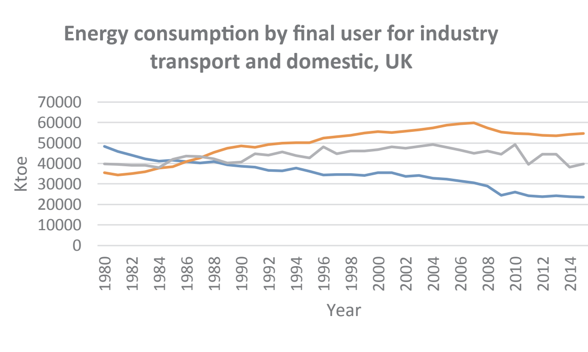

Fig. 2. Energy consumption by final user for industry, transport & domestic, UK (1980–2014).
Source: ONS [51].

[8] Though the original purpose of input-output analysis was to analyse inter-dependencies between economic sectors and trading economies, in this case it has been developed for the investigation of environmental factors ([20]:12).

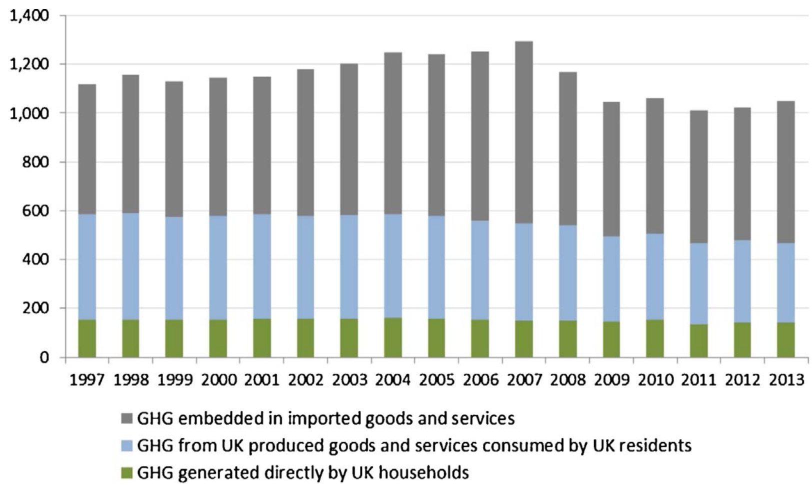

Fig. 3. Greenhouse gas emissions associated with UK consumption (1997–2013). Million tonnes CO2 equivalent.
Source: DEFRA [44].[9]

activity and associated energy consumption, particularly since 1970 ([53]:28).

The UK's industrial sector, which includes the manufacturing and construction sectors, refining of petroleum products and activities linked to energy supply (extraction and production of oil, gas and solid fuels) ([54]:118), now accounts for only 17 per cent of the country's total final energy consumption at approximately 24 million kilo tonnes of oil equivalent (Ktoe) ([53]:28, see Fig. 2) and is responsible for almost a quarter of the country's GHG emissions [56], less than transport and domestic consumption. The UK has de-industrialised faster than any other developed country and its manufacturing performance has been weak compared to other industrial competitors in terms of research and development, expenditure on capital equipment and share of global manufacturing exports [57]. Yet in consumption terms the UK is increasingly energy-intensive and emissions-intensive. Between 1993 and 2010 the country's consumption-based emissions grew by 16 per cent while its production emissions fell by 19 per cent ([20]:26). By 2010 the UK's consumption emissions were nearly 80 per cent higher than its production emissions, compared to 35 per cent higher in 1993 ([20]:23, see also Fig. 3).

Securing "ambitious international action on climate change" and the cost effective reduction of domestic carbon emissions was one out of four objectives of DECC's 2015–2020 five year departmental plan [59]. Yet despite this, and a number of apparently progressive developments that have been introduced in the UK in recent years in order to comply with national targets for GHG emissions reduction, such commitments deal exclusively with territorial emissions and consumption-based emissions do not feature. These commitments include: a government commitment to set legally binding targets to reduce national GHG emissions to 80 per cent of 1990 levels by 2050 under the 2008 Climate Change Act; the Low-carbon Transition Plan launched in 2009 with a target to produce 30 per cent of the UK's electricity from renewables by 2030; the 2011 Carbon Plan, which anticipates a reduction in per capita final energy consumption of 31–54 per cent by 2050; and the 2014 National Energy Efficiency Action Plan and Building Renovation Strategy (NEEAP), which includes various policy measures to increase energy efficiency in the domestic, commercial and public sectors.

The adoption of the fifth carbon budget in June 2016, a requirement under the 2008 Climate Change Act, sets the UK on a legally-binding path to cut emissions by 57 per cent compared to 1990 levels by 2032, despite criticisms and serious doubt as to whether such a target could be reached.[10] In 2016 electricity generation from solar PV exceeded that of coal during the months of May and July for the first time, with six per cent of total generation coming from solar PV and less than four per cent from coal [60]. UK coal use has been falling rapidly and fell to its lowest level since the industrial revolution in 2014 [61].

While the UK does produce figures on consumption-based emissions (see for example [44,62]), there are no signs that these will be incorporated into national policy. This despite reports produced by the UK House of Commons Energy and Climate Change Committee in 2012, and the Committee on Climate Change [20], both of which argued that the UK government should explore options for setting national level targets on a consumption basis.

The clear rise over time in the import of emissions via goods, services and commodities into the UK as well as the majority of OECD countries, demonstrates the interdependencies that exist between embodied energy consumption at the national level with production chains across borders. The shifting nature of the source of these emissions is also significant, reflecting the emergence of China as the world's largest manufacturing economy, the leading exporter of consumer goods and the world's top emitter since 2006 ([30]6:329). Notably emissions imported into the UK from outside European OECD countries rose by nearly 60 per cent between 1993 and 2010 ([7]:152) and China now accounts for 20 per cent of the UK's imported emissions ([44]:5).

In 2004 the emissions generated in China for the production of goods consumed in the UK were higher than all the direct emissions of UK households, including gas and car fuel at over 81 million tonnes of CO2e ([63]:19). Of these emissions, over 43 per cent are associated with electronic equipment and textiles. More generally, China's emissions exports grew by 320 per cent between 1990 and 2010 ([20]:30). And because China's electricity sector is twice as carbon intensive as that of the UK's due to its heavy reliance on coal-fired power, the emissions embodied in products made in China are much higher than they would be if the product were made in the UK ([63]:21, [6]). Notably, it is estimated that China's power sector emits almost seven times as much CO2 per pound of economic output as the UK (the [20]:29) and there are eight times more emissions embodied in China's exports than its imports ([6]:202). Not only does the "magnitude and growth of emissions embodied in Chinese trade pose a dilemma for trade and climate policy" ([6]:201) but also raises significant

[9] Note that due to uncertainties in the emerging methodology, DEFRA [44] classifies this data as 'experimental'.

[10] The UK government sets its carbon budgets in consultation with the Committee on Climate Change (CCC) which sees only for a 50 per cent probability of achieving a 2 °C limit [10,52]. Although the UK has complied with "the first round of Kyoto targets set under the UNFCCC and is well underway to comply with the second phase target" ([7]:152), commitments under the Climate Change Act are insufficient to meet the level of ambition expressed in the 2015 Paris climate change agreement to limit global temperature rise to below two degrees C.

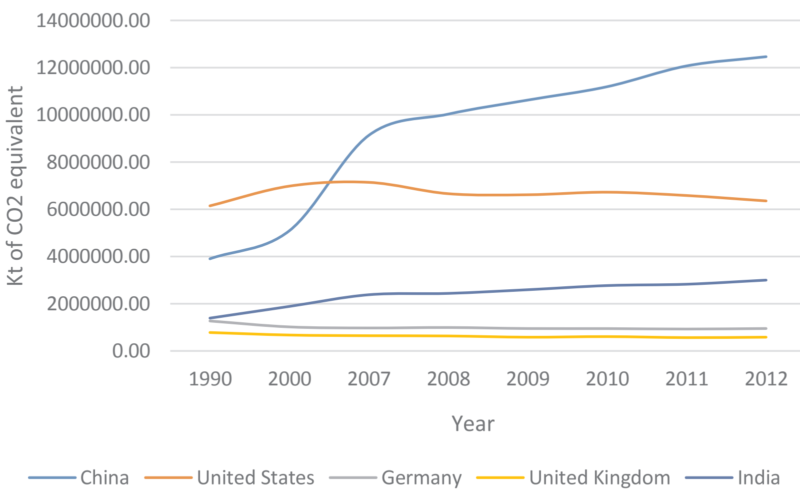

Fig. 4. Total greenhouse gas emissions by country (kt of CO2 equivalent). Source: adapted from World Bank development indicators: trends in greenhouse gas emissions.[11]

questions with regards to how carbon-intensive production is embedded in capital stock elsewhere, including in power stations, energy transmission and distribution systems and the transport sector, and how this should be accounted for in policy and economics.

However, while China's coal-fuelled, export-led economic development model now puts it in the lead as the world's largest emitter since 2006, and its per capita production emissions at 6.7 metric tonnes in 2013 have almost doubled since 1995, they are still much lower than those of the USA at 17 metric tonnes and just below those of the UK at 7 metric tonnes (see Figs. 4 and 5).

Meanwhile, recent evidence suggests that China is becoming less energy-intensive as it moves towards a service-based, consumption-oriented economy, with production of some sectors shifting to other countries in East Asia and the Pacific, including Vietnam and Indonesia, and South Asia such as India and Bangladesh [64]. Such a shift serves to exemplifies two issues. Firstly, the response of globally mobile, export-oriented capital and foreign direct investment (FDI) to increased labour costs, unionisation, and labour and environmental regulations that have accompanied recent industrial shifts in China, has been to go in search of lower-cost, semi-skilled labour (and therefore greater profit) elsewhere ([30]:327–366). Secondly this shift illustrates the problematic of the EKC discussed above in that the reduction or stabilisation of emissions in one country via the offshoring of heavy industry, is likely to result in an increase in another [65] paralleled by the increased fragmentation in production and associated material flows.

The concept of 'carbon leakage' [65], a term referring to the "loss of competitiveness of trade-exposed and carbon-intensive industries" located an industrialised country subject to climate mitigation requirements ([10]:103) is also relevant to this discussion. Following the logic of 'carbon leakage' a high-income country's emission reductions are achieved at least in part via the offshoring of production. Such a move inevitably contributes to the rise in emissions elsewhere, generally in a country not constrained to the same level of climate change mitigation commitments. However rather than as a direct result of climate and energy policy, carbon leakage has largely occurred as an unintended consequence of international trade flows (Peters, 2010) and rising labour costs. In addition to the methodological problems of measurement discussed in section 3, this raises uncomfortable and complex questions as to how responsibility should be allocated as I now discuss.

5. 'Polluter pays'? Towards a spatial and relational approach to the energy transition

Clearly a 'reallocation of responsibility' (cf [30]:331) from production-based to consumption-based accounting is thoroughly necessary. But beyond this general consensus, how should this responsibility be addressed and allocated? From a policy perspective at least, little thought has been dedicated to this, and that which has largely been focussed on trade and border carbon adjustments [2].

Helm is quite categorical that "the polluter is the consumer, not the producer" ([47]:221) and therefore carbon emissions "should be measured on a consumption not production basis" ([47]:p. 224). However, while behavioural change and personal responsibility play a role in reducing emissions, restricting the focus to individuals, particularly at the household level, fails to tackle political, industrial and economic structures and configurations over which the individual consumer has little, if any, control. As Sorrell ([13]:79) cautions, focussing on autonomous decision making by individuals neglects how their preferences and behaviours are "embedded in and shaped by broader" socio-technical systems. Moreover, a binary perspective that pits the individual or even industrial consumer against the producer in responsibility terms impedes a more comprehensive understanding of energy consumption in its embedded and dispersed form throughout global supply chains, and therefore a more radical challenge to it.

Secondly, the individualisation of responsibility for reducing emissions risks exacerbating inequalities between high-income and low-income consumers [67], whereby those with greater purchasing power are more able to absorb any additional monetary costs of carbon responsibility or carbon reduction incentives. One example of this is the feed-in tariff for solar PV in the UK, the benefits of which have mainly accrued to homeowners with sufficient capital to pay for the upfront costs of installation, while the overall costs have a "been spread across all households as additional costs on bills (Grover, 2013)" (in Eyre and Lockwood [68]:21). Similarly, low-income consumers may be shamed or financially penalised for consumption activities that are deemed high-carbon, such as driving old cars, simply because they cannot afford to do otherwise. Tackling the issue of responsibility therefore raises the question of how to avoid the politics of condemnation and the 'vanity-oriented virtue politics' of self-denial and sacrifice ([67]:828).

Thirdly, and as a challenge to Helm's assertion, the term 'consumer pays' is not synonymous with that of 'polluter pays'. Without an awareness of the more fundamental determinants of supply and demand within the complexity of economic systems, the nature of ownership and processes of production may end up being overlooked. This invokes deeper questions over who owns the means of the production and how related patterns of consumption are determined [30].

Developing concepts of the core and periphery discussed in Section 2, a key challenge therefore is to address how emissions from commodities, goods and services arise across complex and geographically dispersed supply chains involving a variety of intermediate stages and the fact that environmental costs and responsibilities are often eschewed during the

[11] Available: http://wdi.worldbank.org/table/3.9.

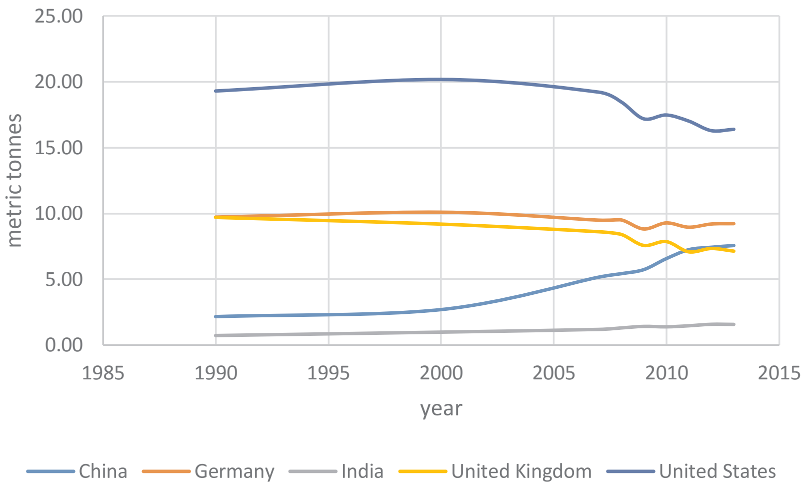

Fig. 5. CO2 emissions metric tonnes per capita.
Source: Adapted from World Bank Development Indicators Database.[12]

production process and passed on to the ultimate consumer. In this sense, production and the pollution it generates are *processes* far more often than a singular event or action that occurs in one location alone.

Understanding this question in practical terms therefore requires a consideration of actors and forces beyond national (e.g UK) and regional (e.g EU) borders in order to better understand many of the significant transnational dynamics and spatial interdependencies that may affect and determine any potential low-carbon transition. As DEFRA argues, in order to understand the effect that UK consumption has on GHG emissions "we need to take into account where the goods we buy come from and their associated supply chains" [44]. Such an argument resonates with Allwood et al's ([69]:85) ambitious call to understand "the full directory of who's involved and why" and "where does the money involved in final purchase eventually flow?", and Scott and Barrett's ([7]:154) assertion that the scope of emissions reductions should reflect the UK's role as "an industrialised global consumer" and account for net emissions embodied in trade. This brings us back to the literature on the low-carbon transition and the need to take a closer look at "the geographical unevenness of transition processes from the perspective of global networks and local nodes" ([70]:968).

Two approaches may be useful here, neither of which have yet engaged with questions of energy and emissions in any great depth but which I put forward as areas for future research. Firstly, the Systems of Provision approach sees the connection between initial production and final consumption as a vertically integrated 'chain of activities' [71,21]. As Fine argues, "what gets produced must more or less get consumed" ([72]:222) and that it is generally the *producer* that dominates over consumer policy. There is therefore a need to restore "production to a position of prominence" ([72]:p. 233). Secondly, the literature on Global Production Networks (GPNs) [73,74,31] may also help to facilitate a more spatially-aware understanding of embodied energy and emissions, for its consideration of forces and factors that transcend national regimes and jurisdictions, and less evident power structures and networks.

6. Conclusion

This paper has argued that not only is the measurement of territorial and/or production emissions at the national level a case of ecologically unequal exchange, but also an inadequate and arbitrary spatial scale of analysis [45]. Despite the important role played by the national-level, technology-focussed perspective of much of the energy policy and transitions literature to date, in isolation it risks presenting an "unrealistic view into the kinds of transformation of energy consumption patterns that are needed" ([24]:333). Consequently, a deeper analysis is necessary that allows for a more distributional awareness of energy demand and consumption, and associated GHG emissions.

Energy consumption therefore, needs to be "approached through a wider lens focussed on institutions and sectors" ([11]:7), with more attention given to the growing separation of systems of production and consumption, in particular the acknowledgement that emissions are generated in one, or indeed several countries by one or many firms, for the benefit of consumers in another and that dematerialisation on one side of the world may directly or indirectly result in the relocation of energy-intensive production elsewhere. This includes unpacking the simplistic assumptions often made about the relationships between energy consumption, carbon emissions and economic development; focussing on underlying processes that drive geographies of energy demand; and examining the role of large organisational producers and consumers.

As this paper has demonstrated, tackling energy demand is as much an issue of bargaining power in trade, FDI, foreign policy, industrial strategy and international relations as it is domestic policy on energy efficiency and demand reduction. And understanding the allocation of responsibility in the case of embodied energy and embodied emissions is as much an area for climate, energy and environmental policy as it is for theoretical discussions of global distribution [36]. Therefore beyond policy there is a need to look at structures and processes, relating to Bradshaw's claim, that "The problems at Copenhagen suggest a need to spend less time on setting long-term targets that few can agree on, let alone achieve, and more time on understanding the relationship between energy demand, economic growth and carbon emissions" ([1]:7).

Given the dual concern of ecologically unequal exchange with both socio-economic and ecological inequality, I argue that greater consideration should be given to concepts of embodied labour in parallel to concepts of embodied energy and emissions. This would include types of labour which, like nature and energy, are not accounted for within formal systems of capitalist production such as unpaid work of women. While an in depth discussion of the role of labour and wage inequality in relation to embodied emissions went beyond the scope of this paper, it is identified as a key priority for future research. Rather than a zero-sum game between ecological stewardship and labour rights, with one being prioritised at the expense of the other, those concerned with the low-carbon transition and those concerned with labour exploitation should seek to understand the interaction and interdependence between ecological and socio-economic inequalities. Doing so would go some way to respond to calls for a concepts of a transition that is at once just and low-carbon [75,76].

Finally, the low-carbon energy transition, in addition to a technological process, is also a geographical one, "that involves reconfiguring

[12] Available: http://data.worldbank.org/indicator/EN.ATM.CO2E.PC.

current spatial patterns of economic and social activity” ([24]:331) as well as relationships both within countries and regions, and between them. For a comprehensive understanding of the low-carbon transition, matters of energy demand and consumption must be situated within a broader geopolitical and socio-economic context [1] that is at once *spatial* and *relational*. Such a focus enables us to pose “systemic questions about the relationship between energy, geography and society” ([11]:12) and the inevitable implications and challenges this poses for contemporary policy-making.

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