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Modelling Multi-Regional Ecological Exchanges: The case of UK and Africa

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Abstract

As environmental impacts continue to rise, the need to identify and quantify the underlying causes of these impacts has prompted important research questions. This is heightened by the fact that the production of goods and services is becoming increasingly global with countries relying on each other through trade. As such, it is important to have a mechanism in place to understand the environmental burden shifts from one country to another. To this end, this paper exploits a paradox in global environmental analysis, which stems from a false decoupling between economic and production systems as observed in most developed nations, which results in improved territorial emissions of these developed countries at the expense of developing countries.

Ecological unequal exchange is one such contemporary ecological economic concept that is used to highlight such asymmetric transfer of embodied natural resources and biophysical indicators between countries. Attempts at environmental impacts reduction efforts has largely focused on carbon emissions but given the complex supply chain created through globalisation and international trade, it is important to consider other important metrics such as land and water use alongside carbon emissions to drive environmental policies that will holistically address ecologically unequal exchanges. For developing countries in Africa where the dependence on land use and water use for agricultural activities are crucial to the development of national economies and in combating poverty, an assessment of these metrics has become even more paramount.

Against this backdrop, the current work draws upon the theoretical constructs of multi-regional input-output (MRIO) framework to trace country specific sectorial-level flows of the aforementioned metrics between a representative developed nation, UK, and 27 African regions in order to fully examine their ecological exchanges. Key findings in the study suggest that for water consumption and land use, there is a net externalisation of these impacts for all the 27 African regions by the UK. It was also determined that the extent of the imbalance between the UK and the African region is exceedingly far greater for water consumption. It is recommended that in formulating a robust multi-national environmental policy where so many factors are at play, country specific and industry targeted approach to ecological unequal exchange between nations provides better and improved insight into addressing ensuing environmental issues.

Key words:

Ecological Unequal Exchange, Multi-Regional Input-Output, United Kingdom, Africa, Carbon, Water and Land Use, Environmental Policies

1. INTRODUCTION

The leakage of carbon emissions as well as the deficit created due to the consumption of natural resources by one country in another as a result of international trade and the flow of goods and services can be described as an imbalance in the ecological exchange between the participating countries. This has been described in the literature as ecological unequal exchange (Emmanuel, 1972, O'Connor and Martinez-Alier, 1998, Jorgenson et al., 2009, Howell et al., 2013, Moran et al., 2013). Indeed, as a result of globalisation and the consequent shift in productions systems mainly from developed to developing and emerging economies, there has been a global increase in embodied emissions from the production of internationally traded goods and service. The World Resource Institute, WRI (2016) recently reported that 21 countries; mainly developed and Western nations are reducing carbon emissions whilst witnessing growth in their gross domestic product (GDP). For instance, in the UK, between 2000 and 2014, there was a 20% reduction in carbon emissions with a corresponding increase in GDP by 27% within the same period (WRI, 2016). These figures highlight a case of false decoupling that is usually created between economic and production systems in most developed nations. This is because of the tendency of developed countries shifting the polluting aspects of their production system to countries where environmental legislations are less stringent thereby improving the environmental profile of the developed nations at the expense of the developing ones (Koh et al., 2016).

Contemporary research on ecological unequal exchange is growing and it seeks to inform international environmental policies (Lachapelle and Paterson, 2013; Yu et al., 2014). In particular, national and the international community has placed a lot of emphasis on it, in relation to anthropogenic GHG emissions because of its direct linkage to climate change (IPCC, 2014). This paper however argues that within the very complex global supply chain created by globalization and international trade, ecologically unequal exchange extends far beyond carbon emissions alone and that for a holistic environmental policy to developed, other important metrics such as land use and water consumption must be measured alongside carbon emissions. This notion of multi-metric measurement strategy is particularly important in the context of developing countries in Africa where the dependence on land use and water consumption for agricultural activities are crucial to the development of national economies and in combating poverty and improved livelihood.

Drawing on the assessments and analysis made in this paper, it is argued that for developing countries in Africa, carbon intensive products do not dominate exported products and services to developed nations. As such, the paper reveals that implications of ecological unequal exchange in terms of land use and water consumption far outweighs that of carbon to African regions and that this must be reflected in the national policies of developed nations. This paper is further driven by the fact that although research on international trade and associated environmental impacts such as on embodied carbon emissions (Marques et al., 2013, Ren et al., 2014, Ibn-Mohammed et al., 2013), land use (Weinzettel et al., 2013, Kastner et al., 2014), water consumption (Chen and Chen, 2013, Tamea et al., 2014), and in some limited instances a combination of these environmental impacts, has been demonstrated (Wiedmann et al., 2015, Carbon, 2012, Acquaye et al., 2017). However, these studies are not usually specifically targeted at vulnerable regions such as Africa. Rather, they are very often focused on emerging economies such as China (Yu et al., 2014) and in limited cases only cumulative environmental impacts on Africa as a single region are reported from global studies (Moran et al., 2013). This limits the policy formulation insights that can be garnered from such studies. More research with a focus on Africa in terms of carbon trading, unequal exchanges and other related issues that stems from the impact of climate change is therefore required. This view is echoed by (Reddy, 2011, p21) who that "Africa is currently marginal to the carbon market, and the carbon market has been irrelevant to the continent's efforts to tackle climate change". At present, only a few benefits has been gained by Africa in terms of economic globalisation and this is further worsened by the fact that the continent's economies continue to rely on a handful of primary goods and services whose prices are determined externally. This unequal allocation of resources, access and development extends to policies pertaining to climate change given that Africa's interests have remained peripheral to their implementation (Reddy, 2011).

Against this backdrop, an in-depth analysis focusing on individual countries and regions in Africa with respect to their individual sectoral entities is therefore pertinent. Such active research on the aforementioned themes can facilitate and improve the understanding and role in the context of Africa whilst offering assistance in constructing effective and viable solutions to the problem of climate change. It will also put into perspective the extent to which the Africa continent is performing regarding climate change issues with the view to encourage its participation in the global economy as producers of good and services for which other countries (e.g. the UK in this case) benefit from. This is important given that at the moment, the marginalisation of the continent as producers and consumers of goods reveals a relatively low per capita resource use, which translates into low ecological and carbon footprints. This assertion is in line with the study by

Moran (2013), who reported that the ecologically unequal exchange phenomenon usually occurs as a result of the extraction of natural resources from resource-rich but cash-poor countries (as is the case in Africa) used to provide goods to satisfy consumer demand in wealthy countries.

To undertake these developments, this paper draws on the theoretical constructs of multi-regional input-output (MRIO) framework (Miller and Blair, 2009); a model which has been widely used for environmental sustainability accounting (Ibn-Mohammed et al., 2014; Acquaye et al, 2017) to trace country specific sectoral level flow of carbon, land use and water consumption embodied in goods and services between a developed nation (exemplified by using the UK in this case) and 27 African regions. This allows for a full-scale examination of ecological exchanges between the regions. The detailed analysis presented shows that in multi-national environmental policy where so many factors are at play, country specific and industry targeted approach to ecological unequal exchange between two nations provides better insight into addressing ensuing environmental issues.

In light of the above, the rest of the paper is organised as follows: in Section 2, a succinct review is presented by exploring the relevant extant literature on international trade and ecological unequal exchanges. Section 3 highlights the methodological framework and data sources adopted for the analysis presented in this study. In Section 4, the results of the ecological unequal exchange modelling processes are presented alongside policy implications leading to the concluding remarks in Section 5.

2. LITERATURE REVIEW

2.1 Global Supply Chain Networks

Due to globalised production and consumption patterns, supply chains networks have become multi-regional in nature (Coe et al., 2008) because they constitute an integrated economic system, cutting across multiple national boundaries (Johnson and Noguera, 2012). The global production network involves the flow of resources and the consumption of goods and services produced in a given country and consumed in another country. The implication of this from an ecological economics point of view is that there are ecological (e.g. material, water, land use, etc.) exchanges between countries which may result in imbalance in environmental impact, a phenomenon that is collectively termed ecological unequal exchange (Emmanuel, 1972, O'Connor and Martinez-Alier, 1998, Jorgenson et al., 2009, Howell et al., 2013, Moran et al., 2013a).

Although ecological economics theory and practice emphasise the fact that economic and production systems cannot be separated from the environment (Costanza, 1984, Harte, 1995, Asafu-Adjaye, 2000), it has been acknowledged that in most developed nations, there is a false decoupling created between economic and production systems and the environment (Peters et al, 2011). This is because, the production systems of most developed nations which are sometimes energy and resources intensive have been shifted to developing countries, resulting in a corresponding shift in environmental burden and ecological damage. This is a case of environmental injustice and has prompted the Department of Environmental, Food and Rural Affairs (DEFRA) to submit that for a country such as the UK to achieve sustained growth, it will require a decoupling of its economic growth from its environmental impacts, both at the national and global level (Foster et al., 2007).

Drawing on Peter Drucker; the American management guru's saying that "What gets measured gets managed", we argue that, the measurement of the UK's ecological exchange with one of the world's most sustainable vulnerable regions, Africa, can inform its environmental policy towards actualising its long term sustainable development goal. Per the principles of Positive Accounting Theory (Watts and Zimmerman, 1986) applied within the context of environmental disclosure and accountability (Setyorini and Ishak, 2012), the UK should also be reporting on such indirect environmental impacts as it will put it in the right light that indeed, it truly wishes to ensure its economic development is underpinned by sustainable production and consumption as well as achieving a sustainable economy that helps mitigate against breaching the critical thresholds of certain ecological systems in other countries it depends on through international trade. For instance, such research insight can promote the UK's environmental accountability and ensure economic development is underpinned by sustainable production and consumption. In doing so, the UK can attain an economy that helps mitigate against breaching the critical thresholds of certain ecological systems, for which it forms bilateral trade agreements with.

2.2 Ecological Economics View on Economic Systems

Economic and production systems cannot be separated from the environment given the increasing influence of the impact of humans on the natural environment as supported by ecological economics theory and practice (Harte, 1995, Costanza, 1984). Research has established that for many developed nations, there is a consistent false decoupling in consumption trend of goods and services and the resources and energy used to produce the goods and services and consequently the ecological impacts it creates (Emmanuel, 1972; O'Connor and Martinez-Alier, 1998; Jorgenson et al., 2009; Howell et al., 2013). The paper describes this as an economic growth and environmental impacts reduction paradox; refer to Kastner et al (2014) and Wiedmann et al (2015) who further assesses this dichotomy in trends between economic growth and environmental degradation in other context. This phenomenon has led to the crossing of certain biophysical threshold and planetary boundaries of eco-system processes (Rockström et al., 2009).

From the perspective of the producing countries, the impacts on the ecological systems are unique to each individual country because of the uniqueness of local ecosystem and the distinct structure of national economies. Davies and Caldeira, (2010) for instance, reported that developed nations such as Western Europe embodies much more carbon emissions in their imports than exports. Global studies also indicate that these carbon intensive imports are particularly unique for emerging economies such as China, Russia, India, and the Middle East (Acquaye et al, 2017). This is because the economies of these emerging markets are predominantly based on energy intensive manufacturing with higher emissions intensities than the technologically more efficient productions systems in developed countries.

Similar studies (Moran et al, 2013, Davies et al, 2011) have also highlighted similar trends in higher carbon emissions intensities in Africa but falls short of undertaking studies focusing on individual countries with an emphasis on the inter-dependence and exchanges with a developed country or countries. Beyond these, the uniqueness and reliance of the individual African countries on their ecological systems mean that international emphasis on carbon emissions embodied in trade and how these are linked to policies should by no means exceed equally important issues with ecological systems such as land use and water consumption. Shiferaw (2014) reports on how agriculture and the economies of Sub-Saharan African countries are highly sensitive to climatic variability in particular drought. As such, the long-term sustainable economic growth and development of these African countries may be affected because of continual degradation of their ecological systems through ecological exchanges. Despite these, studies on the indirect impacts of developed countries on the ecological systems of African countries are limited. This therefore highlights the importance and timeliness of this paper and so this work seeks to bring these issues to the fore.

Most countries under the Kyoto Protocol agreement undertakes carbon emissions accounting using production-based perspective-a technique that takes into account only the direct carbon emissions caused by activities or production processes within the boundaries of the producing country. The UK on the other hand acknowledges the merits of a consumption-based perspective (Barrett et al., 2013, Schaffartzik et al., 2014) and provides measurements for public reporting purposes. The carbon emissions resulting from the whole supply chain network as a result of goods and services imported from other nations to the UK is also documented through the use of consumption-based approaches to carbon accounting and auditing. This accounting perspective provides a complete visibility of upstream and indirect impacts along the supply chain in addition to the direct impacts. However, the impacts on ecological systems of measures such as land use and water use in vulnerable countries in Africa are not measured alongside carbon thereby limiting the scope of emissions reduction policies of the UK.

As such, in this paper, it is argued that a consumption-based perspective should be formulated within a framework that provides an empirical research approach to measure the UK's water use and land use ecological exchange *vis-à-vis* Africa alongside carbon emissions. To achieve this, a Multi-Regional Input-Output framework between the UK and 27 African regions is developed to critically to examine the net ecological impacts between the UK and these countries. Following on from the analysis, the results are then discussed within the context of current environmental policies.

2.3 Principle of Ecological Unequal Exchange

Ecologically unequal exchange, as a concept builds on the notion of 'unequal exchange', which is mainly addressed in Marxian economics; refer to Emmanuel (1972) and De Janvry and Kramer (1979). This contrast classical economics thinking, which rather desires unequal exchange given that it is seen as a natural outcome in specialization and trade (Arrow et al, 1998). Within Marxian economics, unequal exchange was first used to highlight the fact that countries with lower wages generally exported more embodied labour time than they imported, and vice versa. Analyses of unequal exchanges therefore revealed that there were discrepancy between market price paid for goods and services and quantities of embodied resources (labour in this instance).

Ecologically unequal exchange, as a contemporary ecological economics concept formally draws on from these Marxian economics views. It submits that just like labour, there can be unequal flows of natural resources (such as land, water, etc) and biophysical indicators such as carbon between countries or regions (Rice, 2007; Hornborg, 2009; Roberts and Park, 2009).

In analysing ecologically unequal exchange for eight biophysical indicators, Moran et al (2013) adopted the Multi-regional input-Output (MRIO) model to help evaluate the net balances in trade due to the embodied biophysical indicators.

This analytical principle of ecologically unequal exchange is further reinforced by Jorgenson and Rice (2007) and Jorgenson and Clark (2012) who in their analyses of ecological unequal exchange, highlighted that rather than placing a value in terms market price on the embodied resources and biophysical indicators, it would seem more useful to restrict the analysis to demonstrating that there is an asymmetric transfer of embodied resources between two social categories such as nations. In this study, the asymmetric transfer of carbon, land and water between the UK and the 27 African regions are therefore explored as the unequal ecological exchanges between the regions.

2.4 The Case for Consumption-based Accounting Method

The use of the consumption-based accounting method has been proposed as a better alternative to the production-based method which accounts only for emissions arising from production activities within a country. (Davies and Caldeira, 2010, Barrett et al, 2013). Several studies provide empirical evidence to the limitation of the production-based accounting framework (Boitier, 2012; Peters and Hertwich, 2008; Jorgenson et al, 2009). For instance, in their research, Jorgenson et al., (2009) concluded that environmental policies based on production-based accounting system for measuring national emissions do not favour developing countries since the developed ones are able to clean up their countries at the expense of developing countries. However, the consumption-based accounting method to a large extent captures CO_2 emissions outside national boundaries by including embodied emissions in imports (Bruckner, 2010).

Despite the advantages offered by consumption-based method as a fairer means of identifying and apportioning environmental responsibility of emissions arising from consumption, there is a growing debate on its long-term suitability as a prominent alternative to the production-based method. In their review paper, Afionis et al, 2017 discuss the counterarguments highlighting the associated issues of technical complexity, mitigation effectiveness, and political acceptability of the method. Since the consumption-based method is typically constructed using production based emission inventories (and then accounting for embodied emissions in trade), the authors assert that the method also suffers from the statistical uncertainties associated with the production-based method. Lui (2015) also argues that the consumption-based method can lead to complexities in policy and decision making by exerting pressure on consumers and not producers to reduce emissions. As a result, this may encourage the use of cleaner production practices by producers with the cost burden of these cleaner production practices shifted to the final consumers.

Despite the difference on opinion regarding the consumption-based method, it remains an invaluable approach in explaining the correlation between emissions and consumptions patterns. The use of consumption-based method brings to light some problematic mitigation efforts employed by developed countries engaging in the leaking of ecological impacts to regions outside their national boundaries made possible through international trade.

3. METHODOLOGICAL FRAMEWORK

3.1 Multi-Regional Input-Output (MRIO) Framework

In this paper, the generic IO approach l, 2009 (Miller and Blair, 2009, Minx et al., 2009) is extended to characterise the overall production system for the UK-Africa-Rest of the World (ROW) in a multi-regional framework. Because the UK and the African region are not closed economies to all the other countries in the world, the model presented in this paper takes account of the fact that there are also intermediary resource flows (products and services) between all other countries from the ROW region and the UK and Africa.

Thus, the full technical coefficient matrix, A, the final demand matrix, Y and the total sectorial output in all countries, X for the multi-regional input output framework used in the paper is defined below as.

$$A = \begin{bmatrix} A^{11} & A^{12} & \dots & A^{1n} \\ A^{21} & A^{22} & \dots & A^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A^{n1} & A^{n2} & \dots & A^{nn} \end{bmatrix}; y = \begin{bmatrix} y^{11} & y^{12} & \dots & y^{1n} \\ y^{21} & y^{22} & \dots & y^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y^{n1} & y^{n2} & \dots & y^{nn} \end{bmatrix}; x = \begin{bmatrix} x^{1} \\ x^{2} \\ \vdots \\ x^{n} \end{bmatrix}$$

Where the technical coefficient matrix is calculated as:

$$A = [a_{ij}^{pq}] = \frac{[z_{ij}^{pq}]}{x_j^q} \qquad (1)$$

It shows the monetary flow between sector i in country p to sector j in country q. x_j^q represents the total monetary output of sector j in country q. The final demand matrix presented as a vector and consisting of y^{pq}represents each sector's output produced in country p consumed by the final user in country q.

In the MRIO model for UK-Africa-ROW framework presented above, both p and q are elements of the set 1 to 29 where 1 represents the UK and 29 (identified as n in A, Y and X) represents the ROW region. 2 to 28 represent the 27 African countries and sub-regions. Refer to Appendix I for detailed breakdown of the specific countries.

Applying the MRIO format to Equation 1, the total output in each country for a given final demand can be expressed generally in Equation 2 as:

$$\begin{bmatrix} x^1 \\ x^2 \\ \vdots \\ x^n \end{bmatrix} = \left(\begin{bmatrix} I & \dots & \dots & 0 \\ \vdots & \ddots & \dots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \dots & \dots & I \end{bmatrix} - \begin{bmatrix} A^{11} & A^{12} & \dots & A^{1n} \\ A^{21} & A^{22} & \dots & A^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A^{n1} & A^{n2} & \dots & A^{nn} \end{bmatrix} \right)^{-1} \cdot \begin{bmatrix} y^1 \\ y^2 \\ \vdots \\ y^n \end{bmatrix} \qquad (2)$$

It must be noted that not all intermediate consumption products originates from the source country and sub-subsequently end up in the domestic final demand of the target country. For instance, within the context of this paper, in attempting to evaluate the resource requirements due to final demand from say the UK, the following logical assumptions are implemented. The MRIO model links the UK's final demand not only with its own domestic resource inputs (that is, UK domestic), but also with the resource inputs from other countries that the UK imports from (for example, the 27 African regions). As such, if the UK imports products from say Ghana, and these products were made using imports from Nigeria into Ghana, and from South Africa into Nigeria into Ghana, then MRIO includes into UK's footprint those resources used in South Africa, Nigeria, Ghana. In the bilateral trade analyses between the UK and Ghana, the lack of transparency in these intermediate consumption flows represents a limitation to the model.

3.2 Environmental Extended Multi-Regional Input-Output (MRIO) Framework

The MRIO can be combined with the environmental extension matrix to generate results, which can be used to account for the impacts of environmental externalities as a result of the linkages in the economies of the various countries through trade.

Let:

E_j^q Represent the direct environmental output for any industry j in a particular country p. As the environmental outputs in this paper focus on carbon emissions, land use and water consumption, the units of E_j^q is expressed respectively as 1000tons $CO_{2\text{-eq}}$, 1000ha and 1000m^3 of water.

Given that x_j is the total industry production output expressed in million \$, the direct intensity environmental impact of any industry j in a particular country p is given by:

$$e_j^q = \frac{E_j^q}{x_j} \tag{3}$$

Let

E_{io} The matrix representation of direct environmental intensity matrix (unit/$) of all industries in each country within the MRIO framework. That is $E_{io} = [e_j^q]$ which can be expressed as a row vector $\underline{E_{io}}$. It should be noted that $\underline{E_{io}}$ is also referred to as the production-based environmental impacts per unit of sectoral output.

Given that Equation 2 represents the total requirements needed to produce the output x for a given final y, it implies that if the environmental externality per unit industrial output is E_{io} then the total environmental impacts is represented below as Equation 4:

$$Total\ Impacts = \underline{E_{io}}.\left(\begin{bmatrix} I & \cdots & \cdots & 0 \\ \vdots & \ddots & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & \cdots & I \end{bmatrix} - \begin{bmatrix} A^{11} & A^{12} & \cdots & A^{1n} \\ A^{21} & A^{22} & \cdots & A^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A^{n1} & A^{n2} & \cdots & A^{nn} \end{bmatrix}\right)^{-1} . \begin{bmatrix} y^{11} & y^{12} & \cdots & y^{1n} \\ y^{21} & y^{22} & \cdots & y^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y^{n1} & y^{n2} & \cdots & y^{nn} \end{bmatrix}$$

In Equation 4, the final demand matrix is presented in a matrix format to highlight demands of final products and services in a country from another. For instance, y^{12} is the final demand of goods and services from country 1 to country 2. The use of the Leontief inverse matrix in the analytical framework ensures complete supply chain visibility of all economic activities as associated impacts within the MRIO in what Hoekstra and Wiedmann (2014) describes as the ability to capture both direct (operational) and indirect (supply-chain) components of environmental impacts.

3.3 Assumptions and Limitations of the Model

There are a number of assumptions underpinning the Input-Output model, which also poses some inherent limitations in the application of this methodology (Hendrickson et al., 1998 and Acquaye and Duffy 2010). One of such limitation is the homogeneity hypothesis, which is an aggregation issue. This assumption posits that each industry uses identical inputs and process in production to produce all the products classified in that industry. In reality, this assumption would not hold true as each industry may be a representation of many different products or services.

Even in the event of products being similar, there might be differences in production technology used.

Another limitation in the IO analysis is the proportionality assumption, which implies that there is a linear relationship between production inputs and outputs and subsequently environmental impacts (Baral and Bakshi, 2010). For example, it suggests that in the production process of an industry, the proportions of inputs are used in strictly fixed ratios. However, this assumption of proportionality does not invalidate the use of the IO model since in some cases the linear proportionality gives a good estimate even when non-linear relationship exits (Hendrickson, 1998). Tukker and Dietzenbacher (2013) advocates for the use of the input-output framework especially where there is lack of data exist.

Tukker et al (2009) further highlights the fact that there can be lack of transparency (or transparency is not optimal) in intermediate consumption flows when bilateral trade data between countries or regions are analysed. This represents a limitation in the attempt at using the MRIO framework to model the world economy by attempting to capture the entire international trade network. This limitation is usually apparent when MRIO table are aggregated into the regions of interest before the model is run.

3.4 Data Sources

2007 MRIO table was extracted from the Global Trade Analysis Project (GTAP) database (version 8) following instructions found in Peters et al (2011). The GTAP database is a global database describing bilateral trade patterns, production, consumption and intermediate use of commodities and services with 129 regions for 57 GTAP sectors for the years 2004 and 2007 (GTAP, 2012). In this study, global MRIO table was aggregated into 29 regions including the UK, 27 African countries and regions, and the Rest of the World region. CO_2 emissions data was also collected from the GTAP database.

Land data related to cropland and grazing land was collected from FAOSTAT (2012). GTAP 8 (GTAP, 2012) has 8 aggregate crop sectors, while FAOSTAT contains more than 100 crops. For data consistency, crops from FAOSTAT were aggregated to match these 8 aggregated crop categories in GTAP. In terms of forestland, data on forests designated for production was obtained from FAO global Forest Resources Assessment 2010 (FAO, 2010). Artificial surfaces data by countries were collected from World Resources Institute (WRI) database (WRI, 2000). Total artificial surface area data from WRI was disaggregated to different GTAP sectors with reference to other data sources, such as the European Environmental Agency (EEA, 2011). Sectoral disaggregation of artificial surfaces for African regions were based on Chinese land intensity at sectoral level as benchmarks.

Water data related to agricultural water consumption was calculated based on the blue water estimates [m^3/ton] calculated on 5 arc minute resolution and provided on country level in (Pfister et al., 2011). Industrial water data was obtained from FAO aquastat (FAO, 2014).

4. ANALYSIS OF RESULTS AND DISCUSSIONS

4.1 Country-level Analysis of Ecological exchanges

This work traces the sources and destinations of the environmental indicators (carbon emissions, water consumption and land use) embodied in bilateral trade between the UK and each of the African countries. The inclusion of RoW within the original UK-Africa-RoW MRIO system ensures a complete system is achieved between the inter-dependence supply chain networks. In determining the ecological exchange for any indicator between two countries (the UK and another African country), the impacts embodied in imports to the reference country (in this instance the UK) is subtracted from the impacts embodied in exports from the reference country to the other country (in this instance an African country). Hence, if total embodied footprint exported is less than total embodied footprint imported, then that country has an embodied footprint deficit in the bilateral trade. Further details of all the results presented here are detailed in the Supplementary Information.

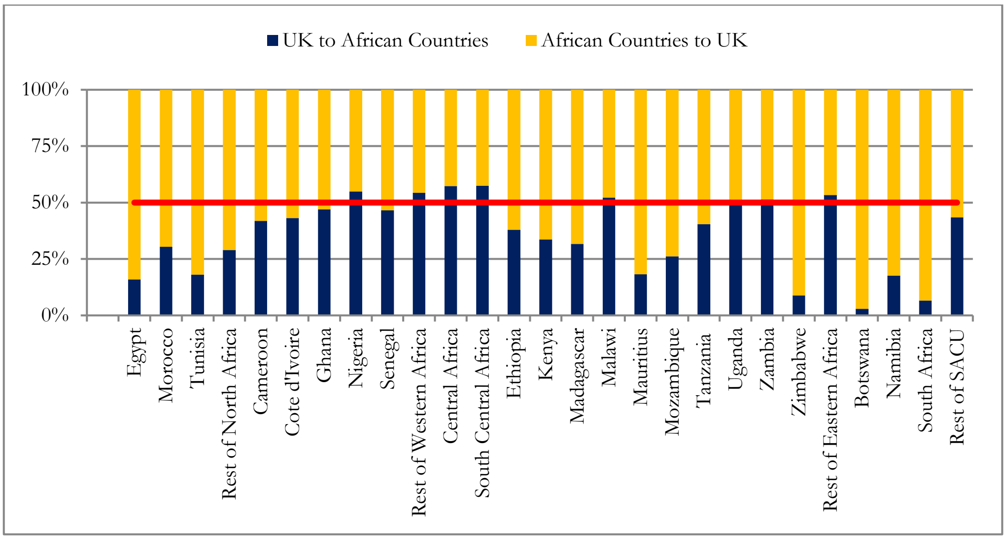

Figure 1: Carbon Emissions Exchanges between the UK and African Countries

Figure 1 highlights the relative distributions expressed as percentages of carbon embodied emissions from the UK to the African countries and from the African countries to the UK. As shown, carbon emissions are exported for the majority of the African countries to the UK than they import. This suggest that the UK leaks carbon emissions in these countries due to consumption. On the other hand, it is seen Nigeria, Malawi, Uganda and Zambia are the only individual African countries where the UK is a net exporter of carbon emissions. To cover the whole of the African region in the analysis, some individual countries are combined together into sub-regions (for instance rest of Western Africa, rest of Eastern Africa, Central Africa, South Central Africa, Rest of South African Customs Union, etc.). In some instances, (rest of Western Africa, Central Africa, South Central Africa) it can be seen that the UK is a net exporter of carbon emissions to these sub-regions. Refer to the Supplementary Information for further detailed accounts of the land use exchanges between the UK and the African regions.

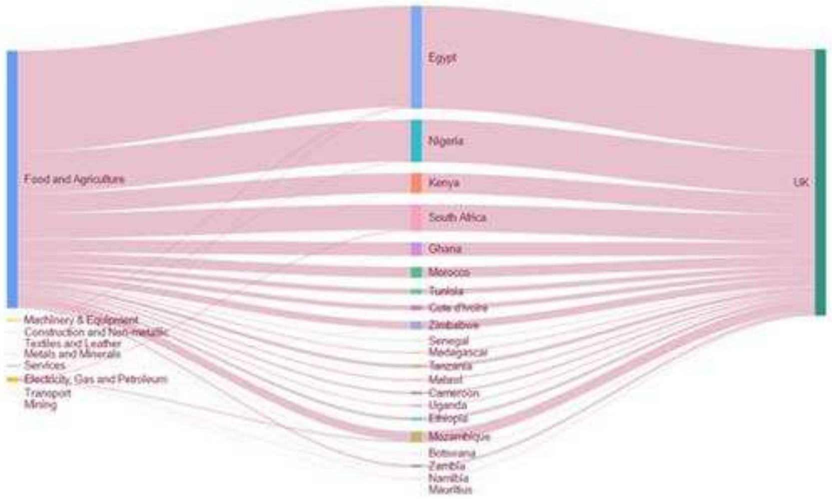

Figure 2: Net Water Exchanges between the UK and African Countries

In terms of flow exchanges pertaining to water consumption for the majority of the African countries, their export embodies more water use resource for production to the UK than their imports implying that as a result of consumption, the UK externalise environmental impacts of water use to these countries. For most of these African countries, a staggering proportion of approximately over 90% of these environmental impacts are externalised to these less developing countries resulting from production for UK consumption. Only few countries such as Mauritius and countries in Central Africa and the rest of North Africa have indirect water consumption exports averaging 75% to the UK. Nevertheless, the key fact shown in the results is that for all the ecological exchanges of water use between the UK and African countries, the UK is a net importer and thus enjoys consumption of goods produced in African countries from water use without the bearing the environmental cost. As can be seen in the Sankey diagram presented as Figure 2 for some West-African countries, a vast majority of these flows emanate from Food and Agricultural-related sectors. Refer to Appendix III for detail breakdown of the results. These presents environmental risk given that some of these African countries depends on the agricultural systems to sustain their economies. Recent studies on water flows and analyses have also begun to focus on water stress (Lenzen et al., 2013; Feng et al., 2014) which measures total annual water withdrawals (municipal, industrial, and agricultural) expressed as a percentage of the total annual available blue water. Within Africa, the World Resource Institute (2015) have highlighted water stress parts of the region to include the north of Africa (including Egypt, Tunisia, Morocco, Algeria), Eastern Africa such as Somalia, southern Africa including Namibia and South Africa. Refer to the Supplementary Information for further details of the results breakdown.

The extent of the imbalance between the UK and the African region is exceedingly far greater for water consumption; a natural resource use indicator than carbon emissions; an environmental emissions indicator. This highlights the economic growth and environmental impacts reduction paradox; refer to Kastner et al (2014) and Wiedmann et al (2015) who further assesses this dichotomy in trends between economic growth and environmental degradation in other context.

Figure 3 is a geo-map which highlights the net land use exchanges between Africa and the UK. In all the countries analysed, the difference between land-use flows from the UK to Africa and from Africa to UK was negative suggesting that relatively, the UK is a net importer. See Supplementary Information for further details of the results breakdown.

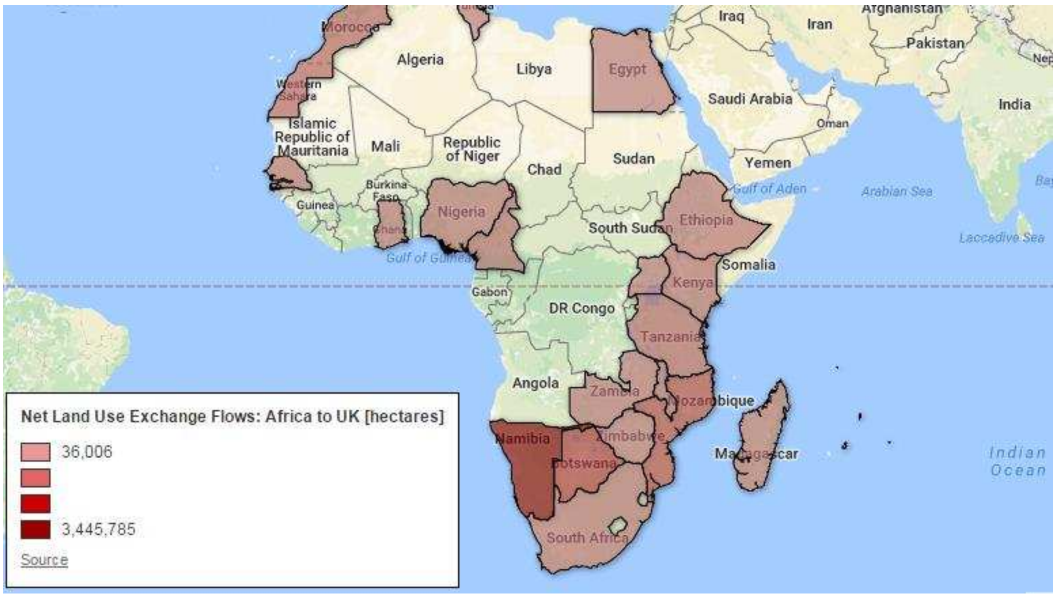

Figure 3: Net Land-Use Exchanges between the UK and African Countries [hectares]

Ecological exchanges of land use show the highest impacts of externalities leaked from the UK to African countries. In terms of the country specifics, the UK by means of local demand for imported goods and services, indirectly imports the highest land use from Namibia followed by Botswana and Mozambique. This is also reflected in the net exchanges of indirect land use flows (when indirect land use exports to these countries are taken into account) because the top three countries were still Namibia, Botswana and Mozambique.

For most of the African countries, the results show a relatively low exchange of land-use 'embodied' in exports from UK to African countries. Relatively, only Egypt and few other countries such as Nigeria and Rest of North Africa collectively receive an approximated average of 20% of land-use 'embodied' imports from the UK. Despite these, the net exchanges were still negative. Refer to Appendix IV for further details of the net detail breakdown of the net land use exchanges.

To gain an insight into any trends in terms of specific sectors in Africa on which the UK economy is dependent on, an industrial level analysis is presented in Section 4.2.

4.2 Industry level analysis of ecological exchanges

In the previous section, the results showed that the ecological exchange of embodied environmental impacts of carbon, land and water use between the UK and African countries were unequal with the UK being a net importer of these environmental outputs. In this section, results based on industry level analysis by tracing the environmental impacts associated with intermediate consumption between sectors in the UK and African countries is presented. For the sake of brevity and simplicity of analysis, the 57 sectors were aggregated into 9 distinct sectors and shown in Figure 4. For the full list of industries which constitutes each group see Appendix II.

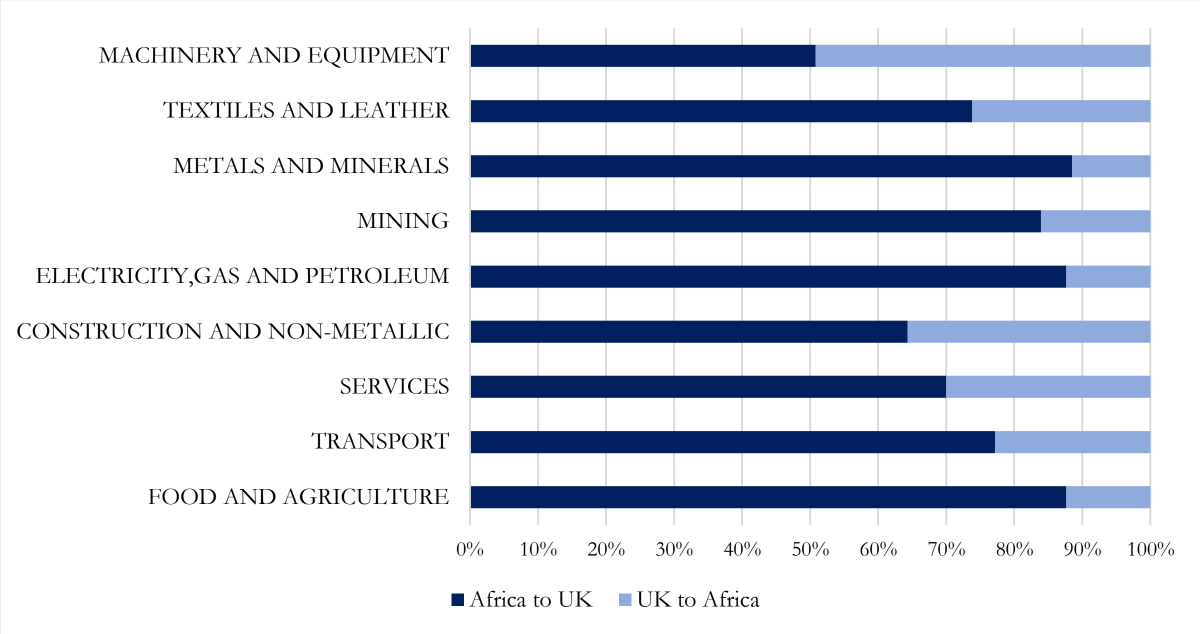

Figure 4: Industrial level flow of Carbon between UK and African countries

For all industries, exchanges of carbon from African countries to the UK were found to be above 50% (Figure 4). Results also showed that risks of carbon leakage are higher in energy-intensive and trade-exposed industries. The Electricity, Gas & Petroleum, Transport and Mining sectors showed high level of carbon embodied imports from African countries to the UK. These three sectors require relatively high carbon intensive production and is therefore not surprising they contribute the highest. Electricity, Gas & Petroleum industry on the average, contributes 60% of the total embodied emissions that UK imports.

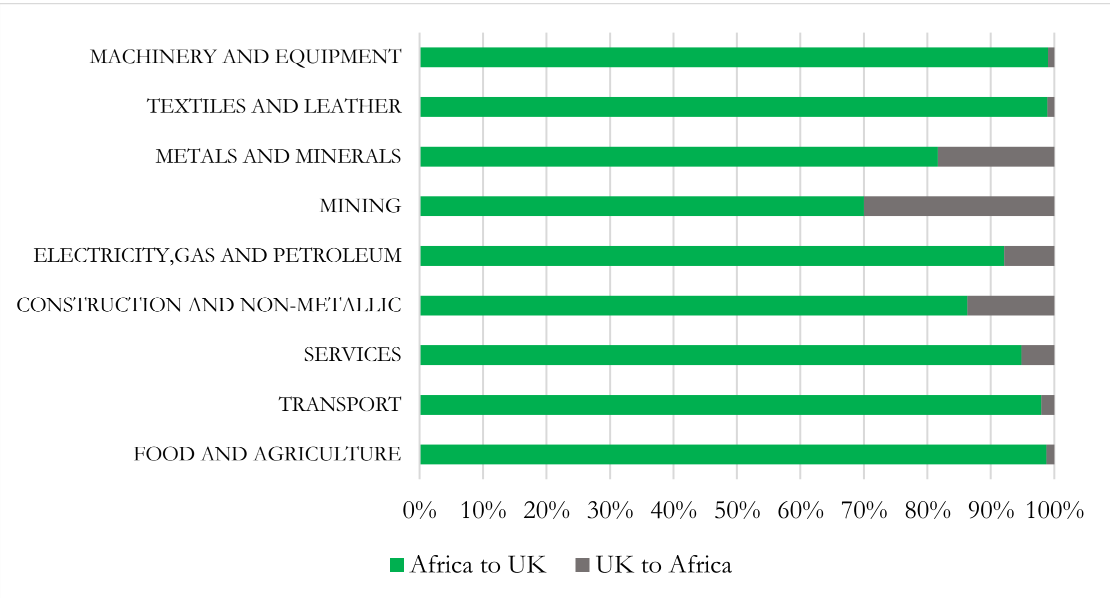

Figure 5: Industrial level flow of Water-use between UK and African countries

Ecological imbalances in industrial flow of water-use is very pronounced as the UK gives very little compared to what it receives from African countries. The UK's Food and Agriculture industry as well as the Machinery and Equipment sector particularly receives approximately 98% of water-use embodied imports from African countries in exchange for only 2% of water use embodied exports to support consumption in these industries in African countries.

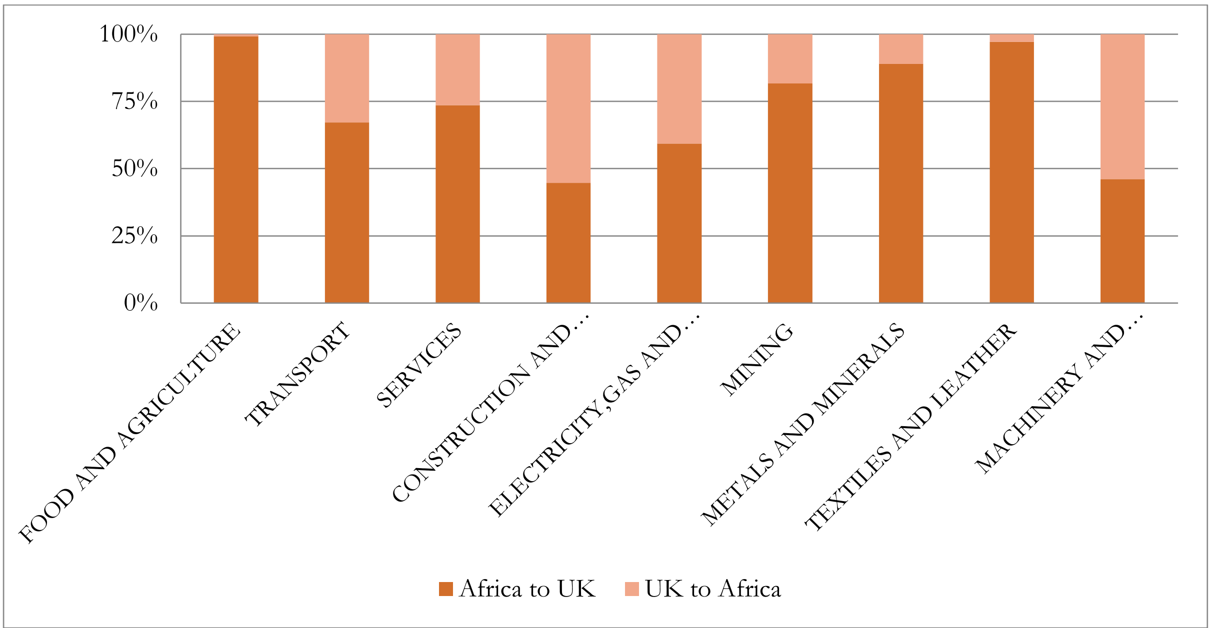

Figure 6: Industrial level flow of Land-Use between UK and African countries

The UK's highest land-use 'embodied' imports from African countries emanates from the Food and Agriculture industry which represents approximately 98% of the UK's total trade exchanges in this sector alone (Figure 5). For most industries, such as the Transport, Textiles and Leather, Mining and Services industry, results show an above 70% of land-use embodied imports to these sectors into the UK. This again implies that these industries in African countries lose more ecologically in producing for UK's consumption. It is only in the Machinery and Equipment and Construction and Non-metallic industries that African countries have more land-use embodied imports than the UK. This can be traced to the fact that most African countries are not heavily industrialised and therefore have to rely on imports of specialised machines from developed countries for production of certain goods.

4.3 Discussion and Implications of Results

4.3.1 International Environmental and Trade Policies

The results of this study have implications for environmental and trade policies, both at national and international levels. For a global environmental problem, such climate change, there is the need for collaborative efforts from all countries especially developing countries which usually tend to emit high GHG emissions. However, a review of the Kyoto Protocol, for example, shows that the method of accounting for national emissions is flawed (Peters, 2008). The use of production-based method in tracking the national GHG emission levels of its participating countries instead of consumption-based method implies upstream emissions beyond national boundaries are unaccounted for to the benefit of mostly developed countries (Davies and Caldeira,2010).

International trade makes it possible for developed countries in this case the UK to displace emissions to other countries in Africa (Ghertner, 2007, Howell et al, 2013). The trade imbalance especially in the food and agriculture industries as highlighted by this study fuels the unequal ecological exchange between the two regions. Similar research on the environmental impacts of trade by Machado *et al*, (2001) on Brazil economy and Li et al, (2008) on UK and China trade relations showed an increase in embodied emissions from more developed countries to less developed because of international trade liberalization. Accordingly, there is clearly a need for reforms on international trade policies and agreements to take in to account and address these embodied environmental impacts.

4.3.2 Fairness and Equity

The results of the study also bring to light issues of environmental fairness and equity in allocating environmental responsibility between developed and less developed countries. The cost and impacts of the environmental damage caused by the rich minority should not be borne more by the poor majority. Indeed, the United Nations Framework Convention on Climate Change (UNFCCC) acknowledges the different capabilities and differing responsibilities of individual countries in addressing climate change and so proposed the principle of "Common but Differentiated Responsibilities" (UNFCC, 1992). Within the context of the Kyoto protocol, this general principle of equity in international law highlights the responsibility that developed countries must bear because of their contribution to GHG emissions and their ability to prevent, reduce and control the effects of climate change. However, because accountability for GHG emissions is only based on territorial emissions with the Kyoto Protocol, emissions which are embodied in trade and are induced indirectly by consumption demands in developing countries in effect are not dictated to by the Common but Differentiated Responsibilities principle. To ensure an all-inclusive participation of environmental policy initiatives, the need for fairness and equity should be extended to emissions embodied in trade as this causes significant ecological exchanges between developed and developing countries.

The submissions above was echoed by Andrew Simms, (2009) in his book "*Ecological Debt*" where he argued that developed countries use up more environmental space compared to developing countries and therefore owes more in ecological debt. Environmental policies must consider such unfair ecological exchanges where high income countries, the UK in this case, despite having more domestic land per capita available than most African countries (Weinzettel et al, 2013) through trade imports still engages in displacement of land use impacts to these low-income countries.

4.3.3 Protection of Biodiversity

For affluent countries like the UK with relatively high population, growing demand for Agric-based products such as meat and dairy implies increased pressure and demand in the agricultural production to support consumption (Kastner et al, 2014). As global diets change especially emanating from high income countries the negative consequences of this is mostly borne by the low-income countries. The results of the current work support the fact that the UK being a high-income country is able to meet increased consumption for land-use based products particularly in food and agriculture industry while preserving their own land per capita. Our findings are broadly supported by similar studies by Steen-Olsen et al, (2012) and Wiedmann et al, (2007) that showed the translocation of natural resource use such as land and water from high income to low income countries. Mechanisms must therefore be put in place to ensure high income countries contribute to conservation and protection of biodiversity in the developing countries where they indirectly cause environmental degradation.

5. SUMMARY AND CONCLUSION

In this paper, evidence of displacement of environmental impacts away from the place of consumption made possible through international trade is presented. In the case of the UK and the African region, the results of the study show that the 27 African countries suffers from an imbalance of ecological exchanges particularly in carbon, land and water use by engaging in bi-lateral trade with the UK. A multi-regional input output analysis was employed to trace country and industrial level exchanges of these environmental outputs between the UK and 27 African countries using data from the GTAP 8.

Country level analysis showed that for the majority of the African countries, they export carbon emissions to the UK than they import implying that as a result of consumption, the UK leaks carbon emissions in these countries. On the other hand, it was observed that Nigeria, Malawi, Uganda and Zambia are the only individual African countries where the UK is a net exporter of carbon emissions. However, in the case of land and water use, all the 27 African countries were net exporters, giving more to the UK than importing from the UK. Ecological land exchanges of land use show the highest impacts of externalities leaked from the UK to African countries among the three exchanges analysed. For most of the African countries, the results show relatively insignificant exchange of land-use 'embodied' exports from UK to African countries. This implies the UK externalises the environmental impacts associated with consumption of these natural resources to the African countries it trades with. This further highlights what we describe as an environmental paradox since there is a false decoupling between economic and production systems in most developed nations.

Analysis at the industry level shows that carbon leakage through embodied imports is highest in energy intensive industry particularly the Electricity, Gas and Petroleum whereas for land and water use, the Food and Agriculture industry in the UK recorded the highest level of net displacement of these impacts. In African countries where dependence on agricultural natural resources is critical for livelihood, an analysis of ecological exchange of land and water use is pertinent.

The results of this study have implications for both environmental and trade policies issue of fairness in environmental responsibility and protection as well as conservation of biodiversity. In terms of environmental policy, the paper argues for the use of the consumption-based method of estimating emissions. This is because, even beyond the grounds of increased emissions coverage and the encouragement of cleaner production practices, it can also facilitate the process for the international community to move closer towards achieving the ultimate objective of the UNFCCC of avoiding dangerous anthropogenic climate change. Such an approach lead towards mitigating carbon leakage as well as ensure the less developed countries are not overly exploited by developed countries like the UK as highlighted in this study. In doing so, developed and developing countries must be differentiated and most importantly mechanism put in place to ensure much of environmental responsibility is borne by developed countries.

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APPENDIX I: African countries and regions included in the MRIO model

1	Egypt
2	Morocco
3	Tunisia
4	Rest of North Africa
5	Cameroon
6	Cote d'Ivoire
7	Ghana
8	Nigeria
9	Senegal
10	Rest of Western Africa
11	Central Africa
12	South Central Africa
13	Ethiopia
14	Kenya
15	Madagascar
16	Malawi
17	Mauritius
18	Mozambique
19	Tanzania United Republic of
20	Uganda
21	Zambia
22	Zimbabwe
23	Rest of Eastern Africa
24	Botswana
25	Namibia
26	South Africa
27	Rest of South African Customs Union

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APPENDIX II: Aggregation of 57 sectors were grouped into 9

No.	57 Economic Sectors	9 Aggregated Sectors
1	Paddy rice	Food and Agriculture
2	Wheat	
3	Cereal grains nec	
4	Vegetables; fruit; nuts	
5	Oil seeds	
6	Sugar cane; sugar beet	
7	Plant-based fibers	
8	Crops nec	
9	Bovine cattle; sheep and goats; horses	
10	Animal products nec	
11	Raw milk	
12	Wool; silk-worm cocoons	
13	Forestry	
14	Fishing	
15	Bovine meat products	
16	Meat products nec	
17	Vegetable oils and fats	
18	Dairy products	
19	Processed rice	
20	Sugar	
21	Food products nec	
22	Beverages and tobacco products	
23	Water	
24	Coal	Mining
25	Oil	
26	Gas	
27	Minerals nec	Metals and Minerals
28	Mineral products nec	
29	Ferrous metals	
30	Metals nec	
31	Metal products	
32	Textiles	Textiles and Leather
33	Wearing apparel	
34	Leather products	
35	Wood products	Construction and Non-Metallic
36	Paper products; publishing	
37	Chemical; rubber; plastic products	
38	Construction	
39	Petroleum; coal products	Electricity, Gas and Petroleum
40	Electricity	

41	Gas manufacture; distribution	
42	Motor vehicles and parts	Machinery and Equipment
43	Transport equipment nec	
44	Electronic equipment	
45	Machinery and equipment nec	
46	Manufactures nec	
47	Transport nec	Transport
48	Water transport	
49	Air transport	
50	Trade	Services
51	Communication	
52	Financial services nec	
53	Insurance	
54	Business services nec	
55	Recreational and other services	
56	Public Administration; Defense; Education; Health	
57	Dwellings	

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APPENDIX III: Net Land-Use Exchanges between the UK and African Countries

	Egypt	Morocco	Tunisia	Rest of North Africa	Cameroon	Cote d'Ivoire	Ghana	Nigeria	Senegal
Food and Agriculture	-635747037.6	-66495272.3	-33362468.7	-10495289.7	-14569616.4	-32402396.7	-85264310.7	-260736511.0	-3966679.5
Mining	-32792.6	59561.0	11517.4	-168407.0	-41938.5	-46193.0	5103.9	46884.2	20793.0
Metals and Minerals	-1060506.1	-142774.0	-4567.3	-36030.2	-9905.7	-68629.7	-175729.1	-48323.2	-4555.0
Textiles and Leather	-1394729.9	-166389.7	-2998.7	27642.6	-29495.3	-176615.2	-315984.3	-91725.2	-2707.0
Construction and Non-Metallic	-7280415.7	-553157.9	-170129.0	101540.6	-702372.6	-368886.0	-1431453.6	77243.7	37031.4
Electricity, Gas and Petroleum	-11291551.8	-136258.8	-27148.6	-266079.8	-12772.2	-112861.3	-886720.7	-9503516.8	-23291.8
Machinery and Equipment	-11291551.8	-136258.8	-27148.6	-266079.8	-12772.2	-112861.3	-886720.7	-9503516.8	-23291.8
Transport	-907243.7	-257585.5	-106478.8	-101555.9	-112735.1	-43734.8	-239921.8	-131062.4	-13953.7
Services	-1302674.2	-449395.1	-94328.4	-258962.5	-307283.4	-164785.0	-467470.3	-12108.2	-23466.8

	Rest of Western Africa	Central Africa	South Central Africa	Ethiopia	Kenya	Madagascar	Malawi	Mauritius	Mozambique
Food and Agriculture	-11380705.0	-867505.0	-1014771.4	-19519704.4	-125897179.6	-8467450.6	-11036151.7	40831.7	-59446581.0
Mining	-1879.0	1109.7	10184.9	5120.3	7668.1	-2463.0	789.4	3343.2	-88359.4
Metals and Minerals	-106853.1	-8005.6	-174110.7	-11353.1	-148606.2	-36960.6	-9210.0	10112.0	-102006.4
Textiles and Leather	-34891.1	-15689.0	-2553691.1	-25438.1	-198310.6	-63336.0	-3941.6	-15773.2	-207980.5
Construction and Non-Metallic	-21589.5	6252.3	-2619002.7	-270056.0	-1153962.9	-157058.7	-412688.3	-61912.9	-19605571.4
Electricity, Gas and Petroleum	-32070.9	-71152.0	-419452.2	-43532.2	-274690.0	-46279.4	-9895.5	-54747.0	-123269.9
Machinery and Equipment	-32070.9	-71152.0	-419452.2	-43532.2	-274690.0	-46279.4	-9895.5	-54747.0	-123269.9
Transport	-219454.5	-15752.5	-295031.2	-1048288.3	-571781.8	-79370.0	-66255.1	-144125.0	-279146.7
Services	-503887.0	-18074.2	-1031990.7	-1043543.4	-881607.1	-71190.1	-279899.4	-145256.2	-622836.3

	Tanzania United Republic of	Uganda	Zambia	Zimbabwe	Rest of Eastern Africa	Botswana	Namibia	South Africa	Rest of South African Customs Union
Food and Agriculture	-23746467.4	-7595796.7	-13074817.5	-46675804.7	-96680742.3	-2332997.1	-2185893.9	-158301523.9	-19977973.5
Mining	-8434.1	1729.9	-1033.1	-12937.0	8780.7	658.2	-36878.7	62296.9	-333684.7
Metals and Minerals	-40453.7	-45588.1	-363088.9	-321038.3	-112456.7	-248882.3	-103749.8	-370460.9	-23619.5
Textiles and Leather	-61867.5	-40359.5	-238877.3	-362464.3	-32575.1	-37729.9	-57427.5	-301233.9	-32705.7
Construction and Non-Metallic	-417911.4	-235496.1	-5486129.1	-3540381.7	-215118.6	-359260.2	-3259554.8	-12812742.1	-167964.2
Electricity, Gas and Petroleum	-42494.6	-75700.0	-322573.7	-279899.5	-53846.8	-67862.8	-47342.2	-600604.1	-26861.7
Machinery and Equipment	-42494.6	-75700.0	-322573.7	-279899.5	-53846.8	-67862.8	-47342.2	-600604.1	-26861.7
Transport	-634224.8	-50117.4	-130961.7	-449251.5	-67494.5	-19343.7	-70546.5	-373322.8	-28646.2
Services	-909487.1	-158716.9	-331118.0	-915959.5	-111013.8	-53319.3	-217447.9	-1592181.2	-200416.4

APPENDIX IV: Net Land-Use Exchanges between the UK and African Countries

Countries/Regions	Net Land Use Exchanges [hectares]
Egypt	-36005.8
Morocco	-681644.0
Tunisia	-78909.6
Rest of North Africa	-96260.1
Cameroon	-291578.1
Cote d'Ivoire	-272562.1
Ghana	-104369.3
Nigeria	-89982.7
Senegal	-51642.2
Rest of Western Africa	-277416.4
Central Africa	-1031141.2
South Central Africa	-235048.2
Ethiopia	-137616.6
Kenya	-240638.5
Madagascar	-85548.2
Malawi	-82214.1
Mauritius	-53505.0
Mozambique	-1188771.9
Tanzania United Republic of	-434288.4
Uganda	-61806.9
Zambia	-114095.5
Zimbabwe	-109521.7
Rest of Eastern Africa	-831221.1
Botswana	-1453328.4
Namibia	-3445785.4
South Africa	-238469.3
Rest of South African Customs Union	-39858.0