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An integration of net imported emissions into climate change targets

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ABSTRACT

There is an international divide between net emissions importers and net emissions exporters, with industrialised nations mainly falling into the former and emerging economies the latter. Integrating emissions transfers into climate policy, so as not to disadvantage export-intensive countries, has been suggested to increase participation in international emissions reduction commitments. Consumption-based scenarios are presented for the UK identifying the geographic and sectorial source of emissions to meet future consumer demands given the current international climate policy landscape. The analysis is applied to the UK yet the discussion is applicable to international climate policy; assigning national responsibility for global emissions reductions; and extending the mitigation potential for net importing countries. Two trajectories for UK consumption emissions are calculated in which (1) international reduction targets are consistent with those pledged today equating to four degrees of temperature rise and (2) international reduction targets achieve a two degree future. By 2050 it is estimated that UK consumption emissions are 40–260% greater than UK territorial emissions depending on the strength of global reduction measures, and assuming the UK meets its 80% reduction in 1990 emissions by 2050 target. Cumulative emissions are presented alongside emissions trajectories, recognising that temperature rise is directly related to every tonne of carbon emitted. Whilst this paper argues that the current UK emissions targets underestimate the UK's contribution to global mitigation for two degrees, it shows how expanding the focus of policy towards consumption introduces new opportunities for reduction strategies at scale. The paper advocates the implementation of consumption-based emissions accounting which reveals underexploited policy interventions and increases the potential to break down barriers that exist between industrialised and emerging economies in international climate policy.

1. Introduction

Drastic cuts in emissions are needed to achieve the global climate objective of limiting temperature rise to two degrees. The IPCC 5th assessment report presents the latest scientific evidence on the relationship between emissions and temperature rise (Stocker et al., 2013). The report shows that global temperature rises are approximately proportional to an increase in cumulative carbon emissions, and not simply end-point targets for 2050, given that emission pathways can differ (Gillett et al., 2013). This has major implications for the way climate change targets are implemented. Contributions to climate policy literature have illustrated the need to replace end-point targets with cumulative carbon budgets (Anderson et al., 2008; Anderson and Bows, 2011, 2012; Meinshausen et al., 2009; Peters et al., 2013; Gillett et al., 2013; Chicco and Stephenson, 2012). Cumulative emissions will depend on the interplay of technology and policy development, and how effective policy can enable the deployment of low carbon technologies (Chicco and Stephenson, 2012).

Reaching global agreement on how much responsibility should be assigned across regions is being contested in international climate negotiations, creating somewhat of a climate 'impasse' (Grasso and Roberts, 2014). Currently greenhouse gas emissions reductions are by-and-large governed by a pledged-based system of end-point targets benchmarked against territorial emissions in a handful of regions implemented under the Kyoto Protocol and Cancun Agreements; however these commitments alone equate to in the region of four degrees of warming (IEA, 2012). Industrialised countries, termed Annex I parties,[1] have the strongest quantitative commitments and

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[1] Industrialised OECD member countries and countries deemed to be economies in transition in 1992.

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reporting obligations compared to emerging and developing economies, non-Annex I parties,[2] which have qualitative obligations, more lenient reporting requirements and eligibility for financial and technological assistance (Depledge, 2009). Countries are often referred to as Annex B and these are the Annex I countries that have ratified an emissions reduction target under Annex B of the Kyoto Protocol, which in its second phase accounts for less than 15% of global emissions (Grubb, 2013).

In contrast to territorial emissions accounting, research papers in the last five-to-ten years have calculated countries' consumption-based emissions accounts: the emissions embodied in a country's final consumption regardless of where they are produced (for example Davis and Caldeira, 2010; Hertwich and Peters, 2009). Studies show that industrialised countries tend to be net importers of emissions whereas emerging and less developed countries tend to be net emissions exporters. In the first round of Kyoto targets the emissions saved were completely offset by net emissions transfers from non-Annex B to Annex B countries (Peters et al., 2011; Kanemoto et al., 2014), referred to as carbon leakage. However, there has been little debate on the use of different system boundaries for international emissions reporting (Peters and Hertwich, 2008), and efforts to incorporate consumption impacts into international negotiations have been marginalised (Isenhour and Feng, 2014). Some now advocate that net emissions importers should take on responsibility for the 'additional' imported emissions generated outside their territories (Singer et al., 2014).

Studies have shown on the grounds of equity that industrialised countries should take on more responsibility than is currently assigned to mitigate global carbon emissions (Steininger et al., 2014; Grasso and Roberts, 2014; Raupach et al., 2014; Athanasiou et al., 2014; Pan et al., 2014). Athanasiou et al. (2014) even suggest that emissions reductions in Annex I countries should be greater than the emissions generated within these countries, meaning they need to take responsibility for reducing emissions in non-Annex I countries. What has not been explicitly analysed in the literature is distributional trends in consumption emissions and whether trends in net traded emissions are likely to continue within existing climate change frameworks.

The UK, for example has an 80% emissions reduction target on 1990 territorial emissions by 2050, to be achieved through implementation of its Carbon Plan (HM Government, 2011), and has interim 5 year carbon budgets (set 4 terms in advance) to try to ensure a reduction in cumulative emissions towards meeting the end-point target. It is unclear however how much of the UK's cumulative consumption-based emissions would continue to sit outside the UK in the country of origin, complicating their inclusion in reduction targets. A few studies have shown for highly aggregated global regions what consumption-based emissions trajectories are needed to meet carbon budgets for two degrees, without considering what they are likely to be given existing climate polices (Bows and Barrett, 2010; Springmann, 2014). Both references provide high-level regional analysis without disaggregated trade and sectorial details. To help inform the evidence gap this paper analyses the corresponding cumulative emissions of implementation of international climate policies from a national consumption perspective. The paper poses four research questions:

(1) Within the existing international climate policy framework, will the UK continue to be a net importer of emissions to 2050?
(2) In which regions and sectors will UK consumption-driven emissions be emitted in 2050?
(3) What is the cumulative impact of UK consumption emissions to 2050?
(4) How can climate policy respond to achieve a reduction in the cumulative global emissions caused by UK consumption?

The paper is the most comprehensive analysis to date of consumption-based pathways at the country and sector level. It extends well established territorial decarbonisation scenarios from the IPCC's representative concentration pathways (Stocker et al., 2013) and the IEA's Energy Technology Perspectives (IEA, 2012) to include trade. While the IPCC provided a detailed analysis of the embodied emissions of trade as part of the assessment of past drivers, the literature was not available to consider future projections within the scenario analysis. This paper is one of the first to provide a detailed analysis of the future emissions embodied in trade within the context of the IPCC's detailed analysis of territorial emissions. Whilst providing this detailed consumption-based emissions pathways for the UK, the results are also discussed in the context of domestic and international climate policy and the feasibility of achieving a two degree future.

2. Method for determining consumption-based emissions trajectories for the UK (2010–2050)

Territorial emissions are published annually in the UK by DECC (Department for Energy and Climate Change), and the UK is one of a handful of countries to publish consumption-based emissions from 1990 to 2013 (DEFRA, 2015; Barrett et al., 2013). National consumption-based emissions are equal to territorial emissions minus emissions generated to produce exports (consumed elsewhere) plus emissions generated elsewhere to produce imports, and are calculated using multi-region input–output models. UK consumer demand will not just induce production in the UK economy but will induce global production activities, resulting in emissions being released outside of its territory. Consumption-based accounts lag a few years behind the release of territorial emissions therefore at the time of this research 2010 was the latest year available.

In this paper consumption-based emissions are projected at 5 year intervals from 2010 to 2050. The modelling framework is built on collaboration between the authors and the UK Committee on Climate Change (CCC) who were investigating emissions associated with future UK consumption patterns, documented in the CCC's report *Reducing the UK's carbon footprint and managing competitiveness risks* (CCC, 2013). In addition this paper presents territorial emissions alongside consumption-based emissions for comparison and the cumulative impacts of the scenarios are calculated based on the direct relationship between temperature rise and carbon emissions (Gillett et al., 2013).

3. Input–output analysis

Environmentally extended multi-region input–output analysis (EE-MRIOA) can evaluate the emission impacts embodied in goods and services traded between nations and is recognised as the most appropriate tool to estimate consumption-based emissions accounts at the national and supra-national level (Peters, 2010; Wiedmann, 2009; Peters et al., 2012). EE-MRIOA reallocates production emissions, which are point source emissions from sectors within a country's territory, to the destination country of the final consumer through complex international trade flows (Peters, 2008). Direct household emissions for heating and transport are added onto the account as they are not allocated to an industry sector.

Using input–output analysis, consumption emissions (F) are given by $F = f_x L y$, where f_x is the direct carbon intensity of

[2] Those deemed as developing in 1992 and recognised as being vulnerable to the adverse impacts of climate change.

production sectors, L is the effect of trade transactions (known as the Leontief inverse), and y is the volume and composition of final consumption. Carbon intensities for production sectors (f_x) are calculated by dividing direct sector emissions (f) by the sector's economic output (X). The Leontief inverse (L) calculates the ratio of upstream requirements (i.e. goods and services) to produce each sectors finished products. When multiplied by the vector of carbon intensities it provides carbon intensities for final products which includes the direct and indirect emissions produced along product supply chains to the point of purchase, referred to as total carbon intensities. Multiplying the total carbon intensities for domestic and imported products by a country's final demand for domestic and imported products (y) determines the emissions released globally in the production of goods and services consumed in a nation – its consumption-based emissions account.

3.1. Scenarios and projections

Two main scenarios are presented, providing different representative trajectories for UK consumption-based emissions to 2050 in which (1) international efforts do not go beyond those currently implemented equating to four degrees of warming, and (2) global production emissions reduce in line with carbon budgets for a two degree future. These scenarios will differ in their emissions embodied in UK imports.

The input–output framework is used to link international and UK emissions reductions with growth in UK final demand via global trade transactions to calculate the UK's consumption-based emissions from 2010 to 2050. One hundred and ten productive sectors are modelled within the UK and their trade with 26 sectors in seven global regions outside the UK to meet UK demand are modelled: OECD Europe (excluding UK), non-European OECD, Russia, China, India, Rest of Asia and Rest of World. Each variable in the input–output model described in Section 3.1 is projected at 5 year intervals from 2010 to 2050 to generate two consumption based emissions trajectories. Emissions at 5 year intervals are then interpolated to estimate cumulative emissions from 2010 to 2050. Projections for UK territorial emissions are produced separately to projections for international emissions (f_{UK} and $f_{overseas}$). The assumptions for each variable are summarised in Table 1 and described in more detail in Appendix A. The resulting consumption-based emissions trajectories are compared to the UK territorial target to determine the distance from the territorial target to achieve a two degree future. The results section presents two representative trajectories for UK consumption-based emissions to 2050, broken down by sector and import share, and from a cumulative perspective.

4. Results

Traded emissions results are limited to CO_2 only due to data availability of global emissions; however the UK production emissions are expressed in CO_2e to benchmark against national targets. UK consumption-based emissions have grown 16% from 1993 to 2010, with imported emissions from outside European OECD countries rising nearly 60%. Looking forward to 2050, implementation of domestic and international mitigation policies drives absolute emissions associated with the UK down. Fig. 1 shows results for UK production and consumption emissions. The two trajectories for consumption emissions represent the two scenarios which consider (1) only the current Cancun Agreements consistent with four degrees of temperature rise (line with diamonds) are implemented, and (2) imports are produced in a world where global mitigation is compatible with limiting warming to two degrees (line with triangles). The UK has already complied with the first round of Kyoto targets set under the UNFCCC and is well underway to comply with the second phase target.

The success of the UK in achieving its reduction targets is offset by emissions generated in other regions to meet UK demand. Even with strong global mitigation the UK could continue to be a net importer of emissions in 2050 with consumption emissions estimated to be 43% higher than the 80% reduction target, increasing to two and a half times the target (257%) if only current internationally pledged reductions were implemented (see Fig. 1).

If strong international abatement efforts towards a two degree future are achieved, emissions generated in the energy sector become a tenth of what they are in 2010, changing the sector profiles considerably by 2050. Emissions generated in the global energy sector are anticipated to contribute an 11% share to UK consumption-based emissions in 2050 compared to 41% today. The share of emissions is shifted to manufacturing and transport services, where there are more barriers to technology deployment, each estimated to represent nearly a 40% share by 2050. If countries fail to achieve the required reductions, current international emission reduction commitments would mean the share of UK imported emissions climbs to nearly 80% (the transparent colours in Fig. 2), with a higher share of the increase in imported emissions being produced in non-Annex I countries.

Table 1
Summary of UK consumption emissions projections (more detail is provided in Appendix A).

Consumption emissions variable	Summary of scenario assumptions 2010–2050
UK production emissions trajectory (f_{UK})	UK production emissions are reduced 80% from 1990 levels by 2050 following the "Barriers in industry" scenario defined by the CCC (2012, p. 46).
International production emissions trajectories ($f_{overseas}$)	This is where the two and four degree scenarios are distinguished. (1) Only currently pledged emissions reductions are achieved consistent with four degrees of temperature rise, and (2) global emissions are reduced from 2010 to 2050 to have a 66% probability of limiting temperature rise to two degrees.
Direct carbon intensities of production sectors (f_x)	Production emissions are divided by projected economic output to describe the carbon intensity of production sectors. The Office for Budget Responsibility (OBR) projections were used to project UK annual economic growth rates and IMF (International Monetary Fund) and other sources were used to project economic output in the seven trading regions. Both scenarios achieve improvements in carbon production intensities.
Global trade transactions (L)	Global trade transactions between sectors and countries destined for UK consumers are taken from the Eora database developed at the University of Sydney (Lenzen et al., 2012, 2013). The share of product inputs along product supply chains are assumed to remain constant, however sales to final consumers change which reflects changes in the structure of the global economy.
UK final demand (y)	The level of UK final demand grows in line with trends over the past 20 years, with demand for domestic and imported products increasing at an average annual growth rate of 1.9% and 2.75%, respectively.

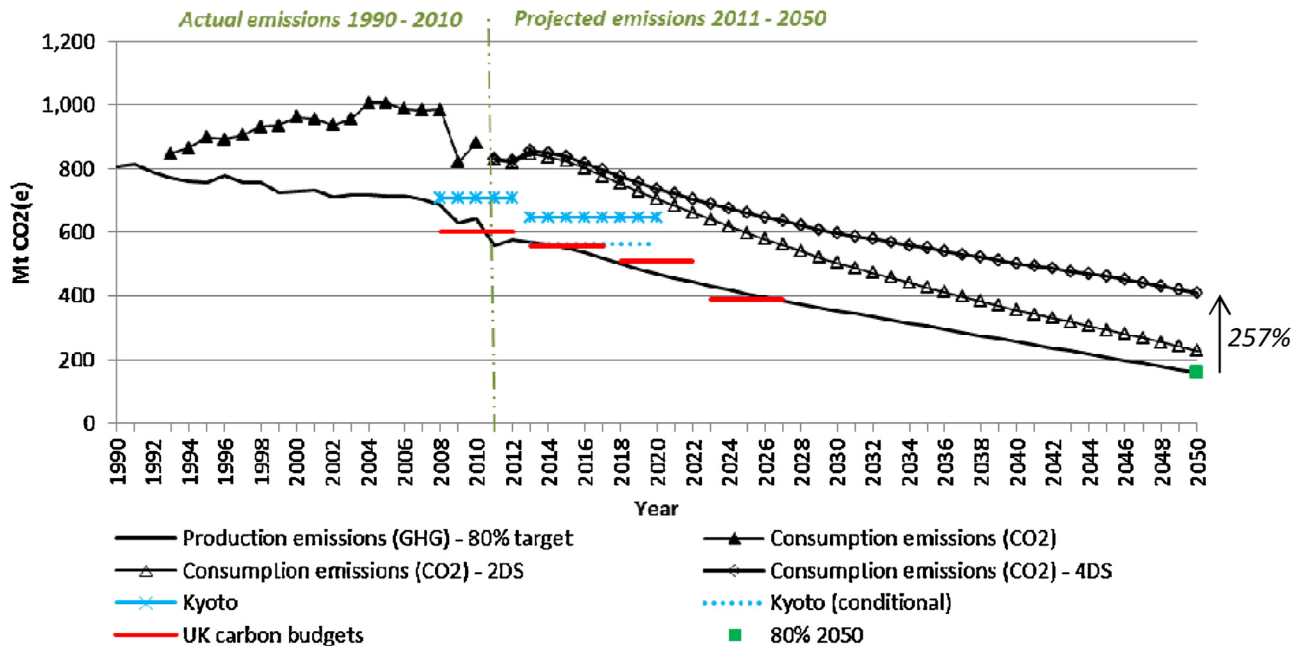

Fig. 1. Emissions trajectory for the UK to 2050 (UK production emissions are in Mt CO_2e and import emissions are in Mt CO_2).

The sum of the bars in Fig. 3 show the cumulative emissions between 2010 and 2050 (blue bars) compared to a baseline situation whereby it is assumed 2010 emission remained constant at 2010 levels to 2050 to give a measure of avoided cumulative emissions (red bars). From a production perspective over 25 $GtCO_2e$ would have been generated by UK industries and just over 11 Gt (44%) would be avoided by meeting the 80% reduction target. From a consumption perspective 33.5 $GtCO_2(e)$ would have been generated, 42% from industries overseas. Only about 10 Gt (30%) would be avoided in a four degree future, compared to 14 Gt (41%) in a two degree future. Imported emissions add more than 9 Gt CO_2 to the cumulative account, and a further 4 Gt CO_2 without a global deal to strengthen current emission reduction commitments.

5. Discussion and policy recommendations

The results of this analysis emphasise that unilateral climate policies can be hampered by carbon leakage. Half of the UK's cumulative consumption-based emissions sit outside the UK in the country of origin, and increasingly within non-Annex I countries, which is of mounting concern without their inclusion in international reduction targets. We illustrate how net imported emissions could increase UK production emissions in the region of 40% to nearly 260% depending on the strength of international mitigation efforts in 2050. This assumes compliance of UK carbon budgets and currently pledged emission targets; however recent analysis raises concerns for whether UK policy is even enough to achieve its fourth carbon budget (CCC, 2014).

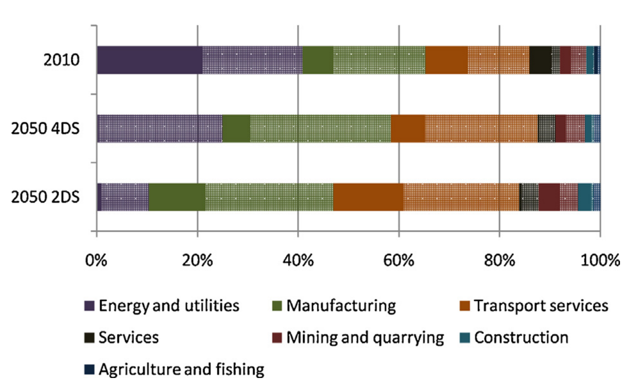

Fig. 2. Share of UK consumption emissions by sector of origin in 2010 and 2050 under a two and four degree scenario. Sectors are disaggregated by their domestic and overseas location with the second transparent colour segment representing the overseas proportion. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Without a global cap on emissions, different policy measures have been proposed to prevent carbon leakage from making unilateral policies ineffective. One of the most widely discussed options is carbon border adjustments where the carbon content of imported products from non-regulated (or weaker regulated) regions is taxed at the emissions price of the regulating region and emission payments for exports to non-regulating countries are rebated (Bohringer et al., 2012a,b, 2014; Bednar-Friedl et al., 2012). Whilst generally but not exclusively thought of as being the most effective means of cutting leakage, they have been found to intensify regional inequalities by penalising the high exporting countries and may be in breach world trade agreements (Atkinson et al., 2011; Bohringer, 2014; Li et al., 2013). The distributional impacts could be reduced if tariff revenues were redirected towards the exporting countries (Bohringer et al., 2012a), and low carbon technology transfers from regulated to unregulated regions enabled developing countries to compete by producing carbon equivalent products. The discussion below identifies options for the UK, and other industrialised nations, for mitigating emissions embodied in their imports, without unfairly taxing export economies.

5.1. Revising the UK's emissions reduction target

From a consumption perspective the UK generates more emissions abroad than it statutes for. This is not an argument to cease trade to the UK as this in itself would not necessarily reduce global emissions (Jakob and Marschinski, 2013), but to extend the scope of emission reductions to reflect the UK's position as an

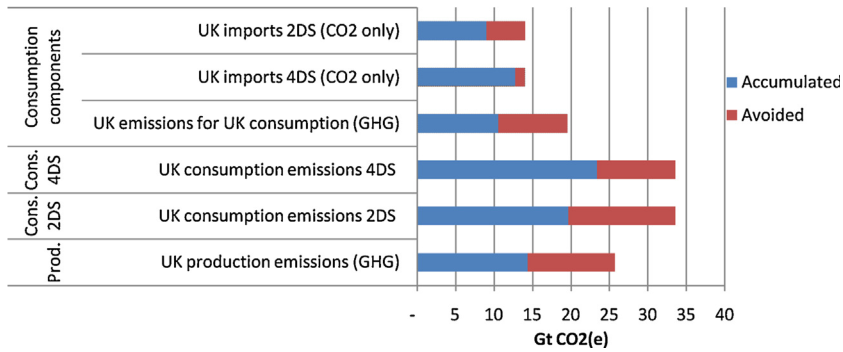

Fig. 3. Accumulated and avoided emissions for scenarios from a production and consumption perspective from 2010 to 2050. Avoided emissions are equal to the cumulative emissions from 2011 to 2050 if emissions stabilised at 2010 level minus the cumulative emissions in the two and four degree futures. (For interpretation of the references to colour in this figure text, the reader is referred to the web version of this article.)

industrialised global consumer. With industrialised nations secured into a legally binding mitigation framework, strengthening their commitments by extending their carbon budget framework to include net emissions embodied in trade could make reduction targets for high-exporting (less industrialised) economies more palatable. To demonstrate the scale of such an initiative, it is estimated that in 2050 the UK drives an additional volume of emissions of between 68 and 251 CO_2 outside its territory depending on global mitigation efforts. Subtracting these figures from the existing 2050 target of 160 Mt CO_2e would result in the UK target being reduced to at least 91 Mt CO_2e (equating to an 89% reduction on 1990 territorial emissions, 805 Mt CO_2e), to having negative emissions of 92 Mt CO_2e by 2050.

5.2. Expanding the focus of climate policy

To achieve the same intended 'climate outcome' of the existing territorial target, which is dependent on cumulative emissions, countries with high consumption-based emissions could be given tighter carbon budgets. There are three broad options in which to achieve greater reductions without taxing exporters: (1) strengthen reduction efforts within the national territory, (2) reduce emissions in countries outside one's territory, and (3) reduce and/or alter resource consumption; of which there are benefits and disadvantages of each.

5.2.1. Increasing domestic emissions reductions

The UK could strengthen its domestic reduction efforts, however the assumptions employed in the scenarios for global and UK production emissions trajectories are heavily reliant on decarbonisation and technology innovation and deployment. It is assumed the technologies are available and cost effective to mitigate for two degrees. Whilst deemed to be technically feasible and within the political scope of national governments, there are risks and barriers to widespread technology deployment (Bruckner et al., 2014) and the transition into practice has not had a promising start. Although the UK met the first round of Kyoto targets and its first carbon budget, the evidence suggests this is mainly due to the exclusion of international aviation and shipping,[3] the economic recession, and generous carbon allowances under the EU ETS. For example less than 1% of the 7% reduction in UK territorial emission reductions in 2011 is attributable to climate policy (CCC, 2014). The under ambitious allocation of allowances in the EU ETS coupled with reduced shares of GDP being spent on energy-related research (Bowen and Rydge, 2011) has meant there is less incentive to innovate and the share of energy consumption from renewable sources remains marginal compared to fossil fuels at 4% of UK energy consumption (DECC, 2013). With annual emissions reduction rates of more than four times the global average (1.2%) needed to 2050, and a diminishing global carbon budget, there is a need to look at alternative reduction options.

Edenhofer et al. (2015) argue that unilateral policies can be effective with the implementation of a national carbon price. This would allow countries to select the policies that work most efficiently for them, and could pave the way to a global dynamic hybrid climate regime. Even though they acknowledge that a national carbon price will not in itself meet the required global emissions gap, evidence has shown that other countries are likely to reciprocate the more ambitious efforts of the lead country (enabled through, for example shared experiences and technology spill over). These more flexible bottom-up unilateral policies could be coordinated into an international framework that is gradually scaled up over time by countries pledging to increase their effort conditional on policy support or more ambitious targets in other countries. Edenhofer et al. (2015) provide examples of linking regional trading schemes, investing in joint research and development initiatives and technology cooperation aiming to harmonise high standards.

5.2.2. Strengthening effort-sharing agreements

National efforts could be strengthened by effort-sharing agreements linked to climate targets. As alluded to in the previous paragraph, this includes the transfer of finance, knowledge, abatement technologies and so forth and therefore allows the UK to take on more responsibility than what is defined by its territorial emissions. This was partly the intention of the Clean Development Mechanism (CDM) which was set up under the UNFCCC to allow countries with reduction targets to gain carbon credits for implementing or financing carbon reduction projects outside their territory; recognising however in theory that the process needs to also ensure it benefits the host population (Mathur et al., 2014). According to Edenhofer et al. (2015), strong leadership and technology spillover can promote actions in other regions, and it can enable emissions intensive consumer countries to negate additional emissions outside of their political jurisdiction. Whilst this can be argued on the grounds of improved equity, whereby net emissions importing countries with higher economic capacity take on responsibility for the impact of their consumption-intensive lifestyles, CDM projects have not necessarily had the

[3] Whilst not in the UK's officially reported territorial emissions, these are included in the 80% reduction trajectory modelled in Fig. 1. This is termed production emissions, not territorial, to identify that emissions from aviation and shipping are included. If these additional emissions were included in the territorial account the first carbon budget would have been exceeded by 2.5%.

intended transferral benefits for the host nation (Costa et al., 2013); they have been unevenly distributed across countries (Rahman and Kirkman, 2015); and it has been hard to prove that the emissions reductions would not have occurred without the CDM (Erickson et al., 2014). Therefore this needs to be corrected for such policies to be effective.

5.2.3. Reducing consumption

Greenhouse gas mitigation from changing consumption has received little attention in climate policy literature (Girod et al., 2014), with the exception of residential energy efficiency. Consumption changes can increase mitigation options beyond decarbonisation. Bruckner et al. (2014) suggest more aggressive energy demand reductions are needed to meet international climate objectives. Girod et al. (2014) show the potential of consumer changes in food, shelter, mobility, goods and services to make a significant contribution to the international two degree target. Currently UK policy influencing consumption deals primarily with the energy consumption of products, stemming from three EU Directives: EU Eco-Design Directive, EU Energy Labelling Directive and the EU Ecolabel Scheme (a voluntary measure). Yet there is also untapped potential for resource efficiency strategies that deal with material and product demand to drive emission reductions upstream, including those generated in its trading partners (Barrett et al., 2013).

Barrett and Scott (2012) show the potential for demand-side strategies applied to non-energy related goods and services[4] to contribute to reducing UK consumer emissions. Strategies can be adopted by both producers such as lean production and green procurement, and households such as changing household's behaviours towards using products for longer and shifting to service-based consumption instead of ownership, for example joining a car club. They estimated savings of up to 28% in the non-energy sectors. These would influence emissions from sectors that under strong decarbonisation and electrification become the most significant source of emissions: transport services and manufacturing.

However, developing countries are dependent on export markets to generate economic growth to develop their infrastructure and increase their living standards. Whilst there is a considerable body of work on degrowth and its implications for developed economies, it has been hard to find how reduced consumption in developed economies or border taxes on developing countries' exports would impact welfare (Li and Zhang, 2012) and further exacerbate global inequalities.

6. Conclusions

This paper presents evidence on the regional and sectorial distributional trends in UK consumption-driven emissions given existing international climate change frameworks from 2010 to 2050. It argues through an analysis of imported emissions, that current UK emissions targets underestimate the UK's contribution to global mitigation for two degrees. In this research paper two scenarios were investigated that project UK consumption-based emissions to 2050. These consider emissions embodied in UK imports and discount emissions embodied in exports which are assigned to the purchasing country. A few studies have shown for highly aggregated global regions the consumption-based emissions trajectories that would be required to meet carbon budgets for two degrees. These are not based on current reduction targets and or pledges, nor do they indicate how emissions will shift between sectors. This paper investigates national representative pathways for UK consumption-based emissions given (1) current international emissions reductions pledges and (2) strong global mitigation efforts aligned with two degrees, implemented mainly through country-wide energy measures and carbon capture and storage. Further analysis testing the sensitivity of the scenario assumptions would increase confidence in the results.

The UK is likely to remain a net importer of emissions. The origin of emissions shifts from energy production to transport and manufacturing, which are harder to mitigate. Under the scenarios for two and four degrees, UK consumption is anticipated to generate 20 to 24 Gt cumulative CO_2 between 2010 and 2050, compared to 14 Gt CO_2e from a production perspective. It is estimated that in the region of 46–55% would be emitted outside UK political jurisdiction. These percentages are higher when looking at the 2050 end-point only (46–76%). Whilst researchers have argued for industrialised countries to take stronger steps to mitigate global emissions on the basis of historic cumulative emissions, present consumption emissions and financial capacity, this paper shows that these distributional issues could prevail even with global mitigation for two degrees, at least this has been found to be the case in the UK.

Global mitigation requires immediate and unprecedented reductions in carbon intensities and strong international collaboration, particularly towards countries with less financial and technical capabilities. Current territorial policies in developed countries such as the UK are most probably inadequate to deal with the emissions released globally in the production of goods for their consumption. To meet cumulative budgets, the literature suggests that industrialised countries are likely to need to increase their annual rate of carbon reactions; more effectively transfer technology, finance and knowledge to non-Annex I countries; and reduce their demand for products (see Fig. 4). In doing so (and somewhat relying on other Annex I countries take similar actions), evidence suggests this will enable non Annex-I countries to reciprocate emissions reductions without risking their economic development by retaining a certain degree of competitive edge. Such unilateral policies and agreements can harness a more flexible international climate change framework that is scaled up in time.

Whilst the analysis supports the finding that a mitigation framework based on consumption emissions would benefit net exporters in terms of emissions reduction, because a share of its export emissions will be the responsibility of the final consuming country, the policy responses from net importers could have economic implications for the exporting countries. Further research however is needed on the regional economic and social consequences of reducing consumption, particularly in developing economies, so as not to impede their development.

The conclusions of this paper need not be alarming for the policy community. International effort-sharing agreements in the form of the Clean Development Mechanism, for example have shown to be environmentally effective (despite not achieving the desired level of technology transfers). Decarbonisation policy in the UK is well defined; yet changing the focus of policy towards consumption introduces new opportunities for reduction strategies at scale. Using consumption-based emissions accounting as a

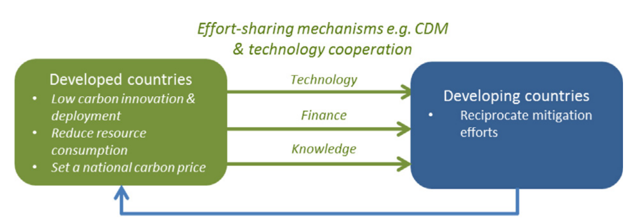

Fig. 4. A climate policy framework for reducing net imported emissions.

[4] The study excluded emissions reductions from energy and transport.

complementary tool to production accounting increases the levers available to policy makers with the potential to provide shorter-term measures whilst waiting for the wide deployment of low carbon technologies. With more systematic research on consumption-based policies on the rise, demand-side measures are a real contender to relieve pressure on large-scale reductions. Given the increasing share of imported emissions in the UK's account, and the political and technological uncertainty of decarbonisation, making consumption-based accounting mandatory gives us the greatest chance to be armed with responses faced with the increasing danger of climate change and could be the catalyst to unlock barriers in international negotiations.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2015.05.016.

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