An Assessment of the Compatibility between Climate Change Mitigation and Global Development

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The candidate confirms that the work submitted is his own, except where work which has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

Some portions of the work in Chapter 3 of the thesis have appeared in publication as follows:

Barrett, J., Owen, A., Sakai, M. (2011) UK Consumption Emissions by Sector and Origin, Report to the UK Department for Environment, Food and Rural Affairs by the University of Leeds, London: DEFRA.

I was responsible for writing the *methods and approach* chapter and for conducting parts of the analysis. The contribution of the other authors was to undertake the remaining analysis and write the rest of the chapters.

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I was responsible for conducting the analysis and writing the methodology included in the Annex. The contribution of the other authors was to write the rest of the report.

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Abstract

Humanity's greatest challenge is to improve the living standards of billions of people across the world without surpassing the planetary boundaries, and especially within the carbon space compatible with a 2°C future. Mitigation actions are thus required to create synergies and address climate and development goals simultaneously. It has been recognised that technology-led mitigation measures can accomplish this task, as long as they are also complemented with demand-side measures. Several bodies of literature have emphasised, for example, the urgent need to reduce consumption levels, particularly in industrialised economies. However, in the context of an ever more globalised world, the climate benefits delivered by demand-side mitigation policies can be offset by the existence of potential negative consequences in developing nations via international trade. This thesis assesses the compatibility between climate change mitigation actions taken in industrialised nations and improving development prospects in the developing world from a demand-side approach. The study contributes to the existing knowledge base by providing answers to four separate but related research questions that were proposed to examine relevant aspects associated with this issue. The results reveal that CO_2 emissions have increased monotonically with income without showing signs of having decoupled over time. The findings also show that while curbing final demand for imports in developed countries can contribute to reduce their consumption-based emissions and free carbon space, they can also curtail the development opportunities available to the global South. Moreover, specific policy instruments, like border carbon adjustments, can potentially distort trade flows and jeopardise development in developing nations. Finally, the analysis unveils that the available carbon space compatible with a 2°C target is insufficient to deliver significant improvements in living standards in less developed countries given the continuity of the status quo. The sharing of the development and carbon spaces should be done in an equitable manner. The longer it takes developed countries to significantly cut their emissions, the smaller is the carbon space available particularly to the poorest nations who need it the most. The conclusions from this work evidence the necessity to formulate alternative development pathways capable of facilitating a transition towards an equitable, low-carbon, high-developed, and sustainable global economy.

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List of Acronyms and Abbreviations

BAT	Best Available Technology
BAU	Business as Usual
BCA	Border Carbon Adjustment
BRIC	Brazil, Russia, India and China
CCS	Carbon Capture and Storage
CDIAC	Carbon Dioxide Information Analysis Centre
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP	Conference of the Parties
ECLAC	Economic Commission for Latin America and the Caribbean
EEBT	Emissions Embodied in Bilateral Trade
EE-MRIO	Environmentally-Extended Multi-Regional Input-Output
EKC	Environmental Kuznets Curve
EU ETS	European Union Emission Trading Scheme
EU	European Union
FDI	Foreign Direct Investment
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GHGs	Greenhouse gases
GLS	Generalised Least Squares
GNI	Gross National Income
Gt	Gigatonnes
GTAP	Global Trade Analysis Project
HDI	Human Development Index
IAV	Impacts, adaptation and vulnerability
IMF	International Monetary Fund
IOA	Input-Output Analysis
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt-hour
LDCs	Least Developed Countries
MDGs	Millennium Development Goals
MRIO	Multi-Regional Input-Output
Mt	Megatonnes

NAMAs	Nationally Appropriate Mitigation Actions
NAPAs	National Adaptation Programmes of Action
ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PHH	Pollution Haven Hypothesis
PPM	Parts per million
PPP	Purchasing Power Parity
RCPs	Representative Concentration Pathways
REDD	Reducing Emissions from Deforestation and Forest Degradation
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
SRES	Special Report on Emissions Scenarios
SSPs	Shared Socioeconomic Pathways
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNSD	United Nations Statistics Division
VAT	Value-Added Tax
WTO	World Trade Organisation

Chapter 1
Introduction

As its title indicates, this thesis offers an assessment of the compatibility between climate change mitigation and global development. Studies of this nature have been seldom conducted from a consumption perspective and the academic literature in the area is still scarce. This research thus constitutes an initial effort to understand the trade-offs that exist between undertaking mitigation actions in industrialised countries to avoid dangerous climate change and improving development prospects across developing nations from a demand-side approach. This introductory chapter provides the rationale for the study in section 1.1. It also highlights the importance of carrying out this investigation and offers a brief background on the subject. Section 1.2 presents the overarching aim and research questions. Finally, section 1.3 explains the general chapter structure and the organisation of the thesis.

1.1. Rationale of the study

1.1.1. The nexus between climate and development

The evidence gathered in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013) reveals that most of the observed increase in global average temperature since pre-industrial times is extremely likely (i.e. >95% probability) due to the growing atmospheric concentration of greenhouse gases (GHGs) derived from human activities (see: Cook et al., 2013). Throughout the last century, global GHG emissions increased significantly, particularly in the last decades. These grew around 70% between 1970 and 2004, whereas carbon dioxide (CO_2) emissions, the most important anthropogenic GHG, rose by about 80% during the same period, mainly associated with energy supply, transport and industry (IPCC, 2007b). Since the year 2000, total CO_2 emissions increased on average 3.1% on an annual basis, and recent estimations suggest they were 58% greater in 2012 than in 1990 (Le Quéré et al., 2012). If these trends were to persist, it is likely (>66% probability) that future global warming would augment more than 2°C above the pre-industrial level (see: Friedlingstein et al., 2011; IPCC, 2013; Peters et al., 2013). Notwithstanding uncertainties about potential effects, there is high agreement among the scientific community (IPCC, 2007a) that this would greatly increase the risk of climate-related impacts on human and natural systems, in some of which irreversible changes could take place (e.g. melting of ice sheets, extinction of species, alteration of ocean water circulation, etc.). Thus, in order to keep global warming below a 2°C threshold in the long-run and mitigate these effects, immediate and considerable actions are required to keep the average atmospheric CO_2 concentration below 450 parts per million (ppm). The amount of cumulative emissions that is compatible with such a target, what in this thesis is defined as the *available carbon space*, is diminishing at a fast rate.

The impacts of long-term climate variability will differ across geographical regions and economic sectors. It has been recognised that the most adverse effects will occur in the developing world. Specifically, the poorest, underdeveloped societies will be most at risk due to their high exposure to climate events and their low adaptive capacities, mainly in Africa and also in Asia and Latin America (see: Huq et al., 2004). Regarding sectors, agricultural activities, for example, are expected to experience declines in crop productivity at lower latitudes due to changes in temperature and precipitation. Other sectors closely linked with climate-sensitive resources (e.g. water, forests, fish, etc.), including industrial, are equally threatened (IPCC, 2007a).

Climate change thus exerts an important influence on sustainable development. Approximately 85% of the world's population are situated in the developing world and about 40% live with less than $2 dollars a day. Improvements in development, however, have been achieved during the last two decades, reflecting what the United Nations Development Programme (UNDP, 2013) calls *the rise of the South*. The first Millennium Development Goal (MDG), for instance, has been accomplished (UN, 2012a). The proportion of people living in extreme poverty on less than $1.25 dollars a day was halved since 1990 from 47% to 24%. In addition, more people around the world have access to health and education services. Nonetheless, the extent to which human development opportunities can still be improved across the planet, what is defined in this thesis as the *necessary development space*, is considerable. Large efforts need to be undertaken especially in the 49 poorest countries, classified by the UN as least developed (LDCs) (see: Guillaumont, 2009)[1]. As these nations enhance their development levels, they will exert more pressure on the environment. Larger populations and higher rates of economic growth per capita will be associated with more GHG emissions, accelerating climate change which, in turn, can threaten their development.

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[1] A list of the countries that comprise the group of LDCs can be found in Appendix A.1.1.

There is, in this sense, a *two-way* relationship between climate change and sustainable development (Beg et al., 2002; Robinson et al., 2006). Climate variability influences the basis for economic and human development, while economic and social decisions determine the generation of GHG emissions and the adaptability of societies to different climate regimes. Hence, the IPCC (2007b) has suggested that policies pursuing sustainable development and climate change mitigation and adaptation are to be mutually reinforcing. In other words, sustainable development involves realising the necessary development space within the limits of the available carbon space (Kartha et al., 2010).

1.1.2. The role of technology in climate change mitigation

The IPCC (2007b, p. 818) defines the term *mitigation* as those policies aimed at reducing GHG emissions and enhancing sinks, placing an important emphasis on "*technological change and substitution that reduce resource inputs and emissions per unit of output*". In national and international policy agendas, mitigation actions have mainly focused on technological solutions, considering the use of low carbon energy sources and less carbon-intensive materials and techniques as key factors. However, as recognised by the IPCC (2007b, p. 701), "*mitigation options should not be limited to technology*" and cover a broader spectrum of economic and social policies. Such policies can address factors like population (*P*) and affluence (*A*) which, recalling the IPAT equation (Ehrlich and Holdren, 1971; Commoner, 1972), jointly determine the degree of an environmental impact (*I*) in conjunction with technology (*T*).

Technological change exerts an influential role on both the environment and development (Huesemann and Huesemann, 2008). Combustion technologies based on fossil fuels, for instance, have allowed societies to become more productive, to change the structure of their economies from agrarian to industrial, and to improve their standards of living since the pre-industrial era. However, these same technologies have significantly contributed to global climate change. In the face of this phenomenon, the paradigm of sustainable development requires technological improvements and substitution of inputs to preserve the integrity of the environment, while enhancing economic and social assets (Beder, 1994). In other words, there is the need for technology-led mitigation policies that have the dual ability to address climate and development aims, particularly in developing countries. In this respect, the Clean Development Mechanism (CDM) constitutes an example of a mitigation scheme that generates these synergies (see: Olsen, 2007). Developing nations receive development support from industrialised economies (i.e. Annex I[2]) in the form of cleaner technology options, while the latter gain by meeting part of their reduction targets.

Despite the relevance of technology as a mitigation solution and the optimism displayed by some policymakers and academics (e.g. Pacala and Socolow, 2004; Vollebergh and Kemfert, 2005), there is a growing uncertainty regarding the pace of future technological change required to deliver on time the deep emissions reductions compatible with a 2°C pathway (Beder, 1994; Schor, 2005; Flavin and Engelman, 2009). Jackson (2009) offers some estimates based on the IPAT equation, assuming a global contraction and convergence towards equal per capita emissions. He suggests that the global average carbon intensity (i.e. emissions per unit of output) would need to register a 21-fold improvement by 2050 given that population and income per capita grew annually at rates of 0.7% and 1.5%, respectively. The necessary improvements could even be 130 times larger if developed and developing countries possessed the current average European Union's (EU) per capita income growing at 2% per annum. This implies a pace of technological change at least ten times faster than the one present today to offset the current trends of population and economic growth. Moreover, it implies overcoming lock-in effects and diffusion barriers (e.g. market, regulatory, trade, etc.) that affect the rapid and effective deployment of technological solutions (see: Arthur, 1989; Unruh, 2000; Unruh and Carrillo-Hermosilla, 2006). Regarding geo-engineering options to remove CO_2 from the atmosphere and blocking solar radiation, the IPCC (2007b, p. 15) has recognised that these technologies "*remain largely speculative and unproven, and with the risk of unknown side-effects*" (also see: Bengtsson, 2006; Boyd, 2008; Fox and Chapman, 2011). Authors such as Huesemann (2006, p. 539) thus believe that mitigation technologies have the potential to deliver the required emission cuts "*only if population and economic growth are halted without delay*" (also see: Anderson and Bows, 2011). Technology, in this sense, is deemed as a necessary, but not sufficient condition for combating climate change, as well as other environmental problems, and achieving sustainability.

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[2] These are the parties to the UNFCCC listed in the Annex I, formed by industrialised economies and economies in transition, including the Russian Federation, the Baltic States, and several Central and Eastern European States. See complete list in Appendix A.1.4.

1.1.3. The need to address consumption

Population and affluence are significant drivers of emissions (Rosa and Dietz, 2012). The former is particularly relevant in developing countries, where population growth rates are still far from reaching stabilisation (Jiang and Hardee, 2011). An expansion of income per capita, on the other hand, has mostly driven the increase of emissions in industrialised nations (Hamilton and Turton, 2002), and has become increasingly relevant in emerging economies (e.g. China, India, Brazil, etc.) as the purchasing power of their societies has improved during the last decades (Hubacek et al., 2007). However, both population and affluence are seldom addressed in policy debates on climate change mitigation, due to political sensitivities and the associated social and economic costs. Reducing fertility rates, for instance, can contribute to sustainable development by alleviating poverty and diminishing pressure on natural resources (Petroni, 2009; Das Gupta et al., 2011), but this action can generate negative social effects when the policies are too stringent, as in the case of China (Feng et al., 2013). Nevertheless, none of the Nationally Appropriate Mitigation Action (NAMA) plans reported by developing countries to the United Nations Framework Convention on Climate Change (UNFCCC) consider the use of population controls. Moreover, none of them address the issue of affluence, since developing countries generally argue in climate negotiations that they have the right to develop and continue rising their incomes and consuming more in per capita terms (see: Jotzo, 2005). On the other hand, in Annex I nations, whose populations have stabilised but whose income per capita levels have led their economies to surpass sustainable scales (Wackernagel et al., 2002), national mitigation strategies do not include measures related to capping affluence and consumption.

Neoclassical economics has traditionally dealt with the relationship between affluence and environmental quality through the Environmental Kuznets Curve (EKC) hypothesis (e.g. Grossman and Krueger, 1991). The EKC basically states that environmental degradation improves after income per capita reaches a certain level during the process of economic development. Said differently, becoming rich can be a potential solution to environmental problems (Beckerman, 1992), which represents a more attractive option for policymakers. However, there is no conclusive empirical evidence indicating that CO_2 emissions per capita have declined with rising affluence (Galeotti et al., 2006).

Consumption is a function of affluence. A higher disposable income is usually associated with a higher amount of consumer spending, and this can be observed on a global scale. The more affluent nations house around 15% of the world's population and account for approximately 75% of total consumption expenditure (Assadourian, 2010). Their high levels of consumption per capita constitute the main driver for increasing emissions (Sanwal, 2009). It is estimated that industrialised countries are accountable for about 7.5 out of every 10 tonnes of CO_2 that have been emitted since the start of the industrial era (Raupach et al., 2007; Wei et al., 2012). Consumption in developing countries, on the other hand, has been growing significantly by almost a factor of 2.5 since 1990, generating a considerable amount of emissions. Acknowledging this situation, a call was made in Rio's Agenda 21 (UN, 1992) to encourage changes in unsustainable consumption patterns, particularly in wealthy nations, and take action against the global imbalances of consumption in order to reverse environmental degradation. This call was taken into account by the IPCC (2007b, p. 12), recognising that changes in lifestyle and consumption patterns "*can contribute to climate change mitigation across all sectors*".

Demand-side climate change mitigation is defined in this thesis as those measures that pursue cuts in consumption-induced emissions by modifying consumption patterns and/or reducing consumption of goods and services. The label *demand-side* is used so as to distinguish these actions from technology-led mitigation, which usually focus on the production process or supply-side, as well as purely technological geo-engineering options. Demand-side policy tools can take the form of market-based (e.g. carbon consumption taxes and subsidies), regulatory (e.g. bans) and information instruments (e.g. carbon-labelling, awareness campaigns). It is important to recognise, however, that production and consumption are opposite sides of the same coin. In this sense, some demand-side instruments can produce indirect effects in supply, just as supply-side measures can cause indirect effects in demand when the costs are transferred to the final consumer. For instance, a carbon consumption tax applied directly to consumers may dissuade them from acquiring a certain product. Consequently, it may also represent an incentive for the producers to manufacture it in a less carbon-intensive manner. Some demand-side schemes are already in operation. For example, the UK and France have initiated carbon-labelling programmes that are currently voluntary, but can become mandatory in the future. Such initiatives seek to inform consumers about the carbon content of products (i.e. the amount of CO_2 generated during all stages of production and distribution) and are thus motivated or discouraged to buy them. This is particularly significant in industrialised nations, where many of the basic consumer goods are of foreign origin, often produced in carbon-intensive regions not subject to costs derived from carbon abatement regulations.

The dependence of industrialised nations on foreign goods has increased during the last decades, making them net-importers of emissions through international trade. Conversely, the developing world has become on average a net exporter (Peters and Hertwich, 2008a; Davis and Caldeira, 2010). Following a consumption-based approach, Peters et al. (2011b) estimate that net emission transfers from developing to wealthy nations grew by a factor of 4 from 1990 to 2008, which exceeds the reductions stipulated in the Kyoto Protocol, and are expected to continue growing. Allocating emissions to countries where the products are consumed (i.e. consumption-based carbon accounting), rather than where they are produced (i.e. territorial or production perspective), thus stresses the responsibility of carbon-importing nations for adopting demand-side mitigation actions along with technological solutions with the aim of achieving a 2°C future.

Reductions in consumption and changes in consumption patterns (e.g. preference for locally-produced rather than for foreign products) in industrialised nations, however, can generate negative effects in developing countries via international trade. Since 1990, the volume of trade (i.e. imports and exports) has grown three times faster than global gross domestic product (GDP), which reflects the increasing globalisation of markets and the interdependence of nations. The international division of labour and the geographical fragmentation of production have intensified (Lanz et al., 2011). Different regions and countries are linked by an intricate network of trade interrelations. It is common that products are manufactured with a range of raw materials extracted from diverse regions. These products are then assembled in some other nations, and then redistributed to yet other countries for consumption. The separation of extraction, production and consumption, often by great distances, is a standard trait of the world's economy (Arndt and Kierzkowski, 2001). The rise of global production chains and the profound interdependency imply that changes in demand in one country may induce effects in several other economies.

1.1.4. The need for further research

The need for making consumption more sustainable is well documented in various bodies of academic literature. The evidence indicates that humanity has surpassed the planet's carrying capacity (Wackernagel et al., 2002) and transgressed the balance of the Earth's ecosystems (Rockström et al., 2009). Global warming is just one of the symptoms of unsustainable consumption, along with the depletion of natural resources, biodiversity loss (Lenzen et al., 2012) and other environmental problems. As was explained, numerous academics and international organisations have recognised the need to address consumption. Steady-state economics (e.g. Daly, 1974) and the degrowth movement (e.g. Latouche, 2006), for example, advocate for the necessity of tackling overconsumption, especially in wealthy nations, either by stabilising it or applying overall reductions. However, the economic consequences of reducing consumption levels and changing consumption patterns have not been sufficiently analysed. In particular, the potential impacts on the developing world have been scarcely explored. This gap in the knowledge has thus motivated the undertaking of the present research.

Humanity's greatest challenge is to keep generating the development that the world needs (i.e. necessary development space) within the planetary boundaries, and especially within the carbon budget compatible with a 2°C future (i.e. available carbon space) to prevent dangerous climate change. The sharing of the development and carbon spaces should be done in an equitable manner. Instigating mitigation-induced changes in consumption in industrialised nations can produce developmental costs in poorer regions, but it can also deliver potential climate and environmental benefits, and leave more carbon space to the developing world. In this respect, it is uncertain to what extent the available carbon space, which is to be shared between both groups of countries, will be large enough to fulfil higher levels of development in developing economies. This would primarily depend on the scale and pace of the emission reductions undertaken by industrialised nations. The longer it takes the latter countries to significantly cut their emissions, the smaller is the carbon space available particularly to the poorest nations who need it the most. Steinberger and Roberts (2010) argue that human development has been gradually decoupling from per capita emissions, and that low levels of energy and carbon can satisfy human development needs. However, this would require substantive efforts to restructure the global economy. Even if wealthy nations achieved emissions cuts of 80% by 2050 relative to 1990 (see: Elzen et al., 2013) by reducing their per capita consumption-based emissions by about 2% per annum, the amount of development that developing nations could attain with their remaining share of carbon space could be limited given their current economic structures. This aspect has also not been explored in the climate change and economic literature and requires further study.

Understanding the trade-offs between implementing mitigation actions in industrialised nations and achieving improvements in development in the rest of the world is thus important, as unilateral policy decisions can undermine the potential synergies created between climate and development goals. Moreover, analysing the trade-offs is relevant to inform the future direction and design of alternative low-carbon development pathways.

1.2. Aim and research questions

This thesis was inspired by a question formulated by Hans Opschoor (2010, p. 7) as a topic that requires further examination: "*How will mitigative actions by developed countries affect development in developing and emerging economies?*" This question allows a range of possible answers depending on the nature of the mitigation options and the different aspects of development. Generally, existing responses have focused on addressing the beneficial features of creating synergies between climate change mitigation and economic development priorities, often referring to schemes like the CDM and the Reducing Emissions from Deforestation and Forest Degradation (REDD) programme. However, as was explained in the previous section, the climate benefits delivered by demand-side mitigation policies can be offset by the probable existence of negative consequences in the developing world. These effects have been seldom considered and there is a lack of studies centred on the subject. In this sense, the **overarching aim** of this study is to **assess the compatibility between climate change mitigation actions in industrialised nations and improving development prospects in the developing world from a demand-side approach.**

Due to the complexity involved and the scope of the overarching aim, four separate but related aspects associated with it were chosen to be explored, each guided by a specific research question. Examining these aspects provides useful insights into the problem and helps to fulfil the overarching aim.

Research question 1: *Is the Environmental Kuznets Curve for carbon valid from a consumption-based approach?*

Exploring this question serves a starting point for this research since, as was explained in section 1.1.3, if the EKC for carbon were valid, then there would be no trade-offs between achieving emission cuts and attaining economic development. A potential policy would then be to promote throughout the world rises in income per capita. As will be explained in Chapter 2, there are no conclusive findings about the applicability of the EKC to CO_2 emissions. By using cross-country panel data for consumption-based emissions and econometric methods, more robust evidence is sought in order to accept or reject the EKC. The results derived from the analysis, apart from validating the hypothesis, also show the extent to which the income-emissions relationship has evolved over time in industrialised and developing nations from a consumption-based perspective.

Research question 2: *How much value added and wages paid to skilled and unskilled labour in developing countries are associated with every unit of CO_2 that is mitigated in different sectors through reductions in consumption in industrialised nations?*

Demand-side mitigation measures designed to change/reduce consumption are deemed as essential to complement technology-led mitigation actions in order to achieve a 2°C target. However, in the context of a globalised planet, changes in demand for imports registered in industrialised nations can bring negative developmental consequences in the global South. This research question addresses the trade-offs between achieving cuts in consumption-based emissions in wealthy countries and attaining economic benefits through international trade in developing economies. Variables relevant for promoting economic growth and improving welfare, such as value added and wages to skilled and unskilled labour, are used here as proxies for development indicators. In this sense, the amount of value added and wages that are associated with every unit of consumption-based emissions are quantified. This examination allows identifying which countries and sectors are more vulnerable to changes in the flow of traded goods. Moreover, the findings can inform future demand-side mitigation policies regarding ways in which to avoid affecting vulnerable nations.

Research question 3: *How much value added and wages paid to skilled and unskilled labour in developing countries are associated with CO_2 emissions that would be captured in different sectors through the implementation of border carbon adjustments in industrialised nations?*

This question refers to the analysis of a specific market-based mitigation policy instrument, which in basic terms constitutes an import tariff. Border carbon adjustment (BCA) schemes are designed to address carbon-leakage effects and competitiveness issues, concepts that will be extensively explained in the next chapter. Although some economists believe that in theory BCAs are not likely to distort trade (Whalley, 1979), other authors suggest that they can lead to losses in efficiency and welfare among exporting nations (e.g. Atkinson et al., 2011). Some developing countries have opposed to their implementation, asserting that they represent trade barriers and shift the mitigation costs onto the developing world (Davidson Ladly, 2012). Discussions are happening in some Annex I nations, regarding the adoption of this policy instrument. The US has stated that it will not implement an emissions trading scheme without a provision for BCAs to compensate for differences in production costs with respect to countries with no abatement schemes. Thus, it is relevant to quantify the trade-offs between the amount of emissions that a BCA scheme can capture from the developing world and its effects on the creation of value added and skilled and unskilled wages.

Research question 4: *To what extent can human development be improved in the developing world within the limits of the available carbon space as defined by the RCP pathways given the continuity of the status quo?*

This question addresses the challenge of the equitable sharing of the development and carbon spaces explained in the first section of this chapter. As said, considerable efforts still need to be undertaken to fulfil the necessary development space within the constraints imposed by the available carbon space. The longer it takes industrialised countries to undertake significant and sustained emissions reductions, the less carbon space will be left for the poorest regions. It is uncertain, however, to what extent human development could be improved with the remaining carbon budget in different areas of the planet given the continuity of the current model of economic development. By using territorial and consumption emissions and historical carbon elasticities of human development, potential improvements in the human development index (HDI) by 2050 are calculated for various groups of developing countries according to the new Representative Concentration Pathways (RCPs) included in the Fifth Assessment Report (IPCC, 2013). The so-called RCP3-PD, also known as RCP2.6, is of special interest, since it describes an emissions pathway that is compatible with a 2°C target (van Vuuren et al., 2007). This analysis does not attempt to make a forecast, explore alternative pathways or examine different allocation schemes. Rather, it seeks to obtain insights about the historical relationship between human development and CO_2 emissions and stress the importance of focusing on the dual climate-development challenge in an integrated and more equitable manner. The findings, moreover, can help to build more comprehensive future emission pathways, as well as to inform global and regional climate negotiations.

1.3. Organisation of the thesis

Chapter 2 links diverse bodies of literature necessary to achieve the objective of the thesis. It offers a critical review of the existing literature revolving around the topics of climate change, consumption, trade and development, and explores the gaps in knowledge related to the research questions presented in the previous section. Chapter 3 then concentrates on the methods and data, explaining the suitability of the selected techniques to address the research queries presented in the previous section. In addition, the data used in the study is described in detail. The next four chapters present the results derived from each of the research questions. The results pertaining to the carbon EKC analysis appear in Chapter 4. This is followed in Chapter 5 by an examination of the effects that take place in developing economies via international trade caused by implementing cuts in consumption-based emissions in wealthy countries. Chapter 6 then focuses on the impacts produced by BCAs in the developing world. Chapter 7 analyses the extent to which human development can be improved in the South given the available carbon space. All these results are then discussed in Chapter 8 in the light of the existing literature, while focusing on their academic and policy implications. Finally, Chapter 9 offers the main conclusions, details the contributions of this thesis, discusses the limitations of the study and highlights future research needs.

Chapter 2
Climate change mitigation and global development: a consumption perspective

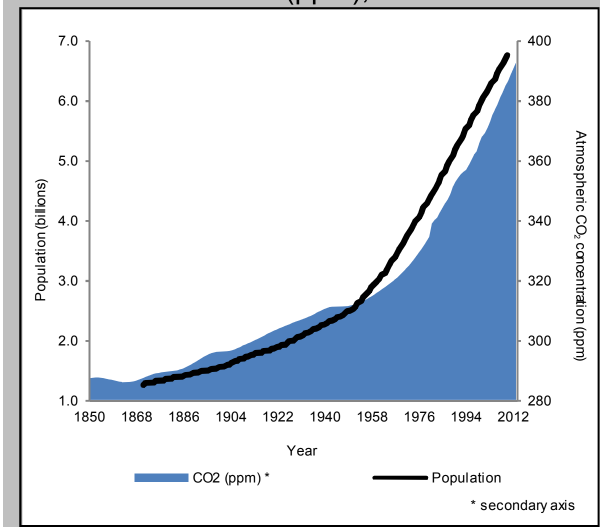
This chapter offers a critical review of the literature and identifies the gaps in the knowledge base that this study aims to address. The nature of this research requires engaging with several bodies of literature. As will be explained, the links between climate and development are shaped to a large extent by consumption and international trade. These topics are deeply interrelated and a proper understanding of their linkages is thus vital to understand the problem at hand. A background of these topics is presented here, covering those studies that are more relevant for this thesis. The chapter starts by discussing the nexus between the carbon and the development spaces in section 2.1. It provides definitions for both concepts and offers information about their magnitude according to existing analyses. Section 2.2 talks about the role of consumption in the fields of development and climate change. The problem of overconsumption is examined, stressing the need to modify consumption patterns and/or reduce the overall level of economic throughput. It also offers a literature review about the carbon EKC from a consumption-based approach. This is followed in section 2.3 by a presentation of the different demand-side mitigation policy options, emphasising the case of border carbon adjustments. Section 2.4 deals with international trade and its influence on development and the environment. Next, section 2.5 reviews the literature regarding the potential impacts experienced in the developing world caused by demand-side changes via international trade. Finally, section 2.6 presents a brief summary and highlights the main research gaps that are addressed in this thesis.

2.1. The carbon and development spaces

2.1.1. The carbon space

Since the Industrial Revolution, the planet has experienced an era of significant environmental change. This era has been labelled the *Anthropocene*, as a way to mark the transition from a geological epoch characterised by relative environmental stability (i.e. the Holocene) to an age in which human activities have exerted a profound influence on the Earth's ecosystems (Crutzen, 2002). During this period, population registered a rapid expansion, which grew more than five-fold since 1850 (Maddison, 2003) (see Figure 1), and an associated eight-fold increase in the use of renewable and non-renewable resources since the start of the twentieth century (Krausmann et al., 2009). The deep reliance on fossil fuels, as the basis for industrialisation, has produced billions of tonnes of GHGs that have been emitted into the atmosphere on an annual basis. The pressure on the environment has thus reached historical levels, threatening the planet's carrying capacity. Rockström et al. (2009) indicate that some planetary boundaries or *tipping points* (see: Lenton et al., 2008) have been transgressed. These boundaries represent the limits below which human societies can function safely without altering biophysical systems and processes. Specifically, the thresholds related to climate and biodiversity, as well as the nitrogen cycle, have been surpassed. The potential effects caused by these transgressions are still surrounded by large uncertainties, but they may lead to catastrophic consequences for human civilisation (Scheffer et al., 2001).

Figure 1 - Population and atmospheric CO_2 concentration (ppm), 1850-2012



Sources: Own figure based on data by Manning et al. (1996); Maddison (2003); Keeling et al. (2005)

In relation to climate, the mean global surface temperature has increased about 0.85°C since the pre-industrial era, mainly caused by the atmospheric accumulation of anthropogenic GHGs (IPCC, 2013). CO_2 is the gas that accounts for approximately 75% of total GHGs and is mostly generated by the combustion of fossil fuels and land-use change (IPCC, 2007b). Its global atmospheric concentration showed a sharp growth of more than 35% since the mid-nineteenth century, ranging from 287 ppm in 1850 to 392 ppm in 2012 (Keeling et al., 2005; NOAA, 2012) (see Figure 1). In terms of annual emissions, these grew on average 2.8% from 1950 to 2000, but in the last decade the pace has slightly accelerated, registering a mean annual rate of 3.1%. Recent estimations suggest that emissions were 58% greater in 2012 than in 1990 (Le Quéré et al., 2012). If this trend persisted throughout the present century, annual emissions could augment by a factor of 4.5 by 2100, which could likely (i.e. >66% probability) lead to a rise in mean global temperature of about 3.8° to 5.7°C with respect to the pre-industrial level (Rogelj et al., 2012; IPCC, 2013). The impacts on natural and human systems associated with such an average temperature are uncertain, but the IPCC (2007a) has estimated that it could cause irreversible biophysical changes, such as sea level rise, a weakening of the meridional overturning (i.e. thermohaline) circulation[3], melting of polar ice sheets, major extinction of species, loss of wetlands, among others. With regards to human systems, many societies would suffer from increased water and food stress, lower crop productivity at lower latitudes, increases in the severity and frequency of tropical storms and coastal flooding, a greater proliferation of infectious diseases, etc.

The impacts from climate variability will differ across geographical regions, but it is highly agreed that the most adverse effects will be felt in the developing world, particularly in the poorest, underdeveloped and most climate-exposed areas (see: Mendelsohn and Dinar, 1999; Huq et al., 2004; Mertz et al., 2009). Many people in these regions rely heavily on agriculture and are sensitive to changes in climate. Moreover, these variations may aggravate their ongoing social and economic situations, thus increasing their vulnerability and exacerbating their already limited economic and technological capacities to adapt (Yohe and Tol, 2002; Adger et al., 2003; Reid et al., 2010). The IPCC (2007a) has identified regions that are likely to be especially threatened. Millions of people located in Africa could be at risk of experiencing water stress and declines in yields from rain-fed agriculture. Small Island Developing States (SIDS), on the other hand, which are already facing problems related to sea level rise, are expected to be affected by even higher sea levels and more frequent and intense coastal hazards, such as flooding, storm surges and erosion. Adverse effects could also take place in the heavily populated megadelta regions in South, East and South-East Asia, where people could be at risk of increased flooding and larger propagation rates of water- and food-borne diseases.

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[3] The meridional overturning or thermohaline circulation refers to the flows of ocean water from high to low density areas caused by differences in temperature and salinity (see: IPCC, 2001).

Changes in climate can equally affect the comparative advantage of different regions in terms of producing goods and services. As said, it is anticipated that agricultural activities will be negatively affected in lower latitudes, but yields could show slight increases at middle to high latitudes depending on the type of crop (IPCC, 2007a). Other economic sectors, such as industrial activities, can also be vulnerable to temperature and precipitation changes. Industries dependent on climate-sensitive inputs, like those related to food processing and manufacturing of paper, natural textiles and others, can be affected by scarcity and higher costs of raw materials (see: Ruth et al., 2004). Climate variations are also likely to affect both energy use and energy production in many parts of the world (see: Schaeffer et al., 2012). Demand for heating and cooling is prone to vary in different regions (see: Xu et al., 2012). Moreover, water reservoirs for hydroelectric generation can dwindle in some areas, while extreme weather events can affect energy production and distribution (see: Mimikou and Baltas, 1997). In relation to the service sector, retail and commercial services, such as those that deal with perishable commodities and agricultural produce, could experience disruptions in their supply chains (see: Sussman and Freed, 2008). Regarding tourism, changes in tourist flows could take place depending on the location, due to variations in temperature and the frequency and intensity of extreme climate events (see: Wall, 2005). Shifts in passenger flows could, in turn, affect the transport sector, which could also face variations in freight prices and alterations of shipping routes (see: Koetse and Rietveld, 2009).

Avoiding dangerous effects from climate change requires urgent, substantial and sustained emission cuts in order to stabilise global mean temperature below a 2°C threshold and not exceed an atmospheric CO_2 concentration of 450 ppm (IPCC, 2007c; Arnell et al., 2013). However, there is a gap between an emissions pathway with a likely chance of meeting the 2°C target and the current trajectory. UNEP (2012) has estimated that this gap could amount to approximately 14 gigatonnes (Gt) of CO_2 equivalent (CO_2e) in 2020 under a *business as usual* (BAU) scenario. The existence of this gap was recognized by the UNFCCC member countries (i.e. parties to the convention) at the 17th Conference of the Parties (COP17), held in Durban, South Africa (UNFCCC, 2011b). The reduction pledges submitted by the parties are still far from the cuts required to achieve the 2°C goal. According to UNEP (2012), the gap could be reduced down to 13 or even 8 gigatonnes of CO_2e in 2020 with the current pledges, depending on the level of ambition and the severity of the accounting rules agreed in future climate negotiations. Completely eradicating the gap, however, requires the willingness of member countries to undertake much greater abatement efforts.

Estimating the potential pathways that emissions will follow in the coming decades has been at the centre of the process led by the IPCC. Since the First Assessment Report (IPCC, 1990) was published, four generations of emissions scenarios have been developed (see: Moss et al., 2010). These scenarios do not represent forecasts, but probable depictions of the future in relation to socio-economic, technological and climate assumptions. Moreover, they represent *baseline* or *reference* projections, as they do not consider the implementation of additional climate policies other than the existing ones. They reflect the judgment of expert scientists in diverse areas and are useful for guiding research and decision-making. The first series of IPCC scenarios are known as SA90 (scientific assessment) (IPCC, 1990), which were updated two years later to produce the so-called IS92 IPCC scenarios (Leggett et al., 1992). In the year 2000, the Special Report on Emissions Scenarios (SRES) (Nakicenovic and Swart, 2000) was released. It included a new set of 40 reference projections, which were then used in the IPCC Third Assessment Report (IPCC, 2007c, a, b). These scenarios are grouped into four categories (A1, A2, B1 and B2), depending on their associated *storylines* or narratives of the future. Each storyline comprises different key assumptions about the demographic, social, economic, technological and environmental forces that drive emissions (see: Rosa and Dietz, 2012). Scenarios in the "*A*" family place a stronger focus on economic aspects, while the "*B*" group gives more importance to environmental issues. On the other hand, scenarios labelled with the number 1 consider a more homogenous world in terms of economic development, with fast economic growth, population peaking around mid-century and the introduction of more efficient technologies. Conversely, scenarios with a number 2 attached indicate heterogeneity in development levels across countries, with lower rates of economic growth and increasing population. These scenarios, along with three variations of A1, are described in Table 1.

Table 1 - Narratives of SRES illustrative scenarios

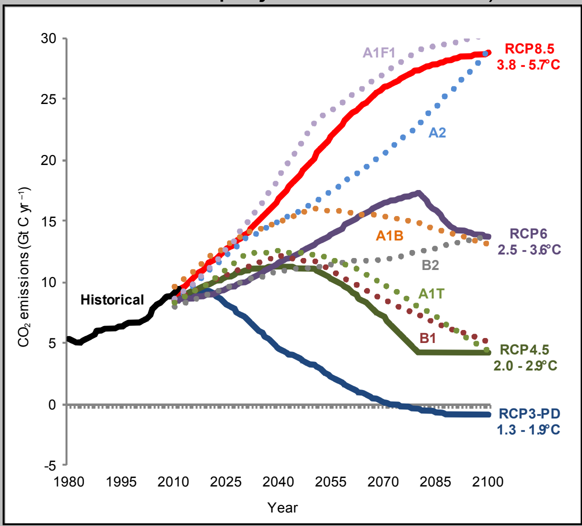
Scenario	Storyline			
	Economic growth	**Economic development**	**Population**	**Technology**
A1	Fast	Convergence	Peaks in mid-century	Rapid introduction of new and more efficient technologies
	A1F1: Fossil-fuel intensive *A1T*: No use of fossil-fuel energy resources *A1B*: Balance across all energy sources			
A2	Slow	Heterogeneous (regionally oriented)	Increasing global population	Slow introduction of new and more efficient technologies
B1	Fast	Convergence	Peaks in mid-century	Introduction of clean and resource-efficient technologies
B2	Intermediate	Intermediate levels of economic development	Increasing global population (lower than A2)	Less rapid and more diverse technological change than A1 and B1

Source: Own table based on Nakicenovic and Swart (2000)

A fourth set of scenarios has been put together, as more detailed and updated information has become available during the last decade. These are called the *Representative Concentration Pathways* (RCPs), and are intended to be used in the IPCC Fifth Assessment Report (Moss et al., 2010; van Vuuren et al., 2011). Different groups of climate modellers were in charge of their development with the purpose of addressing the needs of distinct research communities (i.e. climate modelling, mitigation and adaptation), as well as to stimulate the coordination between them. The term *representative* indicates that each pathway does not constitute a completely new scenario, but represents a larger set of existing scenarios already available in the scientific literature; whereas the word *concentration* is used to stress their primary focus on producing atmospheric concentrations as their main outputs, rather than annual emissions. In contrast to the SRES scenarios, the RCPs do not have explicit socio-economic storylines attached, as these were developed separately. Each RCP essentially represents a potential radiative-forcing trajectory[4]. The four pathways, in this sense, correspond to radiative-forcing levels of 8.5, 6.0, 4.5 and 2.6 watts per square meter (Wm^{-2}), which are associated with a range of likely values for an increase in global average surface temperature (Meinshausen et al., 2011).

[4] Radiative forcing is defined as the net amount of energy irradiated from the planet (i.e. the difference between the energy flowing into the atmosphere and that reflected back to space) due to changes in atmospheric composition, land use change and solar activity. It is measured in watts per square meter (IPCC, 2007c).

Figure 2 - Fossil fuel CO_2 RCP and SRES annual emissions scenarios (observed 1980-2011 and projected 2012-2100)



Source: Own figure based on data by Nakicenovic and Swart (2000); Fujino et al. (2006); Smith and Wigley (2006); Clarke et al. (2007); Riahi et al. (2007); van Vuuren et al. (2007); Wise et al. (2009); Rogelj et al. (2012); IPCC (2013)
Note: Range of temperatures refer to likely (>66% probability) increases by the end of the century above pre-industrial levels.

Peters et al. (2013) indicate that observed emissions have exceeded the trajectories described by the majority of the highest IPCC scenarios included in all four generations. The expected pathway thus seems to be currently more in line with the RCP8.5 projection (Riahi et al., 2007), according to which the given radiative forcing could likely lead to an average rise of 3.8° to 5.7°C in global temperature by the end of the century with respect to pre-industrial levels (see Figure 2). This coincides with the A1F1 and A2 SRES scenarios, which are mainly characterised by fossil fuel-intensive economies, an increasing global population, heterogeneous levels of development and a slow introduction of more efficient technologies. Alternative trends are given by the RCP6.0 (Fujino et al., 2006) and RCP4.5 (Smith and Wigley, 2006; Clarke et al., 2007; Wise et al., 2009) pathways. The former is compatible with the A1B and B2 SRES scenarios, and foresees that emissions will peak until 2080, causing a likely expansion in mean temperature of 2.5° to 3.6°C. The latter, in turn, considers moderate rises in emissions until 2040, and increasing reductions from then on until flattening from the 2080s, leading to a climb in temperature of between 2.0° to 2.9°C. This trajectory is similar to the most ambitious SRES scenarios (i.e. A1T and B1), which reflect a world dominated by fast economic growth, with convergence in development levels across nations, decreasing population rates from mid-century and the complete substitution of fossil fuels by cleaner energy sources. Finally, the RCPs include a novel scenario that illustrates an emissions trajectory which is likely to keep the world below the 2°C threshold (Rogelj et al., 2012). It corresponds to a level of radiative forcing of between 2.6 and 3 Wm^{-2}, and is known as RCP3-PD (i.e. peak and decline), or RCP2.6 (van Vuuren et al., 2007). It considers that emissions will peak in 2020 and then will show a sustained decline until becoming negative from the 2070s onwards, which means that carbon would be absorbed from the atmosphere rather than emitted into it. The possibility of achieving negative emissions by means of the deployment of emerging technologies, such as carbon capture and storage (CCS), is still surrounded by large uncertainties in terms of their future feasibility and potential effects on natural and human systems (see: Szulczewski et al., 2012; UNEP, 2012). There are, nonetheless, other existing scenarios in the literature which suggest that it is possible to attain the same goal without negative emissions, but they basically consider either earlier peaking dates or more abrupt reduction rates (e.g. UNEP, 2012; van Vliet et al., 2012; Arnell et al., 2013). Attaining a 2°C future, moreover, depends strongly on implementing timely actions. Delaying mitigation measures implies achieving higher abatement rates in the future (Friedlingstein et al., 2011) and facing higher costs (Jakob et al., 2012).

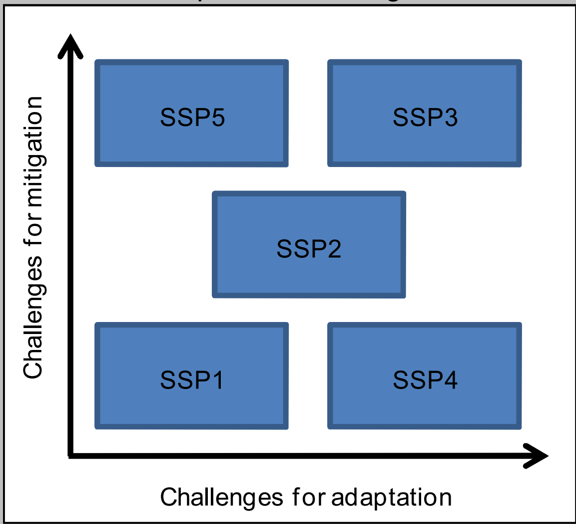
Table 2 - Narratives of Shared Socioeconomic Pathways

Scenario	**Storyline**			
	Economic growth	**Economic development**	**Population**	**Technology**
SSP1 Sustainability	Fast	Achievement of development goals	Peaks in mid-century	Rapid introduction of new technologies.
SSP2 Middle of the road	Intermediate	Development of low-income countries proceeds unevenly	Peaks around 2070s	Dependency on fossil fuels slowly decreases
SSP3 Fragmentation	Slow	Large number of countries struggle to maintain living standards	Increasing population	Slow introduction of more efficient technologies
SSP4 Inequality	Intermediate	Small, rich global elite and a large poor population	Peaks around 2070s	Mitigation efforts are low
SSP5 Conventional Development	Fast	Economic growth as the solution to social and economic problems	Peaks in mid-century	Energy system dominated by fossil fuels

Source: Own table based on O'Neill et al. (2012)

As has been said, the RCPs do not have socio-economic and technological storylines attached. The baseline storylines or narratives are known as *Shared Socioeconomic Pathways* (SSPs), and were developed in parallel by separate groups of researchers based on the RCPs (Kriegler et al., 2012; Rozenberg et al., 2012). They represent possible paths that human societies could follow over the next century. They are termed *shared*, as they are intended to be mutually useful to climate and integrated assessment modellers, as well as to the impacts, adaptation and vulnerability (IAV) community (van Vuuren et al., 2012). Furthermore, SSPs can be shared across multiple RCPs (Moss et al., 2010). In other words, each radiative-forcing trajectory is not associated with a unique SSP, but instead each can result from different combinations of social, economic and technological assumptions depicted in the SSPs. The characteristics of the five SSPs, as have been presented by O'Neill et al. (2012), are shown in Table 2. SSP1 describes a sustainable world that carries out ongoing efforts to achieve development goals, with population peaking at mid-century and the introduction of more efficient technologies, including the replacement of fossil fuels by cleaner energy options. SSP2 is labelled as a BAU scenario, portraying a world that continues along the existing trends, with some progress towards achieving development goals, with a slowly decline in the use of fossil fuels and uneven development, especially in low-income countries. SSP3 illustrates a fragmented world with increasing population and a large number of nations struggling to improve their development levels. SSP4 shows a similar world than SSP2, but more unequal, as the current wealth distribution among countries (i.e. small global elite against a large proportion of poor people) does not improve during the rest of the century. Finally, SSP5 presents a world that follows the existing development paradigm, in which economic growth is deemed as the solution to all social and economic problems and with an energy system largely predominated by fossil fuels. In addition, each SSP represents different challenges in terms of mitigation and adaptation efforts, as can be seen in Figure 3. The sustainable world of SSP1 involves the lower challenges in these areas, while the fragmented planet of SSP3 entails the greatest efforts.

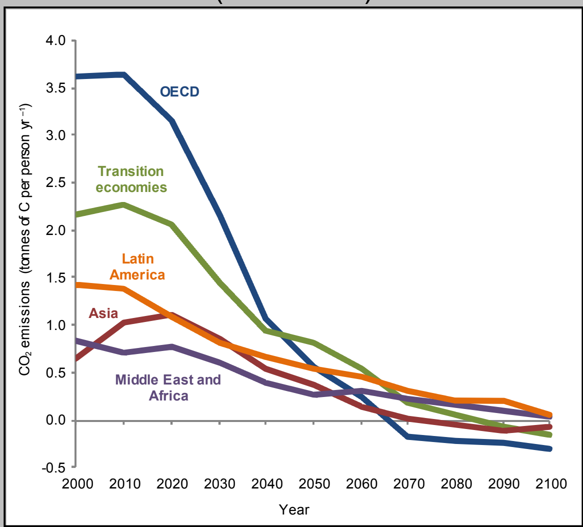
Figure 3 - SSPs according to mitigation and adaptation challenges



Source: Own figure based on Kriegler et al. (2012); Rozenberg et al. (2012)

The amount of available carbon space, understood as the global cumulative emissions consistent with the achievement of the 2°C target, is given by the RCP3-PD pathway. Its magnitude corresponds to the difference between the atmospheric CO_2 concentration present today of approximately 392 ppm (NOAA, 2012) and the 450 ppm mark, which according to this scenario would be met around 2050. The carbon space measured in per capita terms would depend on future population trends. If population figures from the most ambitious SSP are used (i.e. SSP1, with population peaking around mid-century), the largest amount of carbon space would proportionally correspond to the developed member countries of the Organisation for Economic Co-operation and Development (OECD), who are also the ones that need to undertake most urgently the deepest cuts (see Figure 4). Transition economies, which mostly include countries in Central and Eastern Europe and the Former Soviet Union, get the second biggest per capita shares. Smaller proportions correspond to the rest of the developing world. The Middle East and Africa would need to generate almost zero emissions by the end of the century, while Asian nations, mainly China and India, would require achieving negative per capita emissions from the 2080s. Obviously, the carbon space would increase in size for all country groups if different radiative-forcing pathways were chosen (i.e. 4.5, 6.0 or 8.5), but this could put the world at risk of suffering dangerous and uncertain climate impacts. The literature on climate scenarios, in this sense, is not explicit regarding the improvements in development that developing countries, and especially the poorest ones, could achieve with their shares of carbon space compatible with a 2°C future. This represents a gap in the knowledge base, which will be further discussed in section 2.1.3, where the specific literature focused on emissions and development will be reviewed. On the other hand, many of the most ambitious SRES scenarios and SSPs consider high rates of economic growth (i.e. A1T and SSP1) across the majority of countries as a driver of welfare and technological change. This would imply attaining an absolute decoupling between the growth rates of both emissions and income per capita. As will be explained in section 2.2.3, this decoupling has not been yet achieved and significant efforts are required to make it happen.

Figure 4 - RCP3-PD annual per capita emissions pathway according to country group using SSP1 population projections (2000-2100)



Source: Own figure based on data by van Vuuren et al. (2007); IIASA (2012)

2.1.2. The development space

Despite its widespread use, defining the concept of *development* from a socio-economic viewpoint is a contentious issue (Chang, 2011). Its meaning has transformed over the years and there is not a unanimous definition for it. If the word development is understood as "*a specified state of growth or advancement*", according to the Oxford English Dictionary (Stevenson and Waite, 2011), then in basic terms *socio-economic development* refers to a state of expansion or betterment of an economy and its society. The term *economic development* as such, implicitly encompassing a social dimension, started to be utilised in the beginning of the twentieth century. Since then, it has been strongly associated with the notions of progress, wealth, growth and well-being.

In his *Theory of Economic Development*, Schumpeter (1934) viewed the concept as a dynamic and cyclic process, in which innovations play a fundamental role. In the absence of innovative activities, economies tend to stagnate. However, thanks to entrepreneurs, who bring fresh ideas, old practices are destroyed and replaced by new and more efficient ones. This process, known as *creative destruction*, leads to improvements in productivity and an expansion of the economy. During the 1950s, this conception was transformed and economic development started to be more associated with the notion of *structural change*. This is reflected in the linear-stages-of-growth and structural-change theories that appeared in that decade. In basic terms, these theories state that all economies must pass through several stages in a linear progression. Rostow (1959) developed one of the most characteristic models among the linear-stages theory. It describes the transformation of an economy from being a traditional society to then *take-off* and drive to maturity, finally entering into an age of mass consumption. Structural-change theorists (e.g. Lewis, 1954; Chenery, 1960) similarly argued that economies must progress from being primarily agricultural and focused on resource extraction to later become industrialised and then to develop a tertiary sector (i.e. services). In this sense, when an agrarian economy generates a large economic surplus, it can shift labour and capital to spur the creation of more productive industrial activities. The production frontier of the economy thus expands, increasing the value of production which, in turn, leads to employment generation and higher income per capita levels. Industries start demanding a wide array of services, which stimulates the formation of a tertiary sector. The production possibilities of the economy expand even further, generating more value added per capita, replacing low-productivity activities by a process of creative destruction, and leading to an efficient rearrangement of the factors of production (i.e. land, labour, and physical capital). Simon Kuznets argued that structural change constitutes a central feature of the process of development (see: Syrquin, 2010), which is reflected in his original formulation of the inverted-U income-inequality hypothesis (Kuznets, 1955). He stated that while societies increase their income per capita along the industrialisation process, income inequality tends to improve. However, this hypothesis has been refuted (see: Deininger and Squire, 1998; Wilkinson and Pickett, 2010; Palma, 2011).

As can be seen, not only the meaning of economic development has suffered several transformations over the years, but also the ways in which nations could successfully attain it (see: Lin and Rosenblatt, 2012). Currently, several definitions of the concept can be found, but the idea of structural transformation is still embedded in many of them. Black et al. (2009) define the concept as "*an economic transformation of a* *country or a region that leads to the improvement of the well-being and economic capabilities of its residents*". According to Park (2007), it is "*the process of raising the level of prosperity and material wealth in a society through increasing the productivity and efficiency of its economy, particularly through an increase in industrial production*". The World Bank has defined it as the "*qualitative change and restructuring in a country's economy in connection with technological and social progress..., reflecting an increase in the economic productivity and average material well-being of a country's population*" (Soubbotina, 2004, p.133).

The World Bank proposes that the main indicator of economic development is GDP per capita (ibid.). However, it has been recognised that the concept envelops much more than just an acceleration of economic growth (see: Todaro and Smith, 2011). For Amartya Sen (1987), development is a multi-dimensional process that involves major economic and social changes oriented towards the enhancement of human *capabilities*. According to this perspective, the quality of a person's life or his/her well-being is subject to a combination of what he/she can do or be, which Sen calls *functionings*, and the freedom to choose among these options, which the author labels as *capabilities*. In this sense, income and wealth should not be treated as ends in themselves, but rather as means to obtain other goals. People should enjoy access to some minimum requirements, such as acceptable material living standards, health services, education, decent work, a clean environment, among other factors, in order to have the capability to function adequately. Development, consequently, is not only a matter of transforming the material structure of an economy, but it also possesses an important *humanistic* dimension.

Influenced by Sen's ideas, the concept of *human development* started gaining prominence in the late 1980s. This was reflected in the launch of the *Human Development Report* in 1990 by the UNDP. In that report, it was acknowledged that while economic growth is necessary to meet essential human needs, it is equally vital to translate this material expansion into increasing human capabilities. The UNDP thus defines human development as "*a process of enlarging people's choices..., [of which] the three essential ones are for people to lead a long and healthy life, to acquire knowledge and to have access to resources needed for a decent standard of living*" (UNDP, 1990, p. 10). The report was accompanied by series of key indicators, summarised in the so-called *Human Development Index* (HDI), to measure and monitor the progress across different nations (Anand and Sen, 1994a). Income per capita represents a component of the index, along with life expectancy and the observed and expected years of schooling (Klugman et al., 2011)[5]. Since then, the index has been published annually, enjoying an increasing and widespread use. It has also received a number of criticisms, among which are, for example, its narrow focus (i.e. limited amount of variables), not including environmental matters, the component's weightings, and not considering the problem of inequality (see: McGillivray, 1991; Trabold-Nübler, 1991; Lind, 1992; Nübler, 1995; Sagar and Najam, 1998; Chakravarty, 2011; Ravallion, 2012). Some of these issues have been taken into account, and the methodology has thus suffered slight changes over the years. An inequality-adjusted index and a gender inequality index, for instance, have been made available by the UNDP.

The notion of human development complemented the appearance of another concept that attracted attention in policy and academic circles (Anand and Sen, 1994b). In 1987, the UN's World Commission on Environment and Development, known as the Brundtland Commission in honour of its chairman, coined the term *sustainable development*. Its significance, expressed by the famous Brundtland definition, lies in the necessity of meeting "*the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987). In this sense, it places a special emphasis on inter-generational equity. The concept additionally highlights the economic and social dimensions, as well as the natural environment, as the main pillars of development. Improving development in the present should not be done at the expense of the well-being of future generations. Since its creation, sustainable development has represented another much contested term, not only in relation to formulating a more precise definition for it, but also in the ways of achieving it (see: Barbier, 1987; Lélé, 1991; Pezzey, 1997; Fergus and Rowney, 2005; Kates et al., 2005; Sneddon et al., 2006).

The human and environmental dimensions of development were acknowledged in the establishment of the Millennium Development Goals (MDGs), following the adoption of the United Nations Millennium Declaration in the year 2000. All the member states agreed to achieve eight essential goals by 2015, each including individual targets (see Table 3). The UN (2012a) has reported that the progress in achieving the goals has been uneven. Whereas important improvements have been made towards some of them, other targets are still lagging behind. The same occurs in geographical terms, where some regions are advancing more rapidly than others. In relation to extreme-

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[5] See Appendix B.1.2 for a more detailed explanation about the methodology to calculate the HDI.

poverty reduction, the UN has announced that the first goal has been met. The proportion of the total people living on less than $1.25 dollars a day fell from 47% in 1990 to 24% in 2008 (ibid.). However, the target has still not been reached in Sub-Saharan Africa and Southern Asia, where reductions amounted to approximately 9% and 17%, respectively. There is, moreover, a lack of progress in combating hunger. The fraction of people who are undernourished has just decreased by about 4.5%. In contrast, the proportion of people with access to improved water sources almost doubled between 1990 and 2010. On the other hand, primary school enrolment registered an important rise from 82% to 90% between 1999 and 2010, but improvements have slowed down since 2004. Furthermore, gender parity has been achieved in access to primary education, even though some regions are still falling behind, such as Western Asia and Northern and Sub-Saharan Africa. Reducing child mortality has been slow, although considerable declines have been attained in several regions. Similar improvements have been achieved in maternal mortality, which has nearly halved. The spread of HIV is slowly decreasing, but access to treatment has expanded significantly. In relation to the environment, deforestation rates have shown small drops and are far from being reversed. Moreover, almost half of the world's most important areas for species conservation are unprotected. Regarding the last goal, which considers establishing an international development framework, indicators show that official development assistance (ODA) has fallen in real terms, since donor countries have still not recovered from the 2008/09 financial crisis. However, developed nations have continued giving preferential treatment in trade to LDCs by granting duty-free treatment to a considerable proportion of their imports (see: McQueen, 2002; McDonald et al., 2010).

Table 3 - The Millennium Development Goals

Goal	Description
1	*Eradicate extreme poverty and hunger.* Illustrative target: Halve, between 1990 and 2015, the proportion of people whose income is less than $1.25 a day.
2	*Achieve universal primary education.* Illustrative target: Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling.
3	*Promote gender equality and empower women.* Illustrative target: Eliminate gender disparity in primary and secondary education, preferably by 2005, and in all levels of education no later than 2015.
4	*Reduce child mortality.* Illustrative target: Reduce by two thirds, between 1990 and 2015, the under-five mortality rate.
5	*Improve maternal health* Illustrative target: Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio.
6	*Combat HIV/AIDS, malaria and other diseases* Illustrative target: Have halted by 2015 and begun to reverse the spread of HIV/AIDS, malaria and other diseases.
7	*Ensure environmental sustainability* Illustrative target: Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources.
8	*Develop a global partnership for development* Illustrative target: Develop an open, rule-based, predictable, non-discriminatory trading and financial system, and dealing comprehensively with developing countries' debt.

Source: Own table based on UN (2012a)

The MDGs have received several criticisms since their implementation. Some of the most relevant ones relate to the choices made in setting them, as they draw the spotlight on the selected topics, while shifting the development agenda away from other no less significant issues and thus reducing their support (e.g. civil and political rights, income disparity within countries, global environmental problems, etc.). Furthermore, the MDGs understate the importance of addressing the root causes of the problems (e.g. institutional, political, cultural, etc.) (see: Harcourt, 2005; Saith, 2006; Nelson, 2007). Other critiques are centred on their top-down approach and the heavy influence wealthy nations and international organisations had on setting the goals, while the most afflicted states played a limited role in determining their own priorities (see: Bissio, 2003; Amin, 2006; Bond, 2006). In addition, the difficulty to measure the progress of some targets, due to inadequate methodologies and indicators (see: Easterly, 2009; Fukuda-Parr et al., 2013) and data reliability and availability (e.g. Satterthwaite, 2003; Attaran, 2006), has been highlighted as a serious drawback. In relation to the last goal, authors like Gore (2003) and Khor (2003) state that the proposed development framework will be insufficient to pull many nations out of their poverty traps. They argue that more aid and debt relief is required, as well as resolving the asymmetries in international trade policies. Moreover, there is a widespread concern that many targets will not be achieved and that they must be replaced by a set of revised and more complete goals (see: Manning, 2010; Chibba, 2011; Clarke and Feeny, 2011; Webster, 2012). For example, Clemens et al. (2007) have suggested that beyond 2015 the targets should be country-specific and take into account the historical performance of each nation. This would be analogous to the way in which emissions targets are established. Sachs (2012) and Griggs et al. (2013), on the other hand, favour the implementation of a set of *Sustainable Development Goals* (SDGs), which constitute an important outcome of the UN Rio+20 Conference (UN, 2012b). Griggs and colleagues argue that the protection of the planet's life-support systems and poverty reduction must be the two leading priorities.

Despite the criticisms made to the MDGs and the uneven progress that has been attained so far, they embody an unprecedented global consensus to reduce poverty. In addition, they have contributed to enhancing advocacy and aid flows, as well as promoting the design of adequate indicators to monitor development projects (Waage et al., 2010). Moreover, noteworthy improvements in development have been achieved in the developing world. These advances have been highlighted by the UNDP (2013, p. iv). Its latest report asserts that over the last decade, all developing countries "*accelerated their achievements in the education, health, and income dimensions as measured in the HDI*". For example, the expected years of schooling in nations with the lowest levels of human development rose on average by 70% between 1990 and 2012, going from 5 to 8.5 years. Moreover, the mean number of years of education received by people aged 25 and older grew by 75%, increasing from 2.4 years in 1990 to 4.2 years in 2012. However, the gap with respect to the highest human-developed countries is still large, as an average student in this latter group was expected to complete 16.3 years of education in 2012, while an adult had received on average 11.5 years of schooling in that same year. In terms of life expectancy at birth, it went up from 52.4 years in 1990 to 59.1 in 2012 in low-developed nations, whereas a person in industrialised countries was expected to live on average 80.1 years in 2012 (UNDP, 2013). Regarding gross national income (GNI) per capita, significant growth rates were registered especially in the big emerging economies, like China, India and Indonesia. In China, for instance, where income per capita grew approximately 9.5% on an annual basis from 1980 to 2012, there are 600 million fewer people living under $1.25 per day (Chen and Ravallion, 2012). GNI per capita has also grown in other regions, like in Sub-Saharan Africa, where it expanded by about 5% a year from 2003 to 2008, more than twice the rate of the 1990s (UNDP, 2013).

The UNDP classifies nations according to the HDI quartile they belong to. The quartiles are thus labelled as very-high-, high-, medium-, and low-human-development countries[6]. The very-high-human-development nations include all the wealthiest industrialised nations, whereas the low-development group encompasses the majority of the LDCs. The World Bank, on the other hand, groups nations according to GNI per capita, resulting in low-income ($1,025 dollars or less per annum), lower-middle-income ($1,026 to $4,035), upper-middle-income ($4,036 to $12,475) and high-income economies ($12,476 or more)[7]. There are still significant disparities in development levels across these groups. The average HDI score for the low-human-development nations in 2012 (i.e. 0.46) was almost half than that of the topmost group (0.90), while that of the medium-development countries (i.e. 0.64) was almost one third smaller (UNDP, 2013). In terms of geo-political regions, the average HDI score in Middle East and Africa was approximately half than that of the industrialised OECD economies in 2012 (see Figure 5, which shows the same country groupings as those used in SSPs). Asian developing countries, including China, registered a mean annual growth rate of 1.1% in their HDI scores from 1980 to 2012, but are still behind Latin America. Transition economies, on the other hand, possess the second largest scores. These country rankings are similar to those of annual per capita emissions (see Figure 4), which reflects the close relationship between emissions and development. This issue will be discussed more extensively in the following section.

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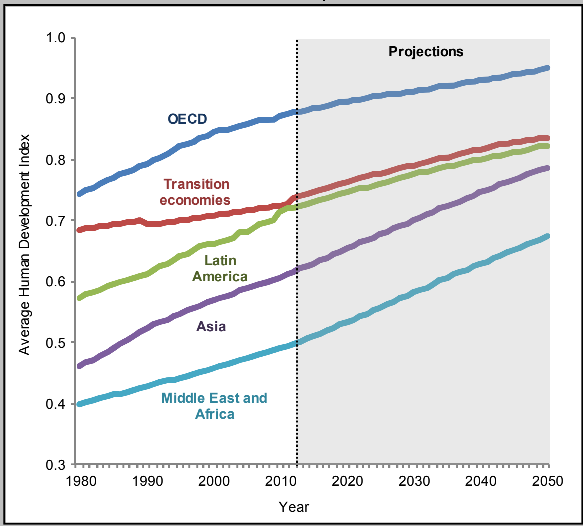
[6] A list of the countries that comprise each of the UNDP and World Bank classifications can be found in Appendices A.1.2 and A.1.3.

[7] The World Bank uses the Atlas method. It entails applying a conversion factor to reduce the impact of exchange rate fluctuations in the cross-country comparison of national incomes, which have all been converted to US dollars (see: http://data.worldbank.org/about/country-classifications/world-bank-atlas-method).

Figure 5 - Human development pathways by country group according to BAU scenario, observed (1980-2012) and projected (2013-2050)



Source: Own figure based on data by the PCIF (2013) and UNDP (2013)

Disparities are not only present between countries, but also within them. Growing inequality rates have been registered in the last decade among both developed and developing nations. The latest Human Development Report (UNDP, 2013) argues that inequality is negatively correlated with human development, threatening further improvements. The report states that almost a quarter of the HDI is lost to income inequality. Low-human-development countries are affected the most, since they tend to possess greater inequality across all dimensions (i.e. income, education and health). Latin America is overall the most unequal region, followed by Africa, with the highest inequality in health, and South Asia, with the highest inequality in education.

From what has been presented, it is clear that humanity faces the enormous challenge of improving the well-being of the people in the planet. The amount of development that still needs to be fulfilled, or the *necessary development space*, is still considerable. Two future human development pathways were developed for the UNDP (2013) report by the Pardee Centre for International Futures (PCIF, 2013), based on an integrated global model. One is a BAU scenario in which historical trends continue into the future, pursuing current development policies. The second one is an accelerated progress scenario, which assumes aggressive policy interventions to reduce poverty, enhance infrastructure, and improve governance. Some of the selected measures are increasing foreign aid, escalating renewable energy production by 50%, and expanding health spending. Figure 5 shows the BAU pathways. The regions that achieve the greater improvements are the Middle East and Africa, whose HDI scores grow by approximately 35% from 2012 to 2050, attaining a level similar to that of the current medium-human-development group. The regions that follow are Asia (28%), Latin America (14%) and the economies in transition (13.7%) (PCIF, 2013). Under the accelerated progress scenario (not shown in the figure), the improvements are larger. Middle East and Africa accomplish a 54% increase, including a rise of 52% in Sub-Saharan Africa and 36% in South Asia (UNDP, 2013). HDI in Latin America expands 22%, enjoying a level of development comparable with today's very-high-development group. Regarding wealthy nations, their HDI improves as well, increasing around 8% in the BAU case and almost 12% in the accelerated scenario (PCIF, 2013).

It is uncertain, however, if these projections are compatible with a 2°C future. Understanding if these development levels can be attained with the remaining carbon budget still requires further study. UNEP (2011) undertook one of the few studies in this respect by developing a set of scenarios for its Green Economy Report based on the *Threshold 21 (T21) World* model created by the Millennium Institute (see: Bassi, 2008). By assuming annual investments of 1% and 2% of global GDP in green investments, similar to those suggested by Stern (2007), the model estimated average global improvements in HDI of about 16% and 19%, respectively, by 2050. These average HDI-scores are, in turn, associated with CO_2 emissions of 3.3 and 2.2 tonnes per capita, which overly exceed the 2°C pathway as depicted by the RCP3-PD scenario (see Figure 4). These levels of per capita emissions are more in line with atmospheric concentrations in the range of 500 to 600 ppm, which are likely to lead to increases in average global temperature beyond 3°C by the end of the century. UNEP (2011) does not offer disaggregated data at a national level, but its model projections show that more ambitious improvements in human development in developing economies might be difficult to attain given the available carbon space. If it is assumed that the required increases in income per capita in poor nations will be associated with growing material consumption and pollution, then it would be necessary to achieve unprecedented levels of decoupling.

There is the need to develop alternative and more complete development strategies that can guarantee a transition to a low-material, low carbon and high-development future. Nevertheless, as argued by Chang (2011), the mechanisms to attain the kind of development that the world needs have been absent from the development discourse during the past couple of decades. This author, along with others like Cornwall and Brock (2005) and Craig and Porter (2006), have asserted that development has come to be understood more as poverty reduction or provision of basic needs, as reflected in the MDGs. However, development is much more than reducing the number of poor people (Ocampo, 2002). The concerns of the development economists of the pre-1980s have been displaced to some extent. The notion of transforming the productive structure, as a way to enhance social, economic and technological capabilities and to ultimately enhance and sustain the well-being of the societies across the planet, is not explicit in the global policy agenda. The only reference to a global development framework is included in the eighth MDG, which makes an emphasis on aid, debt reduction and international trade. Chang (2011) argues that the first two represent enabling factors to initiate a process of development, while relying on trade is a necessary but not sufficient condition to attain sustainable development (more on this topic will be discussed in later sections). The question is then how to develop strategies to address the dual climate-development challenge.

2.1.3. Linking the carbon and development spaces

As was explained in the previous sections, there is a reciprocal relationship between climate change and development (IPCC, 2007b). Climate variability affects the basis for economic and human development, while economic and social decisions determine the generation of GHG emissions and the adaptability of societies to a changing climate. However, the linkages between these two concepts have not been always fully acknowledged in policy and research circles. During several decades, both were usually framed as separate discourses (Beg et al., 2002; Michaelis, 2003; Swart et al., 2003; Robinson et al., 2006; Bizikova et al., 2007; Kok et al., 2008; Melamed et al., 2012). One of the consequences, as noted by Cohen et al. (1998), is reflected in the differences between the scenarios developed by climate and development modellers, who often tend to work independently of each other. The first three generations of IPCC scenarios rely strongly on physical science and focus mainly on exploring different variations of the BAU pathway by adopting different assumptions in relation to the forces that drive emissions, especially concerning technological change, population and income per capita growth (Rosa and Dietz, 2012). The Fourth Assessment Report (IPCC, 2007b) made an effort to recognise the mutual reinforcing nature of sustainable development and climate change policies. However, the trade-offs between emission reductions and increasing human welfare across its different dimensions or the lock-in due to existing infrastructure do not appear explicitly in the SA90, IS92, as well as the SRES scenarios. They are limited to the notion that emissions can be absolutely or relatively decoupled from higher levels of income per capita which, in turn, are associated with higher levels of well-being. The creation of RCPs and SSPs seeks to improve this situation by integrating the views from different research communities (i.e. climate, integrated assessment modellers and IAV), although the development community has still not been fully taken into account. On the other hand, human development scenarios like the T21 projections presented by UNEP (2011) and the ones made by the PCIF (2013), as described in the previous section, do not explain clearly if higher levels of human development can be compatible with a low-risk-climate future. Another consequence of the dissociation between climate and development has been evident in the global policy arena (Kok et al., 2008). The MDGs, for instance, do not incorporate explicit measures in relation to climate change. The seventh goal broadly seeks to integrate the principles of sustainable development into country policies, but without making a direct reference to mitigation or adaptation actions (Urban, 2010). This issue, however, has been changing in recent years as there has been an increasing acknowledgement of the linkages between climate change and development. The Nationally Appropriate Mitigation Actions (NAMAs), prepared by developing states in accordance to the UNFCCC agreements, involve the use of mitigation options in the context of sustainable development. Nonetheless, the climate-development strategies proposed by countries have been limited to the inclusion of CDM and REDD projects, making no references to additional climate-development schemes oriented toward economic restructuring and the enhancement of human well-being (Olsen et al., 2009; UNFCCC, 2011a). The National Adaptation Programmes of Action (NAPAs), on the other hand, place a stronger focus on the nexus between development and adaptation, which has been widely recognised by the scientific community (e.g. Huq and Reid, 2004; Huq et al., 2004; IPCC, 2007a; Lemos et al., 2007; Wilby et al., 2009). Reducing the vulnerability and strengthening the adaptive capacities of developing nations, and particularly of LDCs, is fundamentally linked to development efforts. However, much work is still required to properly align and integrate climate change actions into sustainable development policies at a national level, so as to conceive comprehensive climate compatible development strategies (Pan, 2004; Bruggink, 2012; Linnér et al., 2012; Román et al., 2012). These are defined by Mitchell and Maxwell (2010, p. 1) as those that "*minimise the harm caused by climate impacts, while maximising the many human development opportunities presented by a low emissions, more resilient, future*".

Sustainable development, in this sense, involves realising the necessary development space within the limits of the available carbon space. Baer et al. (2009), Kartha et al. (2009), Kartha et al. (2010) and Khor (2010) argue that a solution to climate change should not be achieved at the expense of reducing the development opportunities of developing countries. These authors thus assert that it is vital to ensure an equitable sharing of both the development and carbon spaces based on a set of rights and responsibilities. They argue that industrialised nations hold a historical ecological debt, being responsible for emitting into the atmosphere about 7.5 out of every 10 tonnes of CO_2 since the beginning of the industrial era (Goldemberg, 1995; Raupach et al., 2007; Wei et al., 2012). In contrast, developing countries have often expressed in international policy forums that they have contributed the less to global warming and are the ones who need to increase the most their development levels. Khor (2010) has calculated in rough terms the carbon debt owed by industrialised economies, which he estimated in the following way. Total cumulative emissions emitted into the atmosphere from 1850 to 2008 amount to around 1214 Gt, of which industrialised countries were responsible for about 72%, corresponding to 874 Gt. Khor argues that if these emissions were proportionally distributed according to population shares, then rich nations would have been duly responsible for about 304 Gt of the observed emissions, since they housed on average 25% of the world population during this period (i.e. 1214*0.25). This means that their carbon debt amounts to approximately 570 Gt of CO_2 emissions (i.e. 874 minus 304), almost twice their proportional fair share. On the other hand, according to Khor, the carbon budget compatible with a 2°C target comprises around 750 Gt of cumulative CO_2 emissions for 2010 to 2050. By allocating this space again according to population shares, industrialised nations would possess around 120 Gt of available carbon space, given that they will house on average 16% of the world population during this second period (i.e. 120*0.16). This leaves developing countries with around 630 Gt. However, by taking into account the carbon debt, the carbon budget available to rich nations would actually become negative (i.e. 120-570=-450 Gt), increasing the carbon space for the rest of the world (i.e. 630+570=1200 Gt). Khor’s mechanism for the fair allocation of the available carbon space may be too simplistic and not realistic in practice, but it illustrates the magnitude of the challenge and highlights its ethical implications. Moreover, it stresses the historical responsibility of industrialised nations and the rights of the developing world, and specifically the poorest countries, to have an equal access to sustainable development opportunities without having to carry an excessive burden of mitigations costs. This constitutes the basis of what Baer et al. (2009) and Kartha et al. (2009) have called the *Greenhouse Development Rights Framework*. According to this scheme, countries with an average income per capita below a threshold of approximately $16 to $20 US dollars per day ($5,840 to $7,300 per annum) would not be expected to bear mitigation costs and should be assigned a larger share of the carbon space. According to the World Bank classification, this would include all low- and lower-middle-income economies, as well as some upper-middle-income. The rest of the nations would thus carry the burden of absorbing all the mitigation costs and would support the poorest countries by providing them with financial resources, technology transfer and capacity building. Chakravarty et al. (2009) propose a similar framework, but instead of using an income threshold, they put forward a floor of one tonne of CO_2 per capita per year. Individuals below this floor, the lowest one-third of the world's emitters, would be exempt from taking up mitigation costs.

It can prove difficult to mainstream the ideas proposed by Khor, Baer, Khartha, Chakravarty and colleagues into the global climate policy agenda beyond the UN working principle of *common but differentiated responsibilities*, which recognises that climate change is a common problem to all nations, but not all of them should contribute equally to its solution (see: Stone, 2004). However, their ideas represent the few examples in the literature that deal with the equitable use and sharing of the carbon and development spaces. There is thus the need to analyse more profoundly to what extent human development can be enhanced with the available carbon space. This constitutes an important gap in the existing knowledge base, which this thesis seeks to address.

Few studies have focused on the links between indicators of living standards and CO_2 emissions or energy consumption. It has been widely acknowledged that energy requirements increase with economic development. Industrialised economies use more energy per unit of GDP and also in per capita terms than poorer nations (Schurr, 1984; Medlock III and Soligo, 2001; Toman and Jemelkova, 2003; Fischer-Kowalski and Haberl, 2007; Haberl et al., 2011). Some of the first authors to analyse how the quality of life is affected by changes in energy use were Mazur and Rosa (1974). They noted that economic indicators show a high correlation with energy consumption, but lifestyle indicators are not. Hence, they asserted that the US could reduce its energy use without deteriorating health and education levels in the population. Goldemberg et al. (1985) suggested that human basic needs can be properly covered with around one kilowatt per capita of primary energy. Alam et al. (1991) and Alam et al. (1998) consider that the relationship between electrical energy consumption and quality of life, which they define as being a function of life expectancy, infant mortality and literacy rates, follows an asymptotic curve. Quality of life improves rapidly at low levels of energy consumption, until flattening and showing diminishing returns at high levels. Suárez (1995) obtained similar findings, showing that energy consumption per capita helps to elevate the HDI in low-human-developed nations, but it does not contribute to improve quality of life, or can even deteriorate it, in industrialised economies. Rosa (1997) estimates that there have been decoupling patterns between CO_2 emissions and societal well-being since the 1970s in wealthy countries, suggesting that reductions in fossil-fuel use are not necessarily associated with impacts to quality of life. Pasternak (2000) found that HDI tends to level out at an average level of electricity use of 4,000 kilowatt-hour (kWh), which is below the consumption levels of most developed nations. Dias et al. (2006) show that it would be possible to reduce energy per capita in OECD countries around 30% with no significant losses in quality of life. Martínez and Ebenhack (2008) assert that improvements in human development are attainable for the less developed nations with small incremental access to energy. Spreng (2005) believes that a threshold of two kilowatts per capita, which is comparable to Chakravarty's floor of one tonne of CO_2 per capita, is enough to ensure the sustainable development of the planet. This basically follows the reasoning of the *contraction and convergence* approach, put forward by the Global Commons Institute, which suggests that CO_2 emissions per capita across countries should converge over time to a level below one tonne per capita to achieve the 450 ppm target (Meyer, 1999). More recently, Steinberger and Roberts (2010) have established the existence of a gradual decoupling between the satisfaction of human needs and energy and carbon per capita. By conducting a longitudinal analysis from 1975 to 2005, they found that the energy and carbon thresholds required to satisfy human needs are decreasing over time. According to their estimations, thresholds of around 0.25 and 0.7 tonnes of carbon by 2030 can ensure global high human development standards in relation to life expectancy and HDI, respectively. In a separate study, Steinberger et al. (2012) focus on the differences between consumption-based and territorial emissions (defined in section 2.2.2 of this chapter) with respect to human development. They show that emissions corrected for trade correlate better with human development indicators, evidencing their appropriateness to be used in this kind of analyses. Moreover, they affirm that carbon-importing countries (i.e. mostly industrialised economies) receive more development benefits than their counterparts. Additionally, they elucidate that high income per capita levels above $12,000 US dollars per annum (i.e. high-income economies) are not compatible with low carbon emissions, whereas high life expectancies are possible to attain at those levels. Costa et al. (2011), on the other hand, propose a framework to maintain global emissions below a safe level. They suggest that 300 Gt of CO_2 are necessary to raise a considerable amount of developing countries beyond an HDI score of 0.8 in 2050, but developed countries require curbing their per capita emissions by 17% to 33% every five years.

The possibility of enhancing human development within the confines of the available carbon space and achieving some of the proposed thresholds presented in the above paragraph require the undertaking of significant structural change across industrialised and developing economies. However, as declared by Chang (2011), new development strategies are needed to make the transition to a low-carbon, high-developed, global economy. One of such proposed strategies is China's *Circular Economy*, inspired by the notion of *loop-closing* emphasised by German and Swedish environmental policies (Yuan et al., 2006; Mathews and Tan, 2011). Basically, the scheme contemplates a goal of doubling the country's efficiency of resource utilisation by 2020 (Zhu and Wu, 2011), and raising the majority of China's population into a *well-being society*. This approach rests upon the *3R* principle: *reduce* the consumption of energy and resources, as well as pollutants and waste, *reuse* products and resources, and *recycle* used goods and by-products. More recently, Liu et al. (2013) have suggested a similar approach based on recycling, using more renewable energy sources and reinvigorating the domestic energy market to reduce China's carbon intensity around 55% to 60% by 2020 compared to 2005.

Another strategy is embodied in the renowned and closely related notions of the *Green Economy* and *Green Growth*, which have served to mainstream the close relationship between the environment and economic development into the international policy discourse. The former was widely advocated in the UN Rio+20 Conference, and has its origins in the book titled *Blueprint for a Green Economy* by Pearce et al. (1989). According to UNEP (2011, p. 16), a green economy is the "*one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In its simplest expression, a green economy is low-carbon, resource efficient, and socially inclusive*". The OECD (2011, p. 9) states that green growth "*means fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies*". UNEP (2011) recognises the twin challenge of preserving the environment while enhancing human development, which is to be achieved by heavy investments in resource efficiency, emission and pollution reductions and poverty eradication. The proposed enabling conditions to attain a green economy consist of national regulations, policies, subsidies and incentives, market and legal infrastructure, trade and technical assistance. Apart from these, the OECD (2011) places a significant emphasis on innovation and technological change as key enablers of green growth. The proponents of the concepts of green economy and green growth schemes, however, do not consider them as replacements to sustainable development. UNEP

(2011, p. 17) believes that the notion of a green economy is valuable as it focus the attention on "*getting the economy right*" as a condition to achieve sustainable development. The OECD (2011, p. 11), on the other hand, perceive green growth as being narrower in scope than sustainable development, "*entailing an operational policy agenda that can help achieve concrete, measurable progress at the interface between the economy and the environment*". Nonetheless, there have been some critical views about these two concepts. Zysman and Huberty (2011) consider that they reflect good intentions, but that the specifics to attain them have not been sufficiently discussed. Verzola and Quintos (2011) and Dercon (2012) believe that their objective of offering a rapid route out of poverty is not very plausible, since they do not properly address the root causes of poverty and underdevelopment. As expressed by the former authors, by focusing too narrowly on "*getting the economy right, proponents of the green economy and green growth end up getting development wrong*". Khor (2011) warns about the risks of not fully considering the development and equity dimensions. He argues that viewing the concepts in a one-dimensional way and treating them as a *one-size-fits-all* approach can lead to negative outcomes. Moreover, Hoffmann (2011) believe that these concepts are insufficient to deal with the challenge of climate change, as they do not envelop measures to deal with population expansion, global inequality, as well as cultural and governance constraints.

More recently, UNCTAD (2012) proposed the concept of *sustainable structural transformation* as a development strategy. It is based on the decoupling of resource use and environmental impact from the growth process, while achieving significant improvements in human well-being. It emphasises the importance of assuming a structuralist stance in the development discourse and recognises the role of structural change as a necessary condition to replace traditional production structures with more resource-efficient and low-carbon economic activities, as well as to reallocate the factors of production and improve the distributive mechanisms in the process of growth (Ocampo, 2011). This strategy is useful to operationalise the concept of the *green economy* and applies particularly to developing nations, and more specifically to LDCs, whose priority is to achieve higher and persistent rates of economic growth that can deliver greater and more broad-based improvements in human well-being without pursuing the traditional industrialisation pathways followed by wealthy economies. Implementing sustainable structural transformation relies mainly on significant investment rates, technology transfer, a robust framework for international support including fair trade rules and the role of a strong developmental state. More work is still required to operationalise the framework of *sustainable structural transformation* and develop the specifics to implement it successfully. Nevertheless, its validity and usefulness have been recognised in academic circles (see: Swilling, 2013), while the G77, the largest intergovernmental organisation of developing countries in the UN, has manifested its interest in fostering research in the area (G77, 2012).

2.2. The role of consumption in development and climate change

2.2.1. Consumption and development

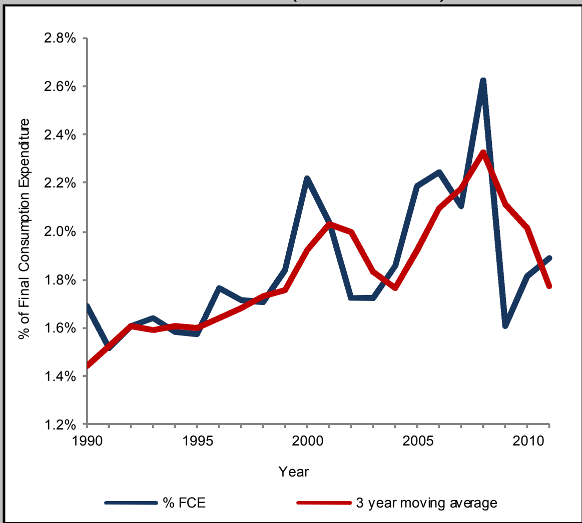
Despite its everyday use, the term *consumption* is open to several interpretations (Princen, 1999). Different schools in economics have defined it in various manners. According to neoclassical economics, consumption refers to "*the final use of goods and services by economic agents to satisfy their needs*" (Black et al., 2009). This connotation is congruent with the system of national accounts, which considers consumption as solely constituting final demand (i.e. final expenditure) of domestic and imported goods and services by households and government. Intermediate purchases by industries are not included to avoid double counting, while private and public investment in fixed (i.e. physical) capital is considered as a separate component of GDP. However, other schools, like ecological economics, question this view as it ignores the linkages between the economic and biophysical systems. Hence, it adopts a wider standpoint. Consumption thus not only entails the final use of goods and services, but also involves the entire stages in their life-cycles, from the extraction of materials and generation of energy to the waste and by-products derived from their production and use (Røpke and Reisch, 2004). This conception is related to the idea of the physical *throughput* of the economy (Boulding, 1966), rooted in the principles of thermodynamics (Georgescu-Roegen, 1971). According to these principles, materials and energy are neither created nor destroyed, but just transformed (i.e. first law of thermodynamics), while systems constantly evolve from low entropy (i.e. disordered) states to high entropy states (i.e. second law). Daly and Farley (2004, p. 29) describe throughput as "*the flow of raw materials and energy from the global ecosystem's sources of low entropy (mines, wells, fisheries, croplands), through the economy, and back to the global ecosystem's sinks for high-entropy wastes (atmosphere, oceans, dumps)*". Moreover, other even broader notions of consumption additionally take into account those amenities and non-use values pertaining to the environment that cannot be exchanged in markets and that deliver benefits to people (e.g. scenery, wildlife, clean air) (Myers et al., 1997; Frey et al., 2004).

Consumption plays a key role in the development process, but this role varies according to how consumption is theoretically conceived. From a neoclassical perspective, social welfare is a function of the utility that individuals obtain by consuming goods and services. Utility in this context is understood as a measure of a society's or an individual's sense of benefit, satisfaction or contentment derived from the use of a certain good or service (Black et al., 2009). In turn, the amount of goods and services that an individual consumes is a function of affluence or personal income (see: Flavin, 1981; Campbell and Mankiw, 1991). Following this line of reasoning, if income is associated with consumption and the latter is closely related to utility and welfare, income should consequently be maximised. A nation's level of development, in this sense, is determined by the level of income per capita of its inhabitants, as is considered by the World Bank (see section 2.1.2). However, utility yields diminishing returns. Once basic material needs are satisfied, further marginal increases in consumption lead to lower increments in utility. It then follows that in wealthy nations higher levels of consumption do not necessarily lead to overall improvements in welfare (Lintott, 1998). This constitutes one of the major arguments of ecological economics, which agrees that consumption contributes to enhancing welfare at low levels of development, but ever-increasing consumption is not sustainable, as it contravenes the principle of strong sustainability (Daly, 1990)[8]. This principle states that natural capital (i.e. forests, fisheries, minerals) is not a substitute for other types of capital (i.e. physical, financial, human, social) and that its stock must remain constant over time. The consumption of goods and services, which require material and energy for their production extracted from the environment and which produce waste and pollution, must be maintained within sustainable limits. In other words, the level of throughput must not exceed the planet's biophysical carrying capacity (Boulding, 1966). Surpassing this threshold leads to unsustainable outcomes, since the costs of overconsumption or misconsumption (e.g. environmental degradation, resource exhaustion, global warming, health problems) offset the benefits of consuming more (Lintott, 1998; Daly, 2005). As can be seen in Figure 6, the costs related to the depletion of natural resources and the damage caused by atmospheric pollution as a

[8] The principle of weak sustainability, on the other hand, is aligned to neoclassical theory, allowing the substitution of natural capital with other types of capital, while the total stock formed by all forms of capital must be maintained constant over time (Pearce and Atkinson, 1993; Cabeza Gutés, 1996).

percentage of final consumption expenditure registered an upward trend in high-income economies during the last two decades, showing a decline during the 2008/09 financial crisis.

Figure 6 - Costs related to the depletion of natural resources and damage caused by pollution as a percentage of final consumption expenditure in high-income economies (1990-2011)



Note: Includes costs related to energy, mineral and forest depletion and impacts derived from CO_2 and suspended particulate matter.
Source: Own figure based on data by the World Bank (2013)

The importance of economic throughput is well illustrated in the concept of socio-ecological metabolism, which has its origins in biological sciences (Fischer-Kowalski and Haberl, 1998, 2007). Analogous to a living organism, economies also take materials and energy from the environment, which are then processed, used and assimilated. Afterwards, what is not required is discarded once more to the environment in the form of waste and pollutants. The scale of this metabolic process or throughput, or what Fischer-Kowalski and Haberl (1998) call the *metabolic profile*, depend on the *mode of production* and the lifestyle of a society. The *mode of production* refers to the way a society is organised to produce goods and services (i.e. primitive communism, feudalism, capitalism). However, it can similarly be said that the metabolic profile in a capitalist system is influenced by the stage of economic development that an economy is going through. In other words, the metabolism of an economy is transformed over time along with its structure, from an early agrarian stage to a later industrialist phase. Agrarian economies consume about 3 to 5 times less energy and materials on a per capita basis than industrialised ones. As shown in Table 4, LDCs clearly possess an agrarian profile, as they use very low levels of energy and material per person, and a significant share of their energy sources comes from biomass. The rest of the developing world, on average, corresponds more to an agrarian than an industrial regime. Their levels of energy and material use are larger than those of LDCs and use much more fossil fuels in their energy mix, but they still have not reached the levels of developed economies, which clearly present an industrial profile. The latter consume significantly more energy and materials and obtain more than two thirds of their energy from fossil fuels (Krausmann et al., 2008).

Table 4 - Metabolic profiles of agrarian and industrial economies

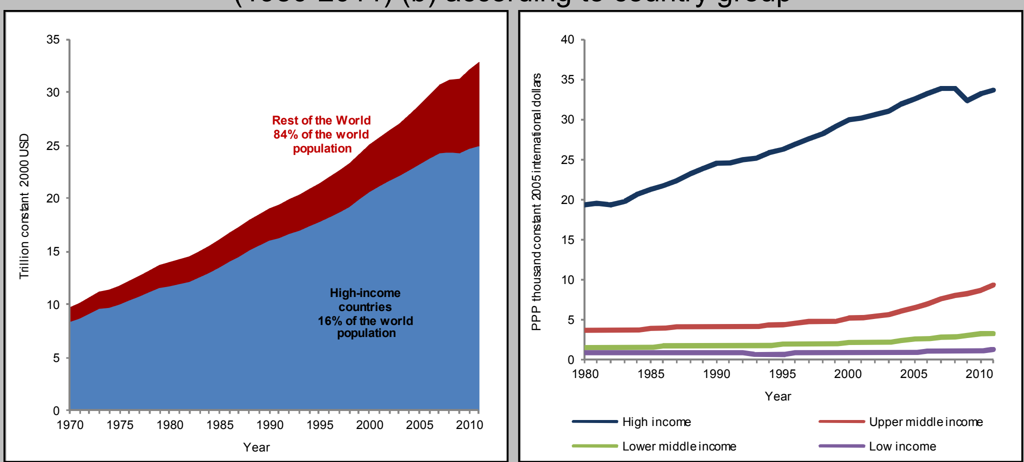
	Unit	**Agrarian economy**	**Industrial economy**	**LDCs**	**Developing**	**Developed***
Total energy use per capita	GJ / person / year	50-70	150-400	33	64	205
Biomass (share of energy use)	%	95-100	10-30	92	50	23
Fossil fuels (share of energy use)	%	0-5	60-80	8	50	77
Use of materials per capita	Tonnes / person / year	2-5	15-25	4.2	6.8	16

Note: * based on EU15; GJ: gigajoules
Source: Own table based on Fischer-Kowalski and Haberl (2007) and Haberl et al. (2011)

The gap between developed and developing economies in terms of materials and energy use is also evident in relation to final consumption expenditure. In the year 2011, the world's richest 16% were located in industrialised nations and accounted for 75% of total consumption expenditure (see Figure 7a). Their consumption per capita was about 16 times greater than that of the rest of the world (UNSD, 2013a). In 2008, they consumed, for instance, 39% of the world's grain for food, feed and biofuels and 41% of animal protein (Moomaw et al., 2012), and on average they have been consuming 58% of the total energy and approximately own 87% of all the vehicles on the planet (Parikh and Painuly, 1994; Elliott, 1999). The people in the US alone accounted in 2011 for more than 30% of global expenditures with only 4.5% of the global population (UNSD, 2013a). In terms of long-term trends, consumption expenditure in wealthy nations almost tripled from 1970 to 2011. A large part of this increase cannot be attributed solely to population growth, which rose approximately by 50% on average in these countries during the same period. The considerable expansion of consumption is attributed mainly to a rise of almost 75% in personal income (see Figure 7b) (UNSD, 2013a) and other cultural and socio-psychological reasons (e.g. status-seeking, competition, feelings of success, social hierarchy) (Røpke, 1999; Jackson, 2002; Jackson and Michaelis, 2003; Assadourian, 2010).

Consumption has increased significantly in the developing world as well. In 1970, its final expenditure represented around 14% of the world's total, but its share increased to almost 25% in 2011 (see Figure 7a). In absolute terms, this corresponds to a six-fold increase. This rise has occurred particularly among the so-called big emerging economies, like China and India, where GDP per capita has expanded on average by around 8.9% and 4.3% per year, respectively (UNSD, 2013a). In their quest to emulate the lifestyles enjoyed by their rich counterparts, these nations have experienced rising consumption trends, also fuelled by an increase in population and an improvement in quality of life (Hubacek et al., 2007). Kharas (2010) estimates that Asia currently accounts for around one quarter of the planet's middle class and that figure could double by 2020, accounting for over 40% of global middle-class consumption. This means that more people in these nations are already demanding and will demand a greater array of consumer goods, from processed food to washing machines, cars and air travel. It is expected that similar consumption patterns will be present in other developing nations. Dobbs et al. (2012) and the UNDP (2013) calculate that by 2025, annual consumption in developing economies will triple with respect to 2010. Population, on the other hand, is projected to keep growing, and could reach 9 to 10 billion people by 2050, who would be demanding more resources (Godfray et al., 2010). Even with effective strategies to curb it, it is thought that population will probably rise by at least another billion before peaking (Assadourian, 2010).

Figure 7 - Final consumption expenditure (a) (1970-2011) and GDP per capita (1980-2011) (b) according to country group



(a) (b)

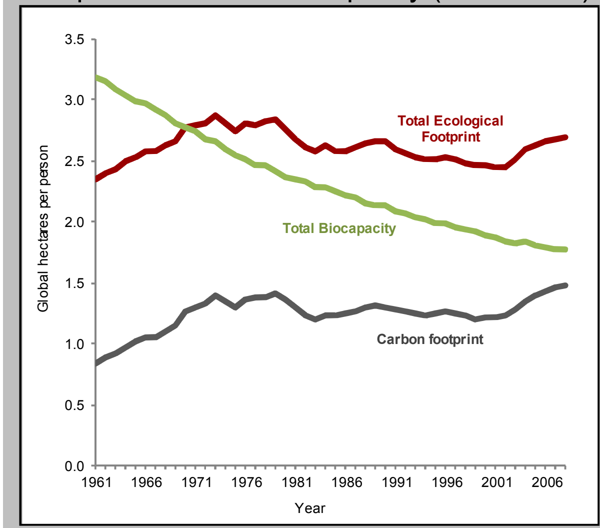
Source: Own figures based on data by UNSD (2013a)

In spite of the *rise of the South* (UNDP, 2013), income inequality will continue to be a severe problem worldwide. Even in big emerging economies, like the ones mentioned above, levels of development will be uneven. It is expected that in large sectors of the world population will continue to survive with barely an essential amount of goods and services in the next decades (UNDP, 2005). The gap between rich and poor countries in most cases is widening (Chen and Ravallion, 2008). For instance, in 1990, an average person in the US was 38 times richer than the average Tanzanian. After less than two decades, that same person in the US was 61 times richer (UNDP, 2005).

Growing consumption rates have translated into an enormous pressure on the planet's ecosystems on which humanity depends. More land has been converted into cropland in order to satisfy a bigger demand for food, while minerals and fossil fuels have been extracted at larger quantities. During the last century, global materials use increased eight-fold, and developed and developing nations use almost 60 Gt of materials per year (Krausmann et al., 2009). Humanity has been utilising more resources than the planet can regenerate, and filling waste sinks more rapidly than the environment can absorb (Princen, 1999). The consequences for global sustainability are significant, as it can negatively affect the ability of future generations to satisfy their own needs.

The ecological footprint is an indicator that illustrates the scale of these consumption patterns (see Figure 8). Broadly defined, it is as an index that measures how much resources individuals, or nations, consume in terms of the amount of land that is required not only to produce them, but also to absorb the waste derived from their use (Rees, 1992). Although it has been criticised for its limited scope, the weight of its components, and its inability to reflect the nature and severity of the environmental impacts, among others (Lenzen and Murray, 2003; Fiala, 2008; Wiedmann and Barrett, 2010), the ecological footprint represents a simple method for comparing the sustainability of human consumption. In this sense, the indicator shows that humanity surpassed the world's biocapacity threshold in the early 1970s (Wackernagel et al., 2002; Kitzes et al., 2008). In 2008, this threshold was 1.8 global hectares per person. In that same year, a regular person living in the US required around 7.2 global hectares to support its lifestyle, while another one in the UK needed slightly less than 5. On average, the footprint per person for high income countries was 5.6 for 2008 (GFN, 2013). This means that if all the people in the planet consumed as much as those who live in the developed world, humanity would need more than three planets.

Figure 8 - Global ecological and carbon footprints and total biocapacity (1961-2008)



Source: Own figure based on data by the GFN (2013)

2.2.2. Consumption as a driver of emissions

The consequences of overconsumption are varied, and range from deforestation, soil erosion, generation of hazardous waste, to abusive labour practices and health problems, like obesity and stress (UN, 1992; Assadourian, 2010). Nevertheless, the greatest symptom of modern consumption patterns may be the continuous increase in atmospheric levels of GHGs, which has led to global warming. This phenomenon has usually been associated with production processes, but some researchers suggest that it should also be analysed from a demand-side or consumption perspective, as this represents the origin of the problem (Munksgaard et al., 2000; Munksgaard and Pedersen, 2001; Ferng, 2003; Bastianoni et al., 2004; Peters, 2008; Peters and Hertwich, 2008b). Larger quantities of fossil fuels have been used in order to generate the energy that is required to support present-day lifestyles, primarily in industrialised nations. Emissions derived from the utilisation of energy-related resources account for the largest part of the CO_2 (i.e. >55%) that has been released to the atmosphere (IPCC, 2001). Likewise, deforestation and land-use change have been the result of an increasing demand for arable land to produce more food, which has also generated a considerable amount of GHG emissions (i.e. >17%). Regarding agricultural activities, these have been held responsible for nearly a fifth of total emissions, where livestock transport and feed have been identified as major contributors (McMichael et al., 2007).

The extreme inequalities in income and energy/resource use between nations have been reflected in significant disparities in terms of emissions. Sanwal (2009) asserts that the high levels of consumption per capita in industrialised economies constitute the main driver for increasing emissions. For example, the 19 million people that live in the US state of New York have a higher carbon footprint than the 766 million persons that reside in the 50 least developed countries. Moreover, the UK, with a population of nearly 60 million, emits more GHGs than Egypt, Nigeria, Pakistan, and Vietnam combined, which have a total population of 472 million (UNDP, 2007).

The influence of consumption on the generation of GHG emissions has important implications in terms of allocation and accounting. Traditionally, countries calculate their emissions inventories from a territorial perspective; that is, they take into account all the emissions that are generated within their own political borders. However, an alternative approach is to allocate emissions according to the consumption that occurs within a country, which includes not only domestically-produced goods and services, but also imports. Hence, the difference between territorial and consumption-based approaches consists in who is to be held responsible for the environmental impact (Munksgaard and Pedersen, 2001; Ferng, 2003; Bastianoni et al., 2004; Peters, 2008; Peters and Hertwich, 2008b). Territorial accounting assumes that nations should only be responsible for the emissions that result from the processes required to fulfil their own production requirements. Alternatively, consumption-based inventories incorporate the CO_2 generated along the entire supply chain from the production of all goods and services demanded by a country, regardless of their geographical origin. From this point of view, nations are thus responsible for the amount of emissions embedded in all the products and services they consume. On the whole, both approaches ultimately consider the same data, but differ on an accounting principle. The territorial approach includes emissions embodied in exports, while the consumption-based subtracts these exports and incorporates emissions contained in imports (Munksgaard and Pedersen, 2001). It is important to emphasize, however, that consumption-based emissions should not be confused with the carbon footprint, as they present conceptual and methodological differences. Although both show the effect of consumption on emissions, the footprint seeks to reflect the extent to which humanity is exceeding the planetary boundaries and is expressed in global hectares, as was explained in the previous section. Consumption-based emissions, in contrast, are the result of an accounting principle and are expressed in terms of CO_2 or carbon per year. Methodologically, the footprint calculates a nation's total consumption by adding imports to and subtracting exports from its national production (Borucke et al., 2013), whereas consumption-based emissions are estimated using an Input-Output Analysis

(IOA) framework to capture the emissions embedded in traded goods along the entire production supply chain (Peters, 2008), as will be explained in the following chapter.

Davis and Caldeira (2010) built a global consumption-based CO_2 emissions inventory using Multi-Regional Input-Output (MRIO) analysis and a database (version 7) created by the Global Trade Analysis Project (GTAP). The authors found that in 2004 approximately 23% of all CO_2 emissions from fossil-fuel burning were emitted during the production of goods and services that were consumed in a country different from that of their origin. Peters et al. (2011b) later constructed consumption-based time series by extending global emissions estimates for 1997, 2001, and 2004 over the period 1990-2010 using a combination of GDP, emissions, and trade statistics from established global datasets (e.g. UN, Carbon Dioxide Information Analysis Centre) (see section 3.4). Figure 9 shows these series, which represent historical trends of territorial and consumption-based CO_2 emissions for Annex B and Non-Annex B countries.[9] As has been explained, the former group of countries constitute industrialised nations and economies in transition that have commitments under the Kyoto Protocol. Non-Annex B nations, consequently, comprise the rest of the world. Regarding territorial emissions, Annex B countries achieved a reduction of approximately 5.6% from 1990 to 2010. In contrast, emissions rose significantly by a factor of 2.4 in the Non-Annex B group, going from 2.0 Gt of carbon in 1990 to around 5 in 2010. In fact, their emissions surpassed those of the wealthiest nations by almost 1.3 Gt in 2010. This increase was mostly caused by highly carbon-intensive activities in Brazil, Russia, India and China (i.e. BRIC countries), as well as other emerging economies, such as South Africa, Mexico, Indonesia, etc. Consumption-based emissions, on the other hand, grew almost 3.2% in Annex B nations, exceeding the Kyoto Protocol emission reductions. On the other hand, the same type of emissions grew about 130% in the rest of the world, reflecting their rising rates of consumption. An important fact is that Annex B consumption-based emissions were a little less than 1% larger than their territorial ones in 1990, and this proportion grew to 9.3% in 2010. In absolute terms, emission transfers via international trade from one group to the other thus increased 10.2% during the period. This reflects the increasing propensity of Annex B countries to rely on imported goods, which have made them net importers of emissions. On the other

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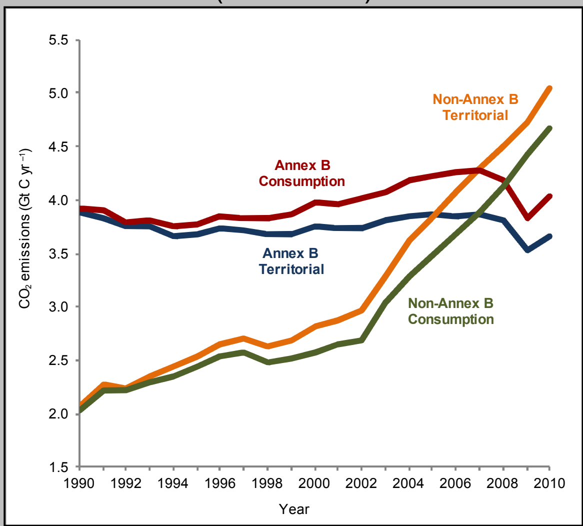
[9] These are the parties to the Kyoto Protocol listed in the Annex B with quantified reduction commitments, which are the same as those in the Annex I of the UNFCCC (see footnote 2), with the exception of Kazakhstan, who only belongs to Annex B, and Turkey and the US, who are only included in Annex I. Moreover, Canada, Japan, New Zealand and the Russian Federation have not pledged reduction commitments under the Kyoto protocol for the period 2013-2020 (UNFCCC, 2012).

hand, the rest of the world presented the opposite pattern. Their consumption-based emissions were 1.6% smaller than their territorial ones in 1990, but this figure grew to 8.1% in 2010. Non-Annex B economies have consequently become net exporters of emissions. Moreover, it is important to highlight that consumption-based emissions from the rest of the world surpassed those of their counterparts in 2009 (Peters et al., 2012).

Figure 9 - Territorial and consumption-based emissions according to country groups (1990-2010)



Source: Own figure based on data by Peters et al. (2011b)

Bows and Barrett (2010) used a consumption-based approach to build scenarios based on cumulative emissions. Considering the amount of emissions accumulated in the atmosphere instead of yearly emissions is deemed as an appropriate strategy for developing emissions pathways and examining future climate policies (e.g. Anderson and Bows, 2008; Allen et al., 2009; Meinshausen et al., 2009; Zickfeld et al., 2009; Anderson and Bows, 2011). Bows and Barrett recognise the challenge of sharing the carbon space between Annex I and Non-Annex I nations, and state that by redirecting responsibility for emissions transfers from the latter to the former group, can be useful to send signals to decarbonise the supply chain and trigger more timely and radical mitigation actions.

2.2.3. The Consumption-Based Carbon Kuznets Curve

As was explained in section 2.2.1, the neoclassical theory argues in favour of the maximisation of social welfare, which is a function of the utility that individuals obtain by consuming goods and services. The ability of these individuals to consume, in turn, depends on their affluence. The relationship between affluence and environmental quality or, in other words, the consequences of affluence in the environment, have been usually dealt by neoclassical economics through the Environmental Kuznets Curve (EKC). Inspired by the hypothesised *inverted-U* or *bell-shaped* relationship between economic development and income inequality found by Simon Kuznets (1955), some authors have suggested that a similar pattern exists between environmental degradation, including the emission of certain types of pollutants, and income per capita levels (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Panayotou, 1993; Selden and Song, 1994; Shafik, 1994).

Traditionally, the EKC relationship has been explained following similar arguments than those originally expressed by Kuznets. In this sense, it reflects the different stages of economic development economies must pass through, suggesting that structural and technological changes in an economy are determinants of environmental quality. When an economy is primarily agricultural, the environment deteriorates at a slow pace. Meanwhile, the average level of income among the population remains low. Afterwards, during the industrialisation phases, rising rates of degradation appear as a result of increasing physical capital intensive activities, rather than human capital intensive. Mass production, income per capita and consumer expenditure grow gradually. At this point, societies are unwilling to exchange consumption for investment on abatement efforts. But once the population achieves a certain level of income per capita, environmental deterioration arrives at a threshold. After this *turning point*, environmental indicators would start to display improvements, as increasing investments in cleaner production technologies and stricter controls on emissions begin to be publicly demanded by a wealthier society. The environment, in this fashion, becomes a luxury good, and the existence of an income elasticity effect becomes evident. Society’s willingness to pay for a better environment depends on the income levels of its members. At low levels, environmental quality is inelastic with respect to income, propensity to pollute is high, and only a minority is willing to pay. Meanwhile, at higher levels, the elasticity is larger, the propensity to pollute is lower, and more individuals are willing to invest to improve their environment.

The main argument is thus based on the assumption that a decoupling of environmental pressure from economic growth is possible (World Bank, 1992). But, at the same time, the EKC also suggests another tantalising idea. Becoming rich is the practical solution to attain a decent environment (Beckerman, 1992). This means that developing countries, where environmental deterioration has been more severe and whose emission intensities are higher, would still need to reach income levels high enough to be able to move beyond their turning points. Nonetheless, after many years of intense research, no consensus has been reached as whether these conclusions are valid or not.

In the early 1990s, evidence was produced suggesting that it is possible to *grow out* of certain environmental problems. Grossman and Krueger (1991) found that at higher incomes, sulphur dioxide (SO_2) emissions and suspended particulate matter tend to decrease. Shafik and Bandyopadhyay (1992) obtained equivalent results for these two pollutants, and asserted that other problems, like access to safe water, urban sanitation, and deforestation, are also likely to decline with higher income levels. Panayotou (1993) and Selden and Song (1994) found comparable support regarding nitrogen oxides (NO_X) and carbon monoxide (CO). Grossman and Krueger (1995) later determined that an analogous pattern applies for several indicators relating to water quality. Overall, many other studies throughout the years have found proof at different levels pointing towards the same kind of results, but these apply to certain pollutants that produce short-term and local impacts. Stern et al. (1996), Ekins (1997), and Dinda (2004) offer good reviews of the literature in this respect. The same logic, however, is not always valid for those pollutants that generate global, indirect, and long-term impacts (Arrow et al., 1995; Cole et al., 1997; Hanley et al., 2013). The immediate effects related to these pollutants are harder to notice in the short-term and their impacts are not limited to specific geographical locations. This is the case of CO_2 emissions, for which the findings have remained inconclusive (Galeotti et al., 2006).

There have been numerous attempts to estimate the carbon EKC from a territorial perspective. These analyses have been conducted either on a world scale, on particular regions, such as OECD members, or on individual countries. Table 5 presents a set of existing studies that have analysed the territorial carbon EKC, either by focusing exclusively on CO_2 emissions or by examining CO_2 within a host of other pollutants. The table shows the number of countries included in the sample, the time period that was analysed, the functional forms used, the statistical models employed, and their main findings. As can be seen, the results have been highly incongruous. Some authors have proved the validity of the carbon EKC; others have found an inverted-U shape with out-of-sample turning points[10], and still others have rejected the

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[10] The estimation of the turning point becomes less reliable as it moves further away from the sample range. Alternate model forms could fit the data equally well and very different

hypothesis. Moreover, a number of studies have also produced an *N-shaped curve*. This indicates that CO_2 emissions gradually decline or stabilise when income is expanding, but only up to a certain level. From that point on, emissions increase again as income rises. This finding consequently indicates that a cubic term should be tested in the model specification.

Numerous authors, on the other hand, have warned about the various econometric shortcomings and inconsistencies that commonly affect EKC analyses (e.g. Stern et al., 1996; Millimet et al., 2003; Perman and Stern, 2003; Dijkgraaf and Vollebergh, 2005; Müller-Fürstenberger and Wagner, 2007; Romero-Ávila, 2008; Wagner, 2008; Vollebergh et al., 2009; Stern, 2010). These are related to model misspecification due to issues such as country heterogeneity, cross-sectional dependence, stationarity, cointegration, among others (see section 3.2.1).

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turning points could be found. Thus, when the turning point lies so far outside the data range, it could be said that emissions just grow monotonically with income. See Loehle (2010) as an example.

Table 5 - Studies that have analysed the Carbon EKC from a territorial perspective

Author(s)	Sample	Years	Findings	Models	Functional form/variables
Shafik and Bandyopadhyay (1992)	149 countries	1960-1990	TP at over $7 million p/c with quadratic specification	Panel data regressions	Quadratic and cubic (log-linear)
Holtz-Eakin and Selden (1995)	130 countries	1951-1986	TP of $35,428 (linear) and of above $8 million (logarithms)	Panel data with country and time effects.	Quadratic specification (linear and logarithms)
Cole et al. (1997)	7 regions	1960-1991	TP of $25,100 (linear) and $62,700 (logarithms)	Panel regressions with Generalized least squares (fixed and random effects)	Quadratic (linear and log-linear)
Dietz and Rosa (1997)	111 countries	1989	CO_2 emissions level off and decline above $10,000 USD	General additive model with a nonparametric regression procedure	Quadratic and cubic (log–polynomial and log-linear). GDP per capita and CO_2 in millions of metric tons of carbon.
Roberts and Grimes (1997)	World	1962-1991	Relationship changed from being linear in 1962 to curvilinear in 1991.	OLS	Quadratic with CO_2/$ instead of CO_2 per capita
Moomaw and Unruh (1997)	16 developed countries	1950-1992	Transition from positive to negative emissions elasticities around 1973	Piece-wise linear spline function	Quadratic and cubic
Schmalensee et al. (1998)	141 countries	1950-1990	Inverted-U with a within-sample TP for highly developed countries.	Segment splines	Linear and log-linear
Galeotti and Lanza (1999)	110 countries	1960-1996	Inverted-U shape emerged in all cases	Three-parameter Gamma and Weibull functions	Non-linear functional form
Roca and Alcántara (2001)	Spain	1972-1997	No evidence to support the hypothesis	Cumulative annual rate of variation of CO_2/$	First derivatives of variables
Neumayer (2002)	148 countries	1960-1988	Inverted-U with an out-of-sample TP	OLS panel regressions	Quadratic with additional variables (temperatures, land area, energy, oil and gas reserves, trend)
Day and Grafton (2003)	Canada	1958-1995	N-shaped curve	OLS with cointegration and causality tests	Cubic in logarithms

Table 5 - (continuation) Studies that have analysed the Carbon EKC from a territorial perspective

Author(s)	Sample	Years	Findings	Models	Functional form/variables
Friedl and Getzner (2003)	Austria	1960-1999	N-shaped curve	OLS with stationarity and cointegration tests	Linear, quadratic, cubic and cubic with additional variables
Martínez-Zarzoso and Bengochea-Morancho (2004)	22 OECD countries	1975-1998	N-shaped curve for the majority of countries	Pooled Mean Group Estimator	Different functional forms
Rosa et al. (2004)	World	1996	Significant quadratic term with out-of-sample TP	Stochastic Estimation of Impacts by Regression on Population, Affluence, and Technology	Quadratic (linear and logarithms). GDP per capita and CO2 in thousands of metric tonnes. Also tested Ecological Footprint
Galeotti and Lanza (2005)	28 OECD nations and 8 Non-OECD	1960-1995	N-shaped curve and some evidence of inverted-U	Various models	Different functional forms
Galeotti et al. (2006)	OECD and Non-OECD countries	1960-1998	Inverted-U for OECD countries with within-sample TPs	Weibull functions	Non-linear functional form
Huang et al. (2008)	40 countries	1990-2003	Inverted-U for 7 out of 21 Annex-II countries	OLS	Log-linear, quadratic and cubic
Atici (2009)	Bulgaria, Hungary, Romania, and Turkey	1980-2002	Inverted-U for all countries	Panel data regressions (fixed effects)	Quadratic with additional variables (energy per capita and trade openness)
Apergis and Payne (2009)	6 Central American countries	1971-2004	Inverted-U for all countries	Panel regressions (heterogeneity and cointegration tests)	Quadratic
Jalil and Mahmud (2009)	China	1975-2005	Inverted-U	Autoregressive distributed lag model	Log linear quadratic with additional variables (energy consumption, economic growth and foreign trade).
Aslanidis and Iranzo (2009)	Non-OECD	1971-1997	No evidence for non-OECD nations	Smooth transition regression model	Generalized Burr-type logistic function
He and Richard (2010)	Canada	1948-2004	Weak evidence of inverted-U	Semi-parametric and flexible nonlinear parametric models	Different functional forms

All the studies that appear in Table 5 were conducted from a territorial perspective. Authors like Ekins (1997) and Rothman (1998), however, have suggested that a consumption-based approach is a more appropriate way to analyse the hypothesis, than by employing the standard territorial or production-based method, which has been used by the great majority of existing EKC analyses. The consumption-based approach regards consumption as a critical driver behind environmental degradation. A country may abate emissions within its own geographical borders, reflecting reductions in its emissions inventories. Nevertheless, the same country may import highly carbon-intensive goods from other regions of the planet. Therefore, it would be responsible for the amount of CO_2 emissions generated overseas associated with the production of those goods. Rothman (1998), in this sense, has asserted that the downward slope of the territorial-based EKC may actually be reflecting the wealthy countries' ability to detach themselves from the emissions they cause in other geographical areas due to their consumption patterns. Hence, the inverted-U shape could be rejected if consumption-based data, rather than territorial, was used to estimate the EKC.

It has been difficult to undertake consumption-based analyses of the EKC mainly due to data availability. The range of existing consumption-based indicators is still very limited. Moreover, there is an ongoing discussion about the proper methodologies that are necessary to calculate these measures (Wiedmann, 2009). As explained in the previous section, Peters et al. (2011b) have recently made available a consistent set of global time series data for consumption-based CO_2 emissions. This motivated testing the hypothesis in this thesis with these figures and attempt to provide further insights into the debate, since no other study has been undertaken at this scale.

Some of the first researchers to analyse the EKC from a consumption-based approach are Gawande et al. (2001), who developed a consumption-side model for hazardous waste sites in the US. Their findings support Rothman's assertion. Aldy (2005) then presented a state-level carbon EKC analysis for the US. Although his results vary by state, he found that the consumption-based curves peak at significantly higher, within-sample incomes than territorial ones. This indicates that per capita CO_2 emissions in rich states may decline "*not because individuals consume less carbon-based goods in those states than before, but because they consume carbon-based goods produced in lower income states*" (Aldy, 2005, p. 62). Similarly, Weber and Matthews (2008) have asserted that 30% of the total US household CO_2 impact in 2004 occurred outside the US. In turn, Peters and Hertwich (2008a) estimated a crude territorial and consumption-based carbon EKC analysis for OECD countries in the supporting information section of their paper. Their results agree with Aldy's conclusions, in the sense that the turning point for territorial emissions was lower ($46,109) than for consumption-based emissions ($73,742). That same year, Bagliani et al. (2008a) and Bagliani et al. (2008b) analysed this issue further by using ecological footprint data, which is considered a consumption-based measure, for 141 countries for the year 2001. In a second study, the authors used data for 151 nations for 1961-2003. In neither one of the studies the authors found evidence in favour of a bell-shaped pattern. In both cases, their results show that the best-fitting curves exhibit either monotonically increasing linear trends or an N-shape. More recently, Caviglia-Harris et al. (2009) tested the validity of the EKC again by using ecological footprint indicators for 146 countries covering a period of 40 years (1961-2000). They found that the ecological footprint increases for both rich and poor nations, and much of this expansion can be attributed to energy use (i.e. CO_2). Wagner (2010) constructed a dataset of oil and total energy embedded in world trade of manufacturing goods for 73 countries from 1978 to 2000. He determined that richer economies use relatively less energy in their industrial production, yet still consume relatively large amounts of energy indirectly.

The literature shows that consumption-based data produces more consistent results. However, until now, the carbon EKC has not been properly tested using this approach at a global scale. This constitutes a gap in the literature that this thesis intends to fill.

2.2.4. Addressing the issue of overconsumption

A call was made at the United Nations Conference on Environment and Development in 1992, also known as the Rio Summit, for countries to promote sustainable consumption (UN, 1992). The outcome document, or *Agenda 21*, recognised that developed economies should take the lead. The rest of the nations should follow suit, guaranteeing the provision of basic needs for their populations, while avoiding the unsustainable pathways followed by their industrialised counterparts. Moreover, the Agenda acknowledged the need to enhance technological and financial assistance to poor nations, as well as to improve international cooperation. A couple of years later, in 1994, sustainable consumption was defined at the Oslo Roundtable on Sustainable Production and Consumption as "*the use of goods and services that respond to basic needs and bring a better quality of life, while minimising the use of natural resources, toxic materials and emissions of waste and pollutants over the life cycle, so as not to jeopardise the needs of future generations*" (Ministry of Environment Norway, 1994).

The definition, however, is somewhat ambiguous as it does not clearly specify whether it is enough to change consumption patterns by substituting some products for others, or if there is the need to reduce overall consumption levels, particularly in developed countries, in order to diminish environmental pressures (Lintott, 1998; Jackson, 2005; Mont and Plepys, 2008). Choosing to substitute the consumption of resource- and pollution-intensive goods and services for more efficient ones while maintaining the total level of consumption constitutes a *weak* version of sustainable consumption (Fuchs and Lorek, 2005), following the logic of the weak and strong sustainability principles. For instance, McMichael et al. (2007) have suggested that global meat consumption would need to drop to 50 grams of red meat per person per day from the current global average of 100 grams in order to stabilise emissions from agriculture. In wealthy nations, this amount of meat can be substituted by other less emissions-intensive products, while maintaining the required daily caloric intake (Smith et al., 2013). Strong sustainable consumption, in contrast, implies diminishing the general level of economic throughput (Lorek and Fuchs, 2013). That is, it focuses on reducing the overconsumption of resources, like water, minerals or fossil fuels, beyond the quantities required to satisfy basic needs. On the whole, both weak and strong approaches are centred on the notion that well-being must be enhanced with less material and more sustainable lifestyles, but they differ on the scale. Lintott (1998) argues that there is much scope for reducing consumption levels while increasing welfare. For instance, Druckman and Jackson (2010) estimate that decreasing consumption to a level compatible with a *minimum income standard*, which is deemed to provide a decent standard of living, could achieve emissions reductions of about 37% in the UK.

Reducing the unsustainable scale of global economic throughput is an idea that started gaining momentum in the 1970s, with works by Meadows et al. (1972) and other authors, like Boulding (1966), Georgescu-Roegen (1971) and Daly (1972). Concerned about the scale of the global economy and the increasing costs associated with overconsumption, these researchers stressed the need to rely less on non-declining material consumption and more on enhancing well-being in qualitative terms. Nowadays, research in the field of steady-state economics and degrowth has intensified. The former, initially created and advanced significantly by Daly, seeks to maintain a nation’s economic throughput at a constant level, while improving societal well-being. The latter, proposed by Latouche (2006), advocates for the need to downscale the size of industrialised economies.

Private and public consumption of goods and services currently represents more than 70% of the GDP in high and middle-income countries. Maximising consumption per capita thus contributes to economic growth, which represents a priority for a government's economic policy. Nevertheless, marginal increases in economic material expansion have not delivered higher levels of well-being in industrialised nations. The costs of ever-increasing economic growth (e.g. resource exhaustion, environmental degradation, health problems) have offset the benefits, up to a point where growth becomes uneconomic (Daly, 2005). Figure 6 in section 2.2.1 shows that environmental costs increase with consumption. Something similar is reflected in some welfare indicators, such as the Index of Sustainable Economic Welfare (ISEW) and the Genuine Progress Indicator (GPI), which subtract from consumption the associated environmental and social costs (e.g. crime, unemployment, loss of leisure time, commuting, etc.). These indicators show an increasing divergence with respect to GDP over time (Lawn, 2003). For this reason, Victor and Rosenbluth (2007), Jackson (2009) and Daly (2013), among others, have proposed that rich countries should abandon their urge to pursue increasing growth as a national policy priority. This would leave space for developing countries, which are the ones that still need to consume and expand their economies.

Numerous efforts have been undertaken at country-scale to include sustainable consumption policies in national legislations (see: OECD, 2000; Spaargaren, 2003; Nash, 2009; Scholl et al., 2010). However, changing consumption patterns is not an easy feat. Adjusting lifestyles and consumer behaviour requires structural transformations not only in the economy, but also in terms of societal conventions and institutions. Research has shown that consumers are most of the time locked-in due to several economic, psychological, social and cultural circumstances (e.g. working conditions, aspirations, pervasive marketing, available information, consumer knowledge, prices, etc.) that restrict changing their patterns (see: Hobson, 2002; Sanne, 2002; Zauberman, 2003; Shove, 2004; Schor, 2005; Jackson and Papathanasopoulou, 2008; Press and Arnould, 2009). Moreover, although the idea of reducing overall consumption levels may be supported by many researchers, it represents a contentious issue and is far from being widely accepted, especially among mainstream economists and politicians.

2.3. Mitigating climate change

2.3.1. The IPAT equation

The IPCC (2007b, p. 818) states that the term mitigation "*means implementing policies to reduce GHG emissions and enhance sinks*", adding that this can be done through "*technological change and substitution that reduce resource inputs and emissions per unit of output*". As was argued in the introductory chapter of this thesis, mitigation actions in national and international policy agendas tend to privilege technological solutions over other options. However, technology is just one of the anthropogenic drivers of emissions (see: Rosa and Dietz, 2012). According to the IPAT identity (Ehrlich and Holdren, 1971; Commoner, 1972), a level of environmental impact is determined by population, affluence and technology, as expressed in the following identity:

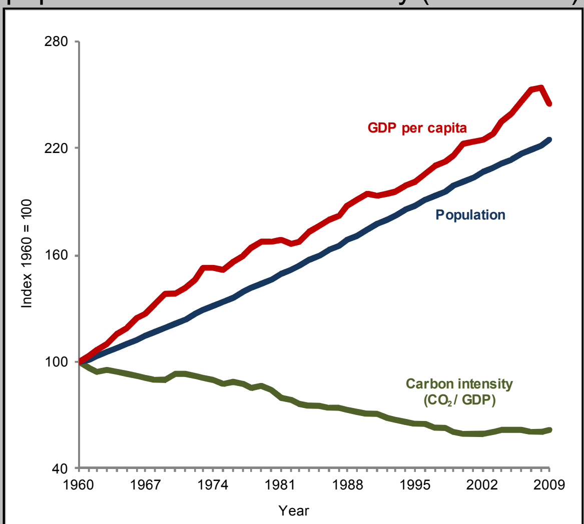
$$\text{Impact} = \text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{Impact}}{\text{GDP}} \qquad (1)$$

Affluence (*A*) is usually expressed as GDP per capita (i.e. income per capita), while technology (*T*) is represented as pollution- or resource-intensity; that is, the amount of pollutants or resources generated or used per unit of GDP. In the case of CO_2 emissions, many future climate projections, like those of the IPCC (Nakicenovic and Swart, 2000), have been developed with the use of the Kaya identity, a variant of the IPAT (Kaya, 1990; Kaya and Yokobori, 1997). Its only difference is that the technology term is disaggregated further into two individual components. In this sense, the technology factor is composed of the energy intensity (i.e. energy use per unit of GDP) and the carbon content of energy (i.e. CO_2 emissions per unit of total primary energy supply).

$$\text{Emissions} = \text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{Energy}}{\text{GDP}} \times \frac{\text{Emissions}}{\text{Energy}} \qquad (2)$$

Improvements in technology will play a very important role to guarantee a low-carbon future. Some policymakers and researchers display wide optimism in technological mitigation (Pacala and Socolow, 2004; Vollebergh and Kemfert, 2005), but it has also been acknowledged that it must be complemented with other measures. Technology is a necessary, but not sufficient condition to combat climate change and achieve a 2°C future (Beder, 1994; Schor, 2005; Huesemann, 2006; Flavin and Engelman, 2009; Jackson, 2009). Historical trends show that global improvements in carbon intensity have been outweighed by population growth and the expansion of income per capita (see Figure 10). Carbon intensity (i.e. CO_2/GDP) worldwide improved on average by around 1% per annum since 1960. Population and income per capita, on the other hand, increased on average by 1.6% and 1.8%, respectively, every year. The pace of technological change was not enough to compensate for the rise in the other two factors. Jackson (2009), in this sense, argues that in order to achieve a 2°C future, carbon intensity would require a 21-fold improvement by 2050, given that population and income per capita grew annually at rates of 0.7% and 1.5%, respectively. This would mean that technology would need to improve significantly faster than in the past, and this would potentially include achieving negative emissions from the 2070s according to the RCP3-PD scenario (see section 2.1.1). In this regard, technologies like carbon capture and storage (CCS) and geo-engineering solutions, which could potentially achieve this objective, are still surrounded by large uncertainties in terms of their feasibility and possible effects on natural and human systems (see: Bengtsson, 2006; IPCC, 2007b; Boyd, 2008; Fox and Chapman, 2011; Szulczewski et al., 2012; UNEP, 2012). Moreover, the deployment of these new technologies would need to overcome current and future lock-in effects and diffusion barriers (e.g. market, regulatory, trade, etc.) (see: Arthur, 1989; Unruh, 2000; Unruh and Carrillo-Hermosilla, 2006). Authors such as Huesemann (2006, p. 539) thus believe that mitigation technologies have the capability to deliver the required emission cuts "*only if population and economic growth are halted without delay*".

Figure 10 - Growth in GDP per capita, population and carbon intensity (1960-2009)



Source: Own figure based on data by UNSD (2013a) and CDIAC (2013)

Population is seldom addressed through climate change mitigation policies, but it is rather treated as a development issue. For instance, family-planning programmes deliver efficient results when combined with polices that seek to educate and empower women. Evidence shows that these actions contribute significantly to reducing fertility rates (Petroni, 2009; Das Gupta et al., 2011; World Bank, 2011). Smaller families imply having less people to feed, clothe and shelter, and this helps societies to preserve resources, lessen environmental burdens and improve quality of life. However, when population policies are too stringent, they can engender negative social effects, as in the case of China (Feng et al., 2013). Consumption, on the other hand, is usually dealt in the context of sustainable development initiatives. As has been explained in section 2.1.3, climate change and sustainable development have tended to be treated as separate discourses (Michaelis, 2003). As a consequence, sustainable consumption policies are not always explicitly labelled as mitigation options. For instance, only two Non-Annex I countries (i.e. Côte d'Ivoire and Ghana) use the precise term *sustainable consumption* in their NAMAs (UNFCCC, 2011a). The majority of developing countries include proposals to reduce energy consumption derived from fossil fuels, as well as to decrease deforestation rates and land-use change, but do not consider the sustainable use of a wider range of resources as climate change mitigation actions per se. Developing nations generally argue in international climate negotiations that they have the right to develop and continue rising their incomes and consuming more in per capita terms (see: Jotzo, 2005). In relation to Annex I nations, their climate and sustainable consumption policies show more integration (OECD, 2000; Nash, 2009; Scholl et al., 2010). For example, the UK's Climate Change Programme calls for setting out a plan for action on sustainable consumption (HM Government, 2006). However, policies in general refer to sustainable consumption in the weak sense of the term, but do not consider imposing caps on the overall levels of affluence and consumption.

2.3.2. Demand-side mitigation

As has been mentioned in the previous section, mitigation policies tend to favour technological change, as expressed by the IPCC (2007b) definition. Most technology-led actions focus on the production of goods and services or the supply-side. Surprisingly, very few efforts have been done in the scientific literature to provide a definition for demand-side mitigation actions, which concentrate on the affluence or consumption factor in the IPAT identity. The term *demand-side mitigation* is usually employed in relation to energy use (see: Tanatvanit et al., 2004). It denotes reductions in electricity or energy utilisation in the consumer end by means of more efficient technologies (i.e. household appliances, heating systems, insulation, etc.). To the best of the researcher's knowledge, Smith et al. (2013) are the only authors who offer a formal and wider definition of the term going beyond technological solutions. They recognise the differences and synergies that exist between supply- and demand-side actions, and understand the latter as those measures that seek to lessen GHG emissions in the context of food demand by (1) reducing "*losses and waste in the supply chain, as well as during final consumption*"; (2) by achieving "*changes in diet towards less resource-intensive food*"; and (3) by a "*reduction in overconsumption in regions where this is prevalent*" (Smith et al., 2013, p. 6). This connotation serves as a basis for constructing a working definition for demand-side mitigation to be used this thesis, which is described more generally as those measures that pursue cuts in consumption-induced emissions by modifying consumption patterns and/or reducing overall levels of consumption. Making this differentiation between supply- and demand-side strategies is useful so as to distinguish the latter from technology-centred approaches.

Mitigation policies can thus be directed either to producers or consumers depending on the desired goal. It is important to have in mind, though, that supply and demand are two faces of the same coin. Some demand-side instruments can produce indirect effects in supply, just as supply-side measures can cause indirect effects in demand when the costs are transferred to the final consumer. For instance, a carbon consumption tax applied directly to consumers may dissuade them from acquiring a certain product. However, it may also represent an incentive for the producers to manufacture it in a less carbon-intensive manner. On the other hand, there are important synergies between supply and demand measures (Smith et al., 2013). As has been discussed, technology-led mitigation should be complemented with consumption-oriented policies. Emissions reductions can be more effective, for example, if supply measures focused on incentivising producers to use more efficient technologies are combined with demand-side actions seeking to inform consumers about pollution-intensive goods. The efficacy of using combined measures depends on their consistency to achieve the desired targets, like technology improvements and changing consumption patterns as in the previous example. Combining policies effectively implies that these should not be contradictory among each other and follow the *Tinbergen rule*, which states that the number of policy instruments must at least be equal to the number of policy targets (see: Knudson, 2009).

Mitigation policy instruments can be of various types. Market-based tools make use of prices and market mechanisms to incentivise economic agents to undertake certain actions, with the aim of correcting market failure and externalities, of which climate change is the most significant (Stern, 2007). These instruments can take the form of taxes, fees, charges, subsidies or other more complex measures, such as tradable permits (see Table 6). As said, carbon taxes can be applied to the supply- or the demand-side. The latter can take a form similar to a value-added tax (VAT), increasing the price consumers must pay for certain goods and services. Among market-based policy instruments are the Kyoto Protocol mechanisms[11] and the EU Emissions Trading Scheme (ETS), which cap the amount of emissions and allocate permits to industries, allowing them to generate a certain amount of CO_2. On the other hand, command and control policy tools, also known as regulatory, are directly administered by the government, and are constituted by regulations, standards and quotas. These have been criticised by being less efficient than market-based approaches and many options are costlier for the government, as they do not always generate revenue (Tietenberg, 1990). From the supply-side, producers can be required to use certain types of technologies and comply with certain standards. In contrast, from a demand-side approach, consumers can be limited by quotas or be banned from acquiring specific goods. The last type of policy instruments are informational, and consist basically of public disclosure schemes, awareness and education campaigns and labelling programmes. Firms, for example, can voluntarily disclose information about their practices to gain trust from their stakeholders. When directed to consumers, these can help them to make better-informed choices and change their behaviour accordingly. Carbon-labelling schemes are designed to advise consumers about the amount of carbon that was emitted during the life cycle of a certain product. Programmes like these have been initiated in several countries, like the UK and France, and are extending gradually to other nations, while covering a wider range of products (Brenton et al., 2009; Vandenbergh et al., 2011). However, the number of studies that focus on how demand-side policies, like carbon labelling and other instruments, may affect the level of exports from other countries, particularly those located in the developing world, is still limited. This is a research gap in the literature that needs to be addressed.

[11] The Kyoto Protocol mechanisms are (1) the emissions trading, (2) the CDM, and (3) the joint implementation.

Table 6 - Types of mitigation policy instruments

Policy type	Policy options	
	Supply-side	Demand-side
Market-based (or economic) instruments	GHG emissions taxes, fees and charges Subsidies and incentives Tradable permits (cap and trade or baseline and credit)	Carbon consumption taxes and charges (domestic and imports) Consumption subsidies and incentives Personal carbon quotas (cap and trade)
Command and control (or regulatory) instruments	Regulations (e.g. building, automobile) Technology or performance standards (e.g. fuel, energy) Production quotas Licenses	Product bans Consumption quotas
Information and voluntary instruments	Voluntary public disclosure Rating programmes	Carbon certification and labelling Awareness/education campaigns

Source: Own table based on IPCC (2007b), OECD (2009) and Fawcett (2010)

2.3.3. Border carbon adjustments

Border carbon adjustments (BCAs), also called carbon import tariffs (CITs) or more generally border tax adjustments (BTAs), are taxes levied by nations that are subject to legally binding carbon abatement schemes, such as the Kyoto Protocol or the EU ETS, on imports produced by nations not bound by equivalent regulations. Although they usually are applied as taxes or tariffs, BCAs can potentially take other forms, like antidumping or countervailing duties, or requirements for importers to acquire emissions trading certificates (Holmes et al., 2011). Whatever form they may adopt, BCAs mainly respond to competitiveness issues, since carbon-taxing countries find themselves in a competitive disadvantage over their counterparts, which do not face carbon mitigation costs. Moreover, BCAs have the additional target of addressing concerns about *carbon leakage*, which is defined by the IPCC (2007b, p. 811) as "*the part of emissions reductions in Annex B countries that may be offset by an increase of the emissions in the non-constrained countries above their baseline levels [, which] can occur through relocation of energy-intensive production in non-constrained regions*". For Peters (2010, p. 36), this represents the *strong* or *policy-induced* version of carbon leakage, which he defines in an alternative and simpler way: "*Strong carbon leakage in country or region R is the increase in greenhouse gas emission outside of R due to climate policy in R*". BCAs thus aim to avoid industries from eluding national or regional climate legislations by relocating in more legally-lenient regions. In this sense, the implementation of this policy instrument ensures levelling the playing field among the different parties involved by internalising abatement costs into the prices of traded goods and services.

The conception of *strong* carbon leakage was conceived with the purpose of distinguishing it from the *weak* or *demand-driven* version, which is also defined by Peters (2010, p. 35): "*Weak carbon leakage in country R is the greenhouse gas emissions outside of R that occur in order to meet consumption in R*". This kind of leakage corresponds to the emissions transfers required to satisfy consumption in net-importing economies via international trade, which were discussed in section 2.2.2. Eckersley (2010, p. 371) provides a slightly different definition for weak leakage, which he also calls *indirect leakage*. It represents "*a type of carbon movement out of developed countries that cannot be directly attributable to new climate policies*". According to him, one of the factors that can cause this movement is "*a more general trend of industry relocation to the Global South to take advantage of a range of lower factor costs*". A further discussion about carbon leakage is offered in section 2.4.3.

Lockwood and Whalley (2010) argue that the discussion about BCAs should make reference to an older body of literature related to border tax adjustments initiated in the 1960s, following the adoption of the VAT in the EU. Such literature acknowledged the different approaches of taxation (Grossman, 1980). Under the origin approach, BCAs are applied to the exports in the country where they are produced. This consequently constitutes a production or supply-side tax. In contrast, following a destination approach, BCAs are applied to imports in the country where they are consumed, thus representing a consumption or demand-side tax. This last approach requires implementing, in addition, a rebate of the domestic tax on exports, since these are not consumed in the country of origin. According to Whalley (1979), taxing at the origin or at the destination does not generate trade-distorting effects, as long as the tax rates are uniform across sectors and the prices of all factors of production and of all goods and services, as well as exchange rates are flexible (see also Meade, 1974). This means that changes caused by the tax are corrected through prices, and they are reflected in monetary terms, but the volume of trade remains intact. Grossman (1980) asserts, however, that when intermediate goods are included in the scheme, trade neutrality is maintained from the destination approach, but distortions in trade are generated from the origin approach unless intermediate goods are equally taxed and not only final products. It is important to remember that Grossman is referring to an indirect consumption tax and not a carbon levy, which would need to include commodities and raw materials. Grossman's assertion is straightforward. From the destination approach, intermediate imports are used to produce final goods in the country of consumption, and these would ultimately be taxed. On the other hand, when intermediates are not taxed in the country of origin, producers hold a competitive advantage. Grossman (1980) thus suggests applying the BCA to all stages of production, in which case trade neutrality is maintained as long as all prices are flexible. Regardless of the approach, however, it is difficult that the principle of price flexibility will hold in the real world, and this means that BCAs can potentially be trade-distorting.

The current discussion about BCAs implies implementing them under the destination approach, as they are being proposed unilaterally by some Annex I nations (i.e. US, EU, Australia, etc.). Trade neutrality is thus a relevant issue, since they need to comply with the existent World Trade Organisation (WTO) rules, and this institution is ultimately not motivated by environmental concerns, but by commercial ones. Developing countries regularly claim that BCAs represent a form of protectionism or trade barrier by industrialised nations and go against the spirit of free trade (Holmes et al., 2011; Kaufmann and Weber, 2011). Furthermore, they assert that this policy instrument conflicts with the UNFCCC principle of common but differentiated responsibilities. The unilateral imposition of BCAs by developed countries would shift climate change mitigation costs onto the developing world, who should carry less onerous abatement obligations (Davidson Ladly, 2012). Along the same lines, Eckersley (2010) states that BCAs emphasise "*the short-term disadvantages of domestic energy consumers and downplays the environmental and social injustices that arise from uneven development*". Industrialised nations, in contrast, argue that the existent situation comprises a subsidy to dirty production in non-regulated markets, and that BCAs represent a strong incentive for the developing world to start adopting legally binding responsibilities (Helm et al., 2012).

Holmes et al. (2011), Monjon and Quirion (2011) and Sheldon (2011) maintain that BCAs are not necessarily in violation of the General Agreement on Tariffs and Trade (GATT), which represents the basis of the WTO framework. GATT has a provision of non-discrimination, which states that members of the WTO can impose border taxes on imports, as long as they are equivalent to a domestic tax applied to the same types of products. In this sense, the BCA rate cannot be proportionally greater than the existing carbon price in the destination country, nor be applied to goods and services which are not covered by the mitigation abatement schemes. Moreover, in order for the BCAs to be effective, the carbon content of imported products should be estimated. Ensuring that imports receive a fair and similar treatment than domestic products thus requires not taxing them in excess of the domestic rates even if their carbon content is larger.

This implies the application of carbon equalisation measures. Ismer and Neuhoff (2007) propose using the principle of the *best available technology* (BAT), according to which imports are supposed to have been manufactured with at least the best technology existent in the country or region of consumption. Yet, the determination of an appropriate BAT can be problematic. Monjon and Quirion (2010) suggest that an easier way is to use product-specific benchmarks, like the ones set in the EU ETS for industry products.

Some BCA proposals include provisions to exclude LDCs and in this way avoid conflicts with the principle of common but differentiated responsibilities (see: Monjon and Quirion, 2010; Winchester et al., 2011; Cosbey et al., 2012). Some authors believe that this could clash with the *most-favoured nation* principle, which states that countries cannot normally discriminate between their trading partners (e.g. Monjon and Quirion, 2011). If a specific nation receives special treatment, this same treatment must be applied equally to all other trading parties. However, the WTO allows certain exemptions according to its *special and differential treatment* provisions, which give LDCs special rights and allow them to be treated more favourably than other WTO members (see: Mah, 2011). In addition, certain proposals also include exemptions for other countries, given that they are responsible for less than 0.5% of total global GHGs and contribute with less than 5% of the total imports in a certain sector of the consuming country or region (Monjon and Quirion, 2010; Winchester et al., 2011). Moreover, the schemes proposed by the US sets criteria for sector coverage. Eligible sectors would be those with an emission intensity of above 5%, trade intensity (i.e. volume of trade per unit of sectoral GDP) of at least 15% or energy intensity higher than 20% (van Asselt and Brewer, 2010; Cosbey et al., 2012).

Exempting LDCs, as well as certain sectors, from BCA coverage can simplify the already complex administration that such a policy instrument would demand. The requirement of complying with the provision of non-discrimination and determining an adequate BAT encompass a significant complexity (Cosbey, 2008). But the challenge in terms of management could be even greater if finished products (e.g. automobiles, electronic appliances) were also included in the scheme, instead of just focusing on intensive primary commodities (e.g. cement, iron, steel, aluminium, etc), given the number of possible countries of origin and the various inputs included in a final good (van Asselt and Brewer, 2010). Furthermore, BCAs require a constant revision of the amount of emissions embedded in products. Updating these figures implies a complicated, data-intensive and time-consuming process with associated monetary costs (Persson, 2010). However, if embedded emissions were rarely updated, then there is the risk that the BCA could be viewed as a fixed import or anti-dumping tariff, irresponsive to improvements in carbon intensity (Winchester, 2012). Moore (2010) thus believes that a BCA scheme is too fraught with administrative difficulties to make it viable in practice, and could additionally lead to an escalation of trade disputes in the WTO.

Research in BCAs is relevant since discussions are happening in some Annex I countries (e.g. US, EU, Australia) about their potential adoption. The US is the nation that has considered this option in more serious terms. It has explicitly stated that an emissions trading scheme will not be set up without a provision for BCAs. The Kerry-Lieberman climate bill, which failed to gain support from the US congress, included this policy instrument. The Waxman-Markey bill, passed by the House of Representatives in 2009, involved a much more detailed BCA scheme, although the bill later failed to obtain approval by the Senate. Nonetheless, it is expected that any future US climate legislation would contain this kind of measures. This has generated concern in some regions, like Latin America, about how the unilateral implementation of BCAs may affect their trade flows (see: Schneider and Samaniego, 2010). Similar reactions have taken place in China, who will become one of the main targets of such a scheme (see: Lin and Li, 2011; Li and Zhang, 2012) and might oppose it, as well as Russia (see: Weitzel et al., 2012). It is thus important to understand how BCAs might impact on the demand from goods produced in Non-annex I nations and ultimately on trade flows and welfare. Grubb (2011) asserts that final consumers are the ones who would absorb the great majority of costs associated with BCAs, and that a carbon price on commodities could reduce demand. The findings described in the literature regarding their potential impacts and effectiveness, however, are mixed. Böhringer et al. (2012) state that BCAs can effectively reduce leakage and, according to Bednar-Friedl et al. (2012), they can be twice as effective when emissions emitted throughout the entire industrial process are considered. Along the similar lines, Dissou and Eyland (2011) claim that they help to improve the competitiveness of industries in consuming countries. Kuik and Hofkes (2010) suggest that they might reduce leakage in the iron and steel industry, but that the reduction would be less for the mineral-products sector. In relation to welfare and trade, Dong and Whalley (2009) believe that the impacts would likely be small, although they recognise that China's imports would register a fall. Burniaux et al. (2010) similarly recognise that welfare impacts would be small, but slightly negative at the global level. However, other authors point out opposing findings. Atkinson et al. (2011) suggest that BCAs would create distortions in trade, in the sense that its volume and composition will change, and this could bring about associated losses in efficiency and welfare, particularly in developing nations. Lin and Li (2011) declare that BCAs would induce a structural transformation in China, shifting production toward the non-industrial outputs, which would generate impacts on the country's regional development strategy. Moreover, Dissou and Eyland (2011) estimate that BCAs would entail a high welfare cost to households, while Jakob and Marschinski (2013) found that they will not necessarily help to decrease overall CO_2 emissions. The existing research, however, has not focused on estimating the amount of global emissions that could be captured with this policy instrument, and analyse which sectors in the developing world could potentially be most affected. This represents a gap in the literature that this thesis seeks to address.

2.4. International trade

2.4.1. Trade and development

Trade between different regions and societies has existed for thousands of years. It has allowed people to enjoy a wider variety of goods and is viewed as a manner of achieving progress and wealth. It was in the sixteenth century when the idea of foreign trade started to be envisaged in Europe as an important doctrine for ensuring a country's political and economic dominance. This doctrine received the name of *mercantilism* and maintained its relevance until the eighteenth century. It was based on the principle that the richness of a nation depends on its ability to accumulate wealth mainly in the form of precious metals (i.e. bullionism) by incurring in a positive trade balance with respect to other countries (see: Barber, 2009; Peukert, 2012). Ruling governments consequently had to encourage exports, while protecting domestic producers from goods manufactured in foreign nations through prohibitions and tariffs. Adam Smith criticised this view in his most notable work, known as *The Wealth of Nations*, in which he proposed the initial basis for a first theory of international trade. For him, the mercantilist approach meant that nations could not benefit simultaneously from trade, since one nation's exports are necessarily other nation's imports, which is now known as a zero-sum game (Engerman, 1994). He thus recommended that a country should specialise in producing those goods which it can produce more efficiently and at a lower cost with respect to others. The divergence in the levels of efficiency and costs of producing traded goods between nations depends on their different endowments of factors of production. In this sense, if a country possesses vast quantities of a certain resource or has enough skilled workers, it could produce more of a given good at a lower cost than its competitors, holding an *absolute advantage*. Smith then argued that a portion of the revenue derived from exporting the surplus of those efficiently-produced commodities could be used to acquire other types of products for which the nation does not have a productive advantage. Although Smith is not properly esteemed as a trade theorist, he established clear link between international trade and economic development (Myint, 1977). By acquiring an absolute advantage in trade, countries can extend their markets and increase the real revenue and wealth of their societies and thus their welfare. This idea was held until some decades later David Ricardo revised the theory. According to him, all economies can gain from trade even if they do not hold an absolute advantage. He thought that it is not the absolute, but the *relative* or *comparative advantage* that determines the benefits of international trade. In his *Principles of Political Economy and Taxation*, Ricardo uses an example involving England and Portugal to explain the principle of comparative advantage.

> "*To produce the wine in Portugal, might require only the labour of 80 men for one year, and to produce the cloth in the same country, might require the labour of 90 men for the same time. It would therefore be advantageous for her to export wine in exchange for cloth. This exchange might even take place, notwithstanding that the commodity imported by Portugal could be produced there with less labour than in England. Though she could make the cloth with the labour of 90 men, she would import it from a country where it required the labour of 100 men to produce it, because it would be advantageous to her rather to employ her capital in the production of wine, for which she would obtain more cloth from England, than she could produce by diverting a portion of her capital from the cultivation of vines to the manufacture of cloth.*" (Ricardo, 1817, pp. 158-159)

Ricardo states that relative costs (i.e. labour cost of wine/labour cost of cloth) vary across nations, and these can gain by specialising in the manufacture of those goods for which the relative opportunity costs are lower. In Ricardo's example, Portugal holds an absolute advantage in both goods. However, it is more convenient for this country to shift its factors of production to cultivate wine in exchange for more cloth than what could be produced domestically, although cloth is more expensive to produce in England. This last country, on the other hand, benefits by acquiring low-cost wine and specialising in cloth. In this way, both parties benefit by engaging in trade, expanding their production frontiers, generating more income and increasing the welfare of their societies. Ricardo's theory thus comprises a *positive-sum* game or a win-win situation (Kitson et al., 2004).

The Ricardian theory of comparative advantage prevailed during the nineteenth century and part of the twentieth, until it started to be criticised by a new school of economic thought. Structuralist economists noticed that trading under the principles of comparative advantage had created an increasing divergence between rich and poor countries. The structural-change school originated during the 1950s by the work of economists working at the UN Economic Commission for Latin America and the Caribbean (ECLAC). They conceived the dependency theory, based on the Prebisch-Singer hypothesis (Prebisch, 1950; Singer, 1950), and is closely linked to the world-systems theory, which is rooted more in sociological sciences (see: Wallerstein, 1974; Chase-Dunn and Grimes, 1995). These theories basically express that the world is divided according to a power hierarchy, where the core or the North, composed of industrialised economies, exploits the periphery or the South, formed by developing countries[12]. The periphery specialises in the extraction of material resources, while the core produces capital goods. Resources thus flow from the periphery to the core, while capital goods flow in the inverse direction, leading to an unequal exchange. Prebisch and Singer noticed that over the years the terms of trade (i.e. price of exports/price of imports) of developing countries, which mainly depended on the production of primary products, had deteriorated rapidly. This is due to the income elasticity of manufactured goods, which is higher than that of commodities. Similarly, technological progress augments the demand for manufactured goods compared to the demand for raw materials. Consequently, as income rises and an economy becomes more industrialised, the demand of manufactured goods relative to GDP increases, while the demand for basic commodities falls. A higher demand of the former goods elevates its price, while the latter become cheaper. For a country that exports primary products and requires importing more elaborate goods, this translates into a worsening of its terms of trade (see: Grilli and Yang, 1988; Sarkar and Singer, 1991; Bleaney and Greenaway,

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[12] The term "North-South divide" originated as an attempt to correct the usage of concepts such as "First-World" and "Third-World" countries, which were introduced by Alfred Sauvy in 1952 (see: Wolf-Phillips, 1987). It refers to a division between industrialised nations, mostly located in the northern hemisphere, and non-industrialised, poor nations that are predominantly located to the south of the equator. However, its meaning goes beyond geographical location, since some countries, like Australia and New Zealand, are considered to be part of the North. This classification has more socioeconomic and political connotations, making a distinction between varying levels of development achieved by different countries.

1993). Hence, developing countries are structurally constrained and increasingly dependent on the core over time. In other words, developing countries face a mounting difficulty to become industrialised[13]. In order to prevent this situation from happening and to reduce their foreign dependency, some regions decided to close their markets to trade and implement an *import-substitution* scheme (Baer, 1972; Bruton, 1998).

Structuralism rejected the notion that Smith's self-regulating market mechanism or the *invisible hand* could lead the process of development. According to a Keynesian rationale, government intervention was deemed as a necessary action. The main task was thus to transform the structure of the economies under the supervision of the state in order to industrialise key productive sectors on a gradual basis. This is how import-substitution schemes started to be implemented. These consisted in putting into practice protectionist measures so as to shield the nascent industrial sectors from foreign competition. The aim was to strengthen the intermediate-goods sectors first and, once they had achieved a higher level of productivity, similar measures would be employed in capital-goods industries. This model delivered some results especially in Brazil and Mexico (Alarcon and McKinley, 1992). However, the objectives were never fully met. Industrialisation of capital-goods sectors was not achieved successfully. State-protected sectors soon felt safe from any kind of competition, not having incentives to become more productive. Moreover, some of the strategic industries were state-owned, and corruption and bad practices started to corrode them. Finally, during the late 1970's and early 1980s, the model collapsed at a moment when the debt crisis impacted some developing countries, especially in Latin America (Rodrik, 1992).

Empirically, the Prebisch-Singer hypothesis has been disputed by several authors (see: Hadass and Williamson, 2003). Although some evidence has been found at the global level, it is still elusive when examining specific cases (Ross, 1999). However, another proposition that follows a similar line of reasoning emerged some years later. It goes in line with post-Keynesian theory, and is known as the *balance of payments constrained growth* (Thirlwall, 1979). Essentially, this model considers that the level of output is demand-determined, and an economy's long-term growth rate is given by the expansion rate of its exports and the income elasticity of its imports. By following the same logic used in the Prebisch-Singer hypothesis, a country that experiences a

[13] Also relevant to this discussion is the *Resource Curse Hypothesis*. It states that countries which possess an abundance of natural resources, such as oil reserves, gas, or tropical forests, have experienced lower economic growth rates and are less developed than resource-poor but industrialised nations (see: Sachs and Warner, 1995).

weakening of its terms of trade would also face an increasing current account deficit. Since it is impossible to finance this deficit indefinitely, this situation constitutes a constraint to growth. This idea was later known as *Thirlwall's law*. Some evidence that supports this law has been produced. López and Cruz (2000) have shown that it is relevant for Latin American economies. More recently, Bagnai (2010) found supportive results in a study of 22 OECD countries.

During the late 1970s, the Ricardian theory stared gaining influence once more. The liberalisation of international trade was sought as a measure to promote economic growth and development in the long-run. Open economies could grow faster than those that imposed restrictions to the free flow of goods and services (Bhagwati, 1988). The export-led growth strategy considers that a country's long-term economic growth rate is determined by its openness to trade and its ability to produce for foreign markets (Krueger, 1978; Edwards, 1992, 1993). In a few words, exports constitute the main driver of industrialisation and development (Giles and Williams, 2000). The reasons behind this assertion rest on demand and supply arguments. An increase in foreign consumption leads to a rise in raw material and labour-based exports. A larger amount of exports generates employment and more income, which can be invested. Present consumption is thus sacrificed in order to promote future productivity gains. This, together with a more efficient allocation of the factors of production and the creation of economies of scale, generates a larger productive capacity. This strategy was supported by the experiences of Japan and a group of Asian countries, known as the Asian Tigers (i.e. South Korea, Singapore, Hong Kong and Taiwan). After the Second World War, Japan implemented an export-led model of growth, which prescribed sacrificing present consumption in order to achieve higher levels of investment in physical and human capital. All this was supported by strong national policy objectives and clear government strategies (Klein and Cukier, 2009). A similar model was used by the Asian Tigers, which started to register high economic growth rates and quickly became industrialised in the 1980s. They had set an example of how developing nations could effectively transform the structures of their economies and increase the living standards of their populations. China later began following a similar approach.

Under the government of Ronald Reagan in the US and Margaret Thatcher in the UK, the example of the Asian Tigers was translated into a set of policy prescriptions known as the *Washington Consensus* (see: Gore, 2000). This model, which ideology then became globally identified as *neo-liberalism*, rescued the core of Smith's doctrine. Mainly, trade liberalisation, privatisation of state-owned industries, downscaling the governmental apparatus, deregulation and fiscal discipline had to be promoted (Williamson, 1993). With the endorsement of international organisations, such as the WTO, the International Monetary Fund (IMF) and the World Bank, this model was applied especially to Latin American countries, which required urgent help after the crises in the 1980s. Soon, it was also implemented in other developing East Asian and African countries as well. A large part of the developing world soon opened itself to international trade and adopted an export-oriented industrialisation model, which is the one that predominates in the world today. When the Eastern bloc of communist states, who had adopted centrally planned models of industrialisation, collapsed at the end of the 1980's, the export-oriented scheme became the option to follow. Thus, for several decades, this strategy has constituted the mainstream policy objective advocated by international organisations, such as the World Bank, to achieve economic development.

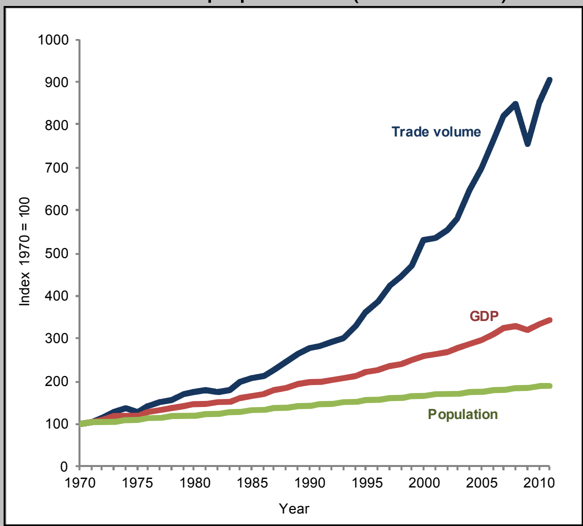
Not all nations, however, followed neoliberal measures. Countries like China and Vietnam possess mixed economies, with strong state-controlled communist regimes and productive export-oriented capitalist sectors. The success of these models, which have been fuelled by significant levels of domestic and foreign investment, has allowed them to grow at very high rates during more than one decade, and this has contributed to raise the living standards of their populations.

2.4.2. Geographical fragmentation and the factor content of trade

During the last four decades, the average volume of global international trade has grown almost three times faster than the world's GDP (see Figure 11), showing a significant acceleration since the 1990s and registering an important downfall during the 2008/09 financial crisis. This trend reflects the increasing globalisation of markets. Free trade has deepened the inter-dependency between nations. The developing world has become more dependent on the North, not only to obtain the financial resources they need via exports and foreign direct and indirect investment, but also to acquire manufactured and capital goods, as well as basic commodities (Shafaeddin, 2009). On the other hand, high-income countries have tended to depend more on the supply of resources offered by resource-rich but underdeveloped countries (see: Muradian and Martinez-Alier, 2001; Bringezu et al., 2004; Giljum, 2004; Giljum and Eisenmenger, 2004; Muñoz et al., 2011).

This intricate network of trade interrelations between different regions and countries has led to an intensification of the international division of labour and the geographical fragmentation of production (Athukorala, 2005; Jones and Kierzkowski, 2005; Lanz et al., 2011). It is common that products are manufactured with a range of raw materials extracted from diverse regions. These products are then assembled in some other nations, and then redistributed to yet other countries for consumption. The separation of extraction, production and consumption, often by great distances, is a standard trait of the current world's economy (Arndt and Kierzkowski, 2001). The rise of global production chains and the profound interdependency imply important challenges to analyse and measure the flows of traded goods.

Figure 11 - Growth in global volume of trade, GDP and population (1970-2011)



Note: Trade volume = (exports + imports)/2. GDP and trade are based on constant 2005 US dollars.
Source: Own figure based on data by UNSD (2013a)

In a world characterised by rapid globalisation and the geographical fragmentation of production, the Ricardian model has been losing its ability to explain the reality. Nowadays, specialisation depends no longer on a country's comparative advantage of producing a final good. Rather, it depends on the comparative advantage of the *tasks* that a nation is required to undertake in order to complete one stage of the production process (IDE-JETRO and WTO, 2011). This creates the need of determining a country's specific contribution to the factor contents of trade; that is, the amount of labour, capital and natural resources that are embodied in trade flows.

The traditional framework to explain the factor contents of trade is the Heckscher-Ohlin factor-proportions theory. Based on the Ricardian rationale, the theory states that countries have different factor endowments of capital, labour and natural resources.

The relative abundance or scarcity of any factor, in turn, influences its price. A nation that is relatively well-endowed with a specific factor of production would enjoy the relative advantage of being able to produce certain goods at a lower cost and more efficiently than other economies. Hence, countries tend to specialise and become net exporters of goods whose production makes intensive use of their most abundant factors. In this sense, the specialised sectors in the economy would benefit from trade, while those sectors that are intensive in the scarce factors would suffer a disadvantage. However, and at least in theoretical terms, the overall gains would offset the losses. In addition, the theory predicts a convergence of relative factor prices (i.e. interest, wages and rents), which positively influences income distribution. Trade consequently generates profits to all participants by expanding production frontiers, in contrast to *autarky*. Economic agents optimise their behaviour and factors of production are reallocated efficiently; consumers are able to acquire a wider array of goods at lower prices; national production levels rise, and societies become better off. The factor-proportions theory has been widely tested in order to prove its validity, and has received numerous criticisms over time (Helpman, 1984; Bernhofen, 2007; Stone et al., 2011). One of the strongest arguments against it is portrayed by the *Leontief paradox*, which reflects the theory's inability to predict the factor content and direction of trade flows. Leontief (1953) found that the US imports more capital intensive goods than what it exports, which represents a contradiction for a country that is considered to be capital intensive.

In order to address the limitations of the factors-proportions theory, some researchers, such as Hummels et al. (2001), Daudin et al. (2011) and IDE-JETRO and WTO (2011), have recently suggested that trade should be measured by the amount of value added that is incorporated in exports and imports, as opposed to using the traditional trade statistics. Value added refers to the amount by which the value of a given product is increased at each stage of its production. Alternatively, value added can also be interpreted as the total payment received by the owners of the factors of production (Black et al., 2009). Trade in value added allows a more precise determination of how much value each economic sector in each country contributes during the production process. Moreover, it is a useful tool to assess the impacts of foreign trade on economic growth and employment. Studies in this subject are still scarce, since its estimation requires a great amount of data in the form of multi-regional input-output tables (see: Mattoo et al., 2011b). The OECD (2013) has recently started publishing data for trade in value added, but it is highly aggregated for the majority of developing countries. IDE-JETRO and WTO (2011, p. 104) used data covering nine Asian countries, finding that "*the 2005 US-China trade shortfall would have even been cut by more than half, from US$ 218 to US$ 101 billion, if it had been estimated in value added*". Alternatively, Stehrer (2012) estimated that the US trade deficit with China would be reduced by about 25%, but would rise in relation to the EU27 by about 20%. Daudin et al. (2011) employed the GTAP database and their findings indicate that 32% of the value added embodied in industrial exports is consumed by foreign consumers. Stehrer et al. (2012) found that industrialised economies are net exporters of high-educated labour as compared to the developing world. Furthermore, they show that the role of services is more emphasised than what conventional trade statistics would reflect, due to the significant contribution of the service sectors in the production of manufacturing exports.

2.4.3. Potential social and environmental effects of trade

As has been explained in the previous sections, free trade contributes to enhancing well-being and strengthening development. It allows an efficient allocation of the factors of production, as incentives are created to shift capital and labour to the most efficient sectors. Moreover, trade facilitates diffusion of knowledge and the transfer of innovations between nations embodied in goods and services and through foreign direct investment (FDI). It also encourages competition between foreign and domestic industries leading to specialisation, increases in productivity and economies of scale (see: European Commission, 2010). Frankel and Romer (1999) found empirical evidence that shows that trade has a large positive effect on income. Along the same lines, Davies and Quinlivan (2006) demonstrate that increases in trade are positively associated with improvements in social welfare as defined by the HDI. In relation to the environment, the role of trade is usually explained once more by the EKC hypothesis. Suri and Chapman (1998) and Dinda (2004) recognised trade as a significant factor that can explain the relationship between income and environmental degradation. If trade positively influences economic growth and promotes structural change, then emissions would fall with increasing levels of income per capita. If the EKC holds true, a country would benefit in economic and in environmental terms by trading products and services with the rest of the world. This optimistic viewpoint was shared by some of the first EKC authors, such as Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992), who asserted that more open economies tend to produce less pollutants. More recently, this assertion was confirmed by Yamarik and Ghosh (2011), who found that trade openness reduces air pollution measured by nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and particulate matter.

Contrary to those who express optimism about free trade, other researchers have a more pessimistic view on the matter. In social terms, some assert that trade can worsen inequality in developing countries, since improvements in income favour the exporting sectors and the benefits are not distributed equally across society. Zhu and Trefler (2005) indicate that trade raises wage inequality in both industrialised and developing countries. Least skill-intensive industries tend to migrate from the former to the latter nations, where they become the more skill-intensive activities (also see: Wood, 1995). They then concentrate the larger shares of exports, generating limited spill-over effects to the rest of the economy. Meschi and Vivarelli (2009) and Popli (2010) suggest that trade with high-income countries worsen income distribution in developing nations for similar reasons. Moreover, Bensidoun et al. (2011) found that an increase in the labour content of trade raises income inequality in poor countries, but reduces it in industrialised economies, while the reverse is true for the physical-capital content of trade. In relation to the environment, some authors state that trade generates negative outcomes (Jayadevappa and Chhatre, 2000; Bulte and Barbier, 2005). Arrow et al. (1995) and Grossman and Krueger (1995) argued that, for some pollutants, reductions in emissions in wealthy countries may not necessarily be due to cleaner production processes and an increasing public demand for a better environment, but to transfers of emissions to other nations. This has become known as the *Pollution Haven Hypothesis* (PHH), which states that whilst income is rising and more restrictive environmental regulations are being implemented, rich countries tend to displace their polluting industries or export their wastes to nations with laxer environmental standards. When the PHH is applied to CO_2, it is better known as *strong* or *policy-induced carbon leakage*, a term that was defined and discussed in section 2.3.3. PHH and strong carbon leakage undermine existing environmental protection laws and treaties, inducing a regulatory *race to the bottom*.

Cole (2004) analysed 10 pollutants using data on North-South trade flows. He found evidence that the pollution-haven effects exist, although these are not found for all pollutants. Dinda and Coondoo (2006), in turn, obtained reinforcing evidence for the PHH. They found that trade openness has helped to reduce CO_2 emissions in Europe as a whole, whereas it has led to increases in Africa and Central America. More recently, Kearsley and Riddel (2010) used data for 7 pollutants, including CO_2 emissions for 27 OECD countries, and tested the validity of the PHH. Their results suggest that trade openness and dirty imports are weakly correlated with a rise in emissions. Studies that have specifically quantified strong carbon leakage have found that it is modest or even negligible (e.g. Kuik and Reyer, 2003; Cole et al., 2005; Barker et al., 2007) and that it can be offset by technology transfers (IPCC, 2007b; Di Maria and van der Werf, 2008). Weak carbon leakage, on the other hand, as was defined in section 2.3.3, corresponds to the emissions transfers required to satisfy consumption in net-importing economies via international trade regardless of the environmental policies in place in the consuming countries. As discussed in section 2.2.2, this type of leakage has been increasingly growing over time as industrialised economies have tended to depend more on imports from the developing world (Davis and Caldeira, 2010; Peters et al., 2011b). Jakob and Marschinski (2013) have recently proposed a way to decompose these transfers. They show, for example, that around 43% of the net transfer of emissions from China to the US is due to the trade balance between both countries, and around 20% from China's specialisation in high carbon intensive products.

2.4.4. South-South trade

As has been argued, international trade has intensified the inter-dependency between nations, which has not only manifested between industrialised and developing countries. Trade flows among members of the latter nations have also tended to increase over time. After observing a slowing down of economic growth rates in high-income economies during the 1970s due to rising oil prices, Lewis (1980) stressed the potential for increasing inter-developing-country trade so as to offset their dependency from the North.

Until the 1980s, trade had been almost monopolised by industrialised economies and the volume of South-South trade was small in comparison. However, in the last three decades it has become the fastest growing segment of world trade. It more than tripled between 1980 and 2011, going from 8.1% of global trade to 26.7%. During the same period, North-North trade declined from 46% to 30% (UNDP, 2013). Moreover, intra-South FDI grew on average 20% per annum from 1996 to 2009 (UNCTAD, 2011). These patterns are mainly due to two factors. On the one hand, tariffs and barriers to trade were significantly reduced in the developing world during the period (Agatiello, 2007). As an example, developing countries signed 70 trade agreements between 1990 and 2003 (Mayda and Steinberg, 2009). On the other hand, several developing nations, particularly China and some East Asian economies, registered high rates of economic growth and increased significantly their demand for goods and services.

South-South trade, however, has been uneven. Trade involving low-income countries has generally grown more slowly than trade related to upper- and lower-middle-income countries. Only fourteen nations conduct three-quarters of Southern trade, of which seven, including China and India, account for more than 70% of low-technology and 80% of high-technology exports from developing economies (UNDP, 2005; Hochstetler, 2013). The rest continue to be providers of natural resources, trading basic commodities. On the other hand, developing countries persist in obtaining imports from the North even though many products are available in other developing countries, often in the same region on similar competitive conditions of price and quality (Kowalski and Shepherd, 2006).

In relation to the environment, South-South trade might not deliver the same improvements as some trade economists advocate in relation to the North-South relationship. The Southern case is more ambiguous in this respect (Hochstetler, 2013). For example, China's trade with Sub-Saharan Africa rose from one billion US dollars to more than 140 billion between 1992 and 2011 (UNDP, 2013). Nevertheless, there is concern that Chinese firms are causing negative environmental impacts not only in that region, but also in Latin America, repeating exploitation patterns followed in the past by industrialised nations (Mol, 2011). The potential social and environmental impacts of South-South trade thus require much more research. Particularly, it is relevant to analyse how it can lead to more benign outcomes in terms of sustainable development.

2.5. Impacts to the developing world

Nobel laureate economist Arthur Lewis (1980, p. 555) recognised that "*for the past hundred years the rate of growth of output in the developing world has depended on the rate of growth of output in the developed world. When the developed grow fast, the developing grow fast, and when the developed slow down, the developing slow down*". The logic behind this argument stresses, on the one hand, the importance of international trade as the motor of growth that links these two types of economies and, on the other, the notion of dependency. As was explained, the global South depends on the larger Northern markets not only to sell its products, but also to attract investments and new technologies, which are vital for its development needs. In this sense, when the growth rate of imports decelerates in the North, developing economies' exports fall and their access to capital products and technology is reduced. The pattern described by Lewis, however, did not apply entirely during the 2008/09 financial crisis. While GDP in high-income nations fell 3.6% on average, the rest of the world as a group still managed to achieve positive growth rates, although an overall deceleration was still observed and the economic performance of several individual developing countries registered important downfalls.

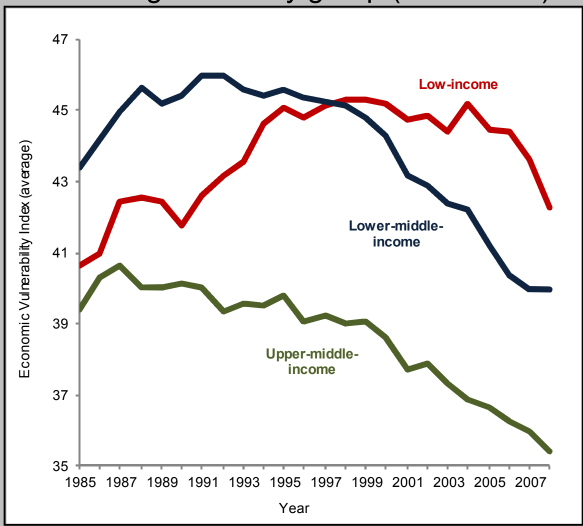
As was argued in section 2.2.4, it is urgent to address the problem of overconsumption, especially in industrialised countries, in order to alleviate environmental pressures and prevent dangerous climate change. As advocated by *Agenda 21*, consumer behaviour needs to become more sustainable, either by making the basket of consumer goods more energy- and environmentally efficient or by reducing the general levels of consumption, like prescribed by steady-state economics and the degrowth movement. However, the potential trade-offs between the environmental benefits of dematerialising consumption and the developmental impacts caused via international trade by lower imports from the developing world have not been properly analysed. A proper examination of this issue is practically nonexistent. Martínez Alier (2009, p. 1117) is one of the few researchers that have recognised the possible trade-offs. He admits that, on the one hand, these nations would benefit by the availability of a larger stock of natural resources freed by their rich counterparts but, on the other, they would "*have something to lose and little to gain from degrowth in the North because of fewer opportunities for commodity and manufactured exports, and less availability of credits and donations*". But apart from this brief assertion, few studies have delved any deeper into the matter.

Studies undertaken either from the perspective of orthodox or heterodox economic theories, have pointed out that when high-income countries have suffered a decline in economic growth rates, the shocks experienced by the South have been more acute (Willenbockel and Robinson, 2009). The majority of these analyses have evaluated situations derived from disturbances to international trade or originated by regional or global economic crises, like the ones experienced in the 1970s and 1980s, or the more recent in 2008/09. In most of these cases, when the flow of goods and capitals from North to South declined, the developing world tended to be affected by currency devaluations, mounting inflation rates, rising levels of unemployment, higher poverty rates, etc. Due to this fact, from the market optic of mainstream economics, deliberate reductions in consumption in the world's largest economies not only go against its main theoretical principles, but they would also represent a clear threat to the less developed nations.

The 2008/09 financial crisis offers some examples of the risks that lower consumption rates could entail for the developing world. The first effects of the crisis were felt by those emerging economies that were closely linked to the global financial markets. But international trade then fell sharply and commodity prices declined rapidly, hitting some of the poorest nations (Karshenas, 2009). Some of the first examinations on this matter, like the one conducted by Berkmen et al. (2009), found that those developing countries that export manufacturing goods were more affected than those who export food. Along similar lines, Willenbockel and Robinson (2009) detected that reductions in welfare among developing nations were due to a high commodity composition of exports and the degree of openness to international trade. For instance, Cambodia's economy was growing at a rate of 10.2% in 2007 (UNSD, 2013a). Its expansion was mainly fuelled by exporting low-value garments to the USA and the EU. But during the second half of 2009, 17% of the workforce was facing unemployment, compared to 2.5% in 2008. Its economy stagnated in 2009, leading to an increase in poverty. The same was true for Mexico, whose economy is extremely linked to that of the USA. Almost 80% of all its annual exports are destined for its Northern neighbour (INEGI, 2013). However, after the economic breakdown, the USA started demanding less imports. Consequently, Mexico's construction, automotive, and electrical appliance sectors, among others, collapsed (World Bank, 2010). Mexico's GDP fell 5.9%, representing the second worst economic performance in seven and a half decades, while the USA suffered a decline of 3.1% (UNSD, 2013a). Income per capita was reduced by 8% in the poorest quintile of Mexican households, while the poverty rate the poverty rate increased by nearly 4% between 2008 and 2010 (Habib et al., 2010).

The effects on developing countries caused by distortions in trade can be seen through the Economic Vulnerability Index published by the UN Development Policy and Analysis Division (UNDESA, 2012). It is mainly composed by seven indicators, which are population, remoteness from world markets, export concentration, share of agriculture in GDP, people affected by natural disasters, instability of agricultural production, and instability of exports of goods and services (Guillaumont, 2009). As shown in Figure 12, the average economic vulnerability of upper-middle and lower-middle-income countries improved by 10.1% and 7.9%, respectively, from 1985 to 2008. These advancements were fuelled particularly by the performance of the big emerging economies like China, India and Brazil. The behaviour of low-income countries, however, showed a peculiar trend. Their average vulnerability score was smaller than that of the lower-middle-income group in 1985, as they had remained closed to international trade. When they started opening their markets, however, their economic vulnerability increased. In 2008, their score was around 4% higher than at the beginning of the period. This means that they became more susceptible to trade shocks. Some improvements have been registered since 2004, mainly due to higher economic growth rates and more stable flows of goods and services.

Figure 12 - Economic vulnerability index according to country group (1985-2008)



Source: Own figure based on data by UNDESA (2012)

Studies that analyse the specific consequences in developing nations of changes in demand due to mitigation actions in the North are practically missing in the scientific literature. The ones that are available are permeated by a strong Northern viewpoint and have mainly concentrated on determining the costs for industrialised countries derived from unilateral emission reductions and the implementation of trade policies (see: Peterson and Schleich, 2007; Ho et al., 2008; Aldy and Pizer, 2011). However, a full quantification of the impacts derived from these actions on developing countries is still required. Mattoo et al. (2009, 2011a) have undertaken some of the few existing analyses. In their first paper, the authors examine how changes in the price for carbon, induced by emissions reductions, emissions tradability and international monetary transfers to developing nations, may affect manufacturing sectors in the developing world. They found that the impact differs according to the carbon intensity registered in different regions. In India and China, even modest cuts would depress manufacturing output by 6% to 7%, while this sector’s exports would fall by 9% to 11%. Meanwhile, low carbon intensive countries, such as Brazil, would be less affected. Furthermore, aggregate welfare would fall by 2% in low and middle-income nations. In their second paper, they explore the effects on the developing world of implementing BCAs in industrialised nations. Their findings indicate that when border taxes are based on the carbon content of imports, China’s manufacturing exports would shrink by one fifth and those of low and middle-income economies by 8%. Moreover, income would decline by approximately 4% and 2.5%, respectively. Other authors, like Atkinson et al. (2011), recognise that demand-side mitigation policy instruments would modify the volume and composition of international trade, leading to associated losses in welfare in developing countries.

Authors, like Victor and Rosenbluth (2007) and Daly (2013), believe that downscaling consumption in the North can be done through a planned and controlled process. However, the specific mechanisms that could allow this to become a reality without harming the developing South have not been detailed or sufficiently researched. This research will address this issue.

2.6. Further remarks and research gaps

This chapter presented a critical review of the main bodies of literature related to this research project. Its nature requires presenting a background of the most relevant studies that focus on anthropogenic GHG emissions, development, consumption and international trade, and explaining the profound interrelation that exists between these topics. In addition, the chapter offers working definitions based on the literature for the main terms used in this thesis (e.g. carbon and development spaces, economic and human development, sustainable consumption, demand-side mitigation, etc.). Throughout the review, research gaps were identified pertaining to the four research questions presented in the introductory chapter (section 1.2). Regarding question 1, it was argued that it is still not clear if the carbon EKC hypothesis is valid when including consumption-based CO_2 data. The majority of the existing analyses have utilised territorial emissions, and there are no global and comprehensive consumption-based studies. If the carbon EKC was to hold true, the best prescription to attain higher levels of development and a better environment would be to increase income per capita throughout the world. This thesis thus seeks to provide evidence in this respect in order to accept or reject the hypothesis. The present chapter also explained that higher incomes are usually associated with greater consumption rates of energy and resources, and that there is the need to address overconsumption in wealthy nations as it constitutes one of the main drivers of climate change. In this sense, there is the need to either modify consumption patterns or reduce the overall levels of economic throughput. This thesis emphasises the importance of achieving these objectives with the use of demand-side mitigation options in conjunction with technological measures, as it will prove difficult for the latter to solve the climate problem by themselves in the available timeframe. However, while changes in demand in the North could free carbon space and deliver environmental benefits, they can generate negative effects in the developing world via international trade and, more specifically, in low-income countries, which are economically vulnerable. A proper examination of these trade-offs is practically nonexistent in the scientific literature. The available studies have been conducted from a Northern point of view and have mainly concentrated on determining the costs for industrialised countries. In relation to research question 2, it is thus uncertain how much value added, and particularly wages to skilled and unskilled labour, embodied in imports from developing nations are associated with every tonne of CO_2 that is mitigated in the North through demand-side mitigation measures. This thesis aims to cover this research gap and provide answers to this query. The present literature review, moreover, identified the different forms that demand-side mitigation policy instruments can adopt. It was explained that it is important to specifically analyse the case of BCAs, as discussions are happening in some Annex I countries (e.g. US, EU, Australia) about their potential adoption. The US has explicitly stated that it will not implement an emissions trading scheme without a provision for BCAs. The existing literature, however, offers mixed evidence about their potential impacts and effectiveness. Several authors have built a strong case about their possible negative effects, suggesting that they may distort trade flows and erode welfare levels in developing countries. Furthermore, others indicate that BCAs would require a complex administration that could make them unviable in practice. In this sense, with regards to research question 3, the literature does not indicate the amount of global emissions that could be captured with this policy instrument and, more importantly, which sectors in the developing world could potentially be most affected in terms of losses in value added, and especially in wages, due to distortions in trade. This thesis thus tries to fill this gap in the knowledge base. The overall question, however, is to determine to what extent human development can be enhanced with the available carbon space. The present chapter presented different quantifications of the carbon budget according to the RCPs that will be used in the IPCC's Fifth Assessment Report. The carbon space compatible with a 2°C target is given by the RCP3-PD pathway, which requires emissions peaking in 2020 and following a sustained decline onwards, becoming negative from the 2070s. The largest share of carbon space per capita, however, would correspond to industrialised nations, whereas low-income countries would receive a significantly smaller proportion. This represents an enormous challenge, as the necessary development space is still considerable. The achievement of the MDGs has been uneven, and large efforts still need to be made to bring millions of people from extreme poverty and grant them access to an acceptable standard of living. Research question 4 is thus relevant, as there is uncertainty in the literature about how much development across the world can be improved with the available carbon space. Although studies have evidenced a gradual decoupling between the satisfaction of human needs and energy and carbon per capita, developmental improvements in the South could be limited given their current economic structures. This gap is thus addressed in this research.

The next chapter presents the different methods and data used in this thesis in order to provide answers to the proposed research questions.

Chapter 3
Methods and data

This chapter presents the research design and describes the methods and data used in this thesis to provide answers to the research questions outlined in the introductory chapter. Due to the nature of such queries, a multi-method approach is required. The chapter starts in section 3.1 by discussing the research design and explaining the reasons for selecting Panel Data analysis and Environmentally-Extended Multi-Regional Input-Output (EE-MRIO) Analysis as the most appropriate methods. This is then followed by a description of these techniques in section 3.2. Next, section 3.3 explains how the MRIO model was built based on the GTAP 8 database. Section 3.4, in turn, covers the data and their sources. A discussion about the strengths and limitations of each method is then presented in section 3.5. Finally, a brief summary is offered in section 3.6.

3.1. Research design

As was explained in Chapter 1 (section 1.2), four separate but related aspects related to the overarching aim were chosen to be explored, each guided by a specific sub-research question. The nature of these queries demanded using different methods, as can be appreciated in Table 7.

Table 7 - Methods used to address the proposed research questions

No.	Research question	Method used
1	Is the EKC for carbon valid from a consumption-based approach?	Panel Data Analysis
2	How much value added and wages paid to skilled and unskilled labour in developing countries are associated with every unit of CO_2 that is mitigated in different sectors through reductions in consumption in industrialised nations?	Multi-Regional Input-Output Analysis (MRIO)
3	How much value added and wages paid to skilled and unskilled labour in developing countries are associated with CO_2 emissions that would be captured in different sectors through the implementation of border carbon adjustments in industrialised nations?	Multi-Regional Input-Output Analysis (MRIO)
4	To what extent can human development be improved in the developing world within the limits of the available carbon space as defined by the RCP pathways given the continuity of the status quo?	Panel Data Analysis

EKC studies have traditionally been carried out using econometric methods, and the majority of them have employed panel data analysis (see: Stern et al., 1996; Dinda, 2004). Standard regression techniques and time series analysis are adequate when a study is conducted using data for a single observational unit (i.e. one country). Nonetheless, it is customary that testing the validity of the EKC involves focusing on more than one unit. In fact, existing examinations have tended to include an increasing number of nations and longer time periods. In this sense, panel data analysis is an appropriate method, since it allows estimating the relationship between a dependent variable and one or more independent variables that change not only over time, but also across numerous observational units. In this case, the income-emissions relationship is wished to be examined using data for 109 individual countries and 20 regions which, in turn, comprise another 126 nations and territories corresponding to the period 1990-2010. The specific panel data models that will be applied are explained in section 3.2.1.

Panel data analysis is also used to scrutinise the evolving relationship between human development and CO_2 emissions due to the same reasons offered in the paragraph above. Data for 187 individual countries pertaining to the period 1980-2010 are utilised in order to assess the extent to which living standards can be improved across different regions within the limits of the available carbon space (fourth research question). This method is used to estimate the historical carbon elasticity of human development, which is then used to project human development levels, as expressed by the HDI, into the future according to the emissions described by the different RCPs (see section 3.2.1.6). These elasticities express how much CO_2 emissions have been required over time to achieve improvements in well-being. Again, the specific models that will be used are described in section 3.2.1.

Input-Output Analysis, on the other hand, is a technique that is employed to assess the interrelationships between economic sectors or industries. It is specifically useful to examine the effects within an economic system caused by changes that take place in other areas of that same system. When these effects are related to industries or sectors that are located in several economies or regions, the technique adopts the name of Multi-Regional Input-Output (MRIO) Analysis. The IO framework has been widely applied to examine the environmental consequences of economic actions, and has thus become a standard instrument in the field of ecological economics (Murray et al., 2010). Furthermore, this method has been increasingly used to assess how much CO_2 is associated with the consumption of goods and services throughout the global supply chain (see: Wiedmann et al., 2007; Wiedmann, 2009). The same procedure can be applied to calculate the amount of value added and wages that are embedded in products and services destined for final consumption (see: Daudin et al., 2011; IDE-JETRO and WTO, 2011; Mattoo et al., 2011b). In this sense, it is an appropriate method to address the second and third research questions. These analyses involve

109 nation states and 20 aggregated regions, each with 57 economic sectors, corresponding to the years 2004 and 2007 (see Appendix A.2 for a complete list).

3.2. Methods

This section focuses on describing the main features of the two methods used in this thesis: Panel Data analysis and EE-MRIO analysis.

3.2.1. Panel Data analysis

As has been explained, panel data analysis is an econometric technique that is useful to identify causal relationships between variables using data that involve several observational units. Data can be either longitudinal (i.e. time series for a single unit), cross-sectional (i.e. several units at a specific moment in time), or both. Panel data is characterised by possessing a spatial (i.e. cross-sectional) dimension and a temporal (i.e. longitudinal) dimension (Wooldridge, 2002). This method, in this sense, is particularly helpful when relationships between variables are wished to be estimated in relation to more than one country over a certain period of time. The amount of methodological and empirical studies that have used panel data analysis has increased significantly during the last two decades. According to Hsiao (2007), this has been mainly due to a considerable increase in data availability, the method's greater capacity for modelling the complexity of human behaviour than by using single cross-section or time-series data, and the growing methodological and computational advancements.

The number of different panel data models has increased significantly over the years. Choosing the right model depends on the nature of the data and on the problem that is wished to be analysed. As an initial exploratory approach, pooled Ordinary Least Squares (OLS) regressions can be used to examine the overall behaviour of the variables. This implies pooling the data for all the observational units and years together and treating it homogeneously. In the case that there are no significant country- or time-effects (i.e. both the intercepts and slopes are constant across units), then it can be said that the estimated OLS coefficients are consistent and unbiased. In the opposite case, a more appropriate model should be chosen. In order to assess the viability of using the pooled OLS model, two tests can be applied. An F-test is usually conducted to compare different models that make use of the same dataset in order to select the one that produces a better fit. In this case, the F-test is employed to identify the presence of specific traits that are fixed to individual countries (i.e. fixed effects) by contrasting this particular specification to a simple OLS model. If these traits were present and were statistically significant, OLS estimators would not be valid, indicating the need to use a fixed effects model (Baltagi, 2005). Moreover, the Breusch-Pagan Lagrange Multiplier test can also be performed. It was designed to evaluate if the variances across observational units are equal to zero. This means that no significant differences exist across units. In case that variations are detected, then a random effects model would be preferred over the OLS estimator (Breusch and Pagan, 1980). Their respective null hypotheses can be found in Table 8.

Table 8 - F-test and Breusch-Pagan LM test

Test	Null hypothesis
F-test: All fixed effects are null	No fixed country-specific traits exist
Breusch-Pagan LM test for pooled versus random effects	Variances across entities are zero

3.2.1.1. Fixed and random effects models

Fixed and random effects models are generally applied in numerous panel data analyses. They are useful since they can help to control for variables that cannot be observed or measured (e.g. geographical location, cultural factors, different industrial practices, etc.) or variables that change over time but not across units (i.e. regulations, international agreements, etc.). According to Wooldridge (2002), one could decide whether to use fixed or random effects models depending on how the term c_i is treated in the following equation.

$$y_{it} = \beta X_{it} + c_i + u_{it} \tag{3}$$

where y_{it} is the dependent variable and X_{it} stands for any independent variables that change across time (*t*) but not units (*i*), or well that may vary across *i* but not *t*, or that may change across *i* and *t*. Moreover, β is the estimated coefficient, u_{it} is a stochastic error term (i.e. disturbance) and c_i represents unobserved effects. If c_i is treated as non-variant, then it is considered as a fixed effect and a parameter is estimated for each *i*. On the contrary, if c_i shows variations across *i*, then it is treated as a random effect.

Fixed effects models should be used when the unobserved time-invariant effects are not of interest. The random effects model should be employed when there are reasons to believe that the differences across units have an influence on the dependent variable. However, in this last case it must be assumed that c_i is not correlated with the predictors included in the model. In other words, the individual unobserved effects or characteristics should not explain the behaviour of the observed traits represented by the independent variables.

In a fixed effects model, the slope coefficients are assumed to be constant (i.e. homogenous) among units, but the intercept may vary across units or over time. In this sense, unit-specific dummies are included to allow the intercept to differ across cross-sectional units, while time-specific dummies allow the intercept to differ across different time periods. On the other hand, the random effects model considers that the intercept is the mean value of all the cross-sectional intercepts (Baltagi, 2005).

The key issue when choosing the appropriate model, however, lies on whether or not c_i is correlated with the observed explanatory variables X_{it} (Hausman and Taylor, 1981). Regarding the random effects model, the correlation must be zero. In order to determine this, the Hausman test is applied. Its null hypothesis assumes that the cross-sectional unobserved effects are not correlated with the regressors. If such correlation does not exist, then the random effects model would produce more consistent estimators. In the opposite case, a fixed effects model would be preferred.

Apart from fixed and random effects, an alternative model can be used in case that only the variations across units are deemed as relevant. The between-groups model, in this sense, ignores the differences that exist within observational units. Its estimators are calculated by using the mean values of the variables of every unit. Only the variations between cross-sectional observations are thus captured and time effects are eliminated. Stern (2010) proposed this method as an option to free the EKC estimation from assumptions about time effects. However, there is a risk that the individual effects would then be blended with the residuals. This can produce inconsistent results if the cross-sectional errors are correlated with the group means of the regressors (Davidson and MacKinnon, 1993). Random effects estimators, nonetheless, also suffer from this potential problem, since individual effects are considered as error components. Consequently, the Hausman test can be useful in this respect. If these effects are correlated with any of the regressors, then the test would suggest that a fixed effects estimator would be more suitable to obtain consistent parameter estimates.

Assessing the influence of the unobserved time-varying effects (i.e. regulations, international agreements, etc.) is important in this thesis. In the case of the EKC and the relationship between human development and emissions per capita, they can affect the shape of the estimated curves. If these effects are eliminated and the results change substantially, then time-related effects can be regarded as important explanatory factors.

3.2.1.2. GLS with panel-corrected standard errors

The generalised least squares (GLS) method is widely used whenever heteroskedasticity is present and when the observations are correlated across panels to some degree. Heteroskedasticity implies that the variance of the errors is not constant over time. As a consequence, it violates the basic assumptions that the errors are normally distributed and uncorrelated (Wooldridge, 2002). This condition often affects cross-sectional panel data and may be caused by various reasons, like measurement errors or data quality. Furthermore, if the observations are correlated across the observational units, this could be reflected in the errors or disturbances, which absorb these unobserved common factors. This matter is of special relevance for the analyses undertaken in this thesis (see: Müller-Fürstenberger and Wagner, 2007; Wagner, 2008). As was explained in section 2.4.2, globalisation has deepened the interdependency between nations through international trade and related policies. As a consequence, actions taken in one nation have repercussions in other regions. A growing body of literature has recognised that panel data of this nature are likely to exhibit cross-sectional dependence in the errors (see: Pesaran, 2004; Baltagi, 2005). Heteroskedasticity and cross-sectional dependence, in this sense, invalidate the use of fixed and random effects models since they cause their estimators to be inefficient and produce biases in the standard errors (i.e. they may be smaller or larger than the true population variance).

Another feature that is frequently present in time series is serial correlation or autocorrelation. This condition indicates that the errors at time t are correlated with those at t-p, where p is the number of lags. This is common when the data shows seasonal or repeating patterns or when the current behaviour of a certain variable can be explained by its past levels. For instance, the levels of public debt that a country currently owes could depend on the debt levels it owed in the past. Serial correlation can cause biases in the estimated coefficients, affecting the scale of their standard errors and inflating the R^2 (i.e. measure of goodness of fit) (Wooldridge, 2002).

The GLS procedure thus corrects the estimation for heteroskedasticity and cross-sectional dependence. In simple terms, it standardises the scale of the errors and de-correlates them. A detailed explanation of the procedure is offered by Baltagi (2005). In this sense, the basic GLS specification is the following:

$$y_{it} = \beta_0 + \beta_1 X_{it} + u_{it} \tag{4}$$

where y_{it} is the dependent variable and X_{it} stands for any independent variables, β_0 and β_1 are the estimated coefficients and u_{it} is the stochastic error term that may be autocorrelated along *t* and/or contemporaneously correlated across *i*.

Serial correlation is addressed through a procedure developed by Prais and Winsten (1954) by transforming the data in a manner consistent with an autoregressive model of order 1, AR(1). In addition, this technique allows specifying if the autoregressive term is common to all observational units or specific to each unit. A detailed description of the Prais-Winsten transformation is also offered by Baltagi (2005).

In order to detect the presence of heteroskedasticity, serial correlation and cross-sectional dependence, a series of tests can be run. The modified Wald test for groupwise heteroskedasticity is used with a fixed effects model and assumes that the errors may be homoskedastic within observational units, but may differ across them (see: Greene, 2012). Its null hypothesis states that the error variance is constant across units. In turn, the likelihood-ratio test for group heteroskedasticity is based on a GLS procedure. Its null hypothesis also presupposes the absence of heteroskedasticity. Regarding serial correlation, the Wooldridge (2002) test is commonly used. Its null hypothesis assumes the absence of autocorrelation. Finally, the Pesaran (2004) test can be applied to identify cross-sectional dependence. These tests, along with their null hypotheses can be found in Table 9.

Table 9 - Tests for heteroskedasticity, serial correlation and cross-sectional dependence

Test	Null hypothesis
Modified Wald test for groupwise heteroskedasticity	Error variance is constant across units
Likelihood-ratio test for group heteroskedasticity	Error variance is constant across units
Wooldridge test for autocorrelation in panel data	Absence of autocorrelation
Pesaran's test of cross-sectional independence	Country-specific independent errors

3.2.1.3. Cointegration

The properties of many econometric techniques generally require the use of stationary variables. Stationarity assumes that the parameters, such as the mean and variance, do not change over time. That is to say, stationary variables do not adopt a trend-like behaviour. If the condition of stationarity is not satisfied, then many techniques could produce biased or spurious results (Enders, 1995). Many time series used in economic analyses are non-stationary. In statistical terms, it would be said that they possess unit roots. Consequently, proper methods need to be used in order to deal with non-stationary and stochastically trending variables.

A variable can become stationary by differencing it; that is, by subtracting the observation at time *t* from that at time *t-1*. If such variable does not display a unit root after differencing, then it can be said that it is stationary of order 1; or well, that its order of integration is 1, which in statistical notation is expressed as I(1). In some cases, however, a variable must be differenced a second time in order for it to become stationary. In that case, it is said that its order of integration is I(2).

Differencing the variables eliminates stochastic trends, but also reduces serial correlation and specification problems derived from country-related effects (Stern and Common, 2001). In addition, pooled OLS regressions can be used with differenced variables, given that the cross-sectional units share a common intercept. If this condition is tested and the null hypothesis of intercept homogeneity cannot be rejected, then this method can be used instead of fixed and random effects.

Tests specifically designed for panel data are used to assess if a variable contains a unit root (i.e. it is non-stationary). A first generation of tests were developed by Levin et al. (2002), Im, Pesaran and Shin (Im et al., 2003), Maddala and Wu (1999) and Choi (2001). The latter two are based on Fisher-type Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, which were originally designed for single-country longitudinal data. The first of these tests considers the null hypothesis that there is a common unit root process across all the cross-sectional units included in the panel, while the rest of the tests allow for individual root processes, so non-stationarity may differ across units. In this sense, the alternative hypothesis in the latter tests presupposes that a proportion of the observational units are stationary. Baltagi (2005) recognises, however, that these tests assume cross-sectional independence. For this reason, a second generation of more complex tests have been developed in order to allow for cross-sectional correlation, as well as for other issues. Pesaran (2007) has designed a unit root test to handle heterogeneous panels (i.e. varying slopes) with cross-sectional dependence. Its null hypothesis assumes that all series across the observational units are non-stationary. On the other hand, when structural breaks are present, the procedure developed by Zivot and Andrews (1992) is useful to detect unit roots in panel data. This test is relevant in this thesis, since several of the time series involved (e.g. income and emissions per capita) often show discontinuities in their trends due to external shocks or structural changes, which can complicate assessing their stationarity (see: Romero-Ávila, 2008). The disadvantage of the Zivot-Andrews test is that it must be applied individually to each cross-sectional unit instead than to the panels as a whole. All these unit root tests appear in Table 10.

Table 10 - Unit root tests

Test	Null hypothesis
Levin et al. (2002)	Common unit root process across all cross-sectional units
Im et al. (2003); Maddala and Wu (1999); Choi (2001).	Unit root process across some cross-sectional units
Pesaran (2007)	Unit root process across all observational units
Zivot and Andrews (1992)	Time series possess unit roots

It is said, on the other hand, that when two variables share the same order of integration, they can be cointegrated if a linear combination of both (i.e. residuals) is stationary. If this condition is met, then the variables follow a common long-term trend (Engle and Granger, 1987). This commonly happens with economic variables that contain unit roots (i.e. are non-stationary). However, if the unit root tests reveal that the time series are integrated of different orders, then cointegration would not be of concern (Enders, 1995).

Westerlund (2007) developed a test to identify the presence of cointegration in the case of heterogeneous panels and cross-sectional dependence. It additionally estimates the short- and long-term coefficients for the variables included in the analysis and produces an error correction term. This term represents the speed of adjustment of a variable. In other words, it expresses how fast a variable returns to its long-run-equilibrium trend after a disruption in the short-run (Engle and Granger, 1987). This test employs two different statistics, called Pt and Pa, whose null hypotheses presuppose no cointegration among all the panels. Moreover, the error correction term must be statistically significant and possess a negative sign when the variables are cointegrated.

The short-run dynamics are modelled with an autoregressive distributed lags function, which allows the estimation of the error correction term (*γ*). The basic specification of this function is given by the following equation when the number of lags is equal to 1.

$$\Delta y_{it} = \beta_0 + \beta_1 \Delta X_{it} + \gamma(X_{it-1} - y_{it-1}) + u_{it} \quad (5)$$

where *Δ* represents variables in first differences. In this sense, the change in the dependent variable y_{it} is related to the change in the independent variables X_{it}, as well as the gap between the dependent and independent variables in time *t-1*. A disadvantage involved in this procedure is that it requires using differenced and lagged differenced series, which reduces the number of observations.

3.2.1.4. Heterogeneous panels

Several studies have found that the assumption of homogeneous slopes across observational units can represent a stringent restriction (see: Dijkgraaf and Vollebergh, 2005). Fixed and random effects models allow a certain level of heterogeneity across units, but they still maintain some rigidity in relation to the slopes. As has been said, the procedure proposed by Westerlund (2007) allows for panel heterogeneity in relation to intercepts, slopes and dynamic processes. It is based on the Mean Group model developed by Pesaran and Smith (1995). It basically consists on running individual regressions for each individual observational unit based on equation (5). Once the unit-specific coefficients are obtained, they are then averaged and their standard errors are computed. Equation (6) shows the procedure in the case of the estimated slope coefficients. Eberhardt and Teal (2010) have more recently suggested a variation of this model in order to correct for cross-sectional dependence. They added an additional variable composed of year dummy coefficients estimated from a pooled regression in first differences to capture cross-country effects. New individual coefficients are then estimated for this additional regressor and are then averaged.

$$\bar{\beta}_1 = \frac{\hat{\beta}_{11} + \hat{\beta}_{21} + \ldots + \hat{\beta}_{nt}}{n} \quad (6)$$

The *β*s stand for the estimated coefficients corresponding to each observational unit and *n* represents the total number of units.

3.2.1.5. EKC functional forms

In order to estimate the parameters of the territorial and consumption-based carbon EKCs, traditional linear, quadratic and cubic specifications are used. A cubic term is regularly included to check for the possibility of obtaining a statistically significant N-shaped curve. As it is commonly done in this literature, variables are expressed in logarithms (see: Stern et al., 1996; Ekins, 1997; Dinda, 2004).

$$ln\, C_{it} = \hat{\beta}_0 + \hat{\beta}_1 ln\, Y_{it} + \hat{\beta}_2 ln\, Y_{it}^2 + \hat{\beta}_3 ln\, Y_{it}^3 + \hat{\beta}_4 ln\, Z_{it} + \varepsilon_{it} \quad (7)$$

In equation (7), *C* represents CO_2 emissions per capita for country *i* at time *t* and *Y* denotes real GDP per capita based on purchasing power parity (PPP). The random disturbances ε_{it} are assumed to be normally distributed and independent across countries. The *βs* correspond to the regression coefficients, where β_0 is a constant.

The *inverted-U* shape demands that β_2<0, and β_3=0. If β_1>0 and β_2=β_3=0, then the relation would be linear and monotonic. Moreover, if β_3>0, then the function would depict an N-shaped curve. On the other hand, the turning point (TP) level of income for the quadratic specification is calculated by:

$$TP = exp\left(-\frac{\hat{\beta}_1}{2\hat{\beta}_2}\right) \quad (8)$$

The TP corresponding to the cubic specification, in turn, is found by identifying the levels of income per capita where the slope is zero. This is equivalent to the points at which the first derivative of the cubic function is null. This can be found using the following equation:

$$TP = exp\left(\frac{-2\hat{\beta}_2 \pm \sqrt{4\left(\hat{\beta}_2\right)^2 - 12\hat{\beta}_1\hat{\beta}_3}}{6\hat{\beta}_3}\right) \quad (9)$$

The equation above yields two roots. However, given the N-shapes of the observed curves, only one of the two roots is relevant. Thus, the case where the radical is added instead of subtracted in the numerator can be ignored.

Apart from income per capita, it is also a common practice to use additional independent variables, represented by Z_{it}. These will be presented in Chapter 4.

3.2.1.6. HDI-emissions functional forms

Several functional forms have been used in the literature to express the relationship between HDI and CO_2 emissions. In this thesis, two different but related forms will be used. The first one corresponds to a hyperbolic saturation curve, which has been proposed by Steinberger and Roberts (2010) and Steinberger et al. (2012). It is expressed as:

$$ln(HDI_{sat} - HDI_{it}) = A + \hat{\beta} lnC_{it} + \varepsilon_{it} \tag{10}$$

where the HDI_{sat} term represents the asymptote or saturation value, *A* is a constant and β is expected to be negative, while C_{it} represents carbon emissions per capita per year for country *i* at time *t*. In turn, the random disturbances ε_{it} are assumed to be normally distributed and independent across countries. According to Steinberger and Roberts (2010), this form offers some advantages. It produces a slightly better fit than other functional forms, is invertible and allows data weighting. The disadvantage is that the asymptote value has to be determined a priori from the data, as will be explained in Chapter 7.

In addition to this functional form, a simplified log-log version is also tested. Its only difference is that the saturation term is excluded. This form is thus not asymptotically bounded, producing a slightly steeper slope at high levels of HDI.

$$lnHDI_{it} = A + \hat{\beta} lnC_{it} + \varepsilon_{it} \tag{11}$$

In this case, β is expected to be positive and represents the carbon elasticity of human development.

3.2.2. Environmentally-extended MRIO analysis

Input-Output (IO) analysis has been regarded as an important accounting technique to study the complexity of economic systems (Miller and Blair, 2009). It was conceived by Wassily Leontief in the 1930s with the purpose of providing a better understanding of the interdependencies that exist among different areas of an economy. It is useful for economic analysis, since it shows how some parts of an economic system are influenced by changes that take place in some other sections of that same system. For example, it can describe how alterations in intermediate or final demand registered in a particular industrial sector may generate changes in the amount of required inputs and outputs in others.

Leontief (1970) also acknowledged that IO models could be useful to determine the environmental repercussions of the economic activity. The different sectors of an economy not only require natural resources in order to produce different goods and services, but they also generate several by-products (e.g. pollution and waste) during their production processes. In this sense, IO analysis can be used to trace the material requirements of each sector, as well as the emissions and waste that are generated by each of them. This means that the environmental pressure derived from the various production stages of a particular good or service can be revealed. For instance, one could calculate the amount of CO_2 that is emitted upstream throughout the supply-chain for any particular product or service. As has been said, IO analysis has become a standard instrument in the field of ecological economics (Murray et al., 2010).

IO analysis relies on input-output tables, which are regularly published by most countries according to guidelines established by the UN. These tables or matrices represent the structure of an economy. In these matrices, all the outputs produced by different sectors are at the same time inputs for the rest. The columns display the inputs, while the rows exhibit the various outputs. In other words, the columns show the flow of goods provided from each sector to the others in monetary or physical units, while the rows depict the flows each sector receives from their counterparts.

The total output for each sector (x_i) is distributed in rows in the following way:

$$x_i = x_{i1} + x_{i2} + \dots + x_{ij} + \dots + x_{in} + y_i \qquad (12)$$

Where y_i stands for final demand for sector *i*, and *i*,*j* = 1, 2,…, *n*. To calculate the technical coefficient matrix, the inputs of the *j*-th sector are divided by the total inputs of that sector (x_j), so that:

$$a_{ij} = \frac{x_{ij}}{x_j} \rightarrow x_{ij} = a_{ij} x_j \qquad (13)$$

The coefficient a_{ij} shows the relative inputs that each sector uses. Substituting this last equation in (12):

$$x_i = a_{i1}x_{i1} + a_{i2}x_{i2} + \ldots + a_{ij}x_{ij} + \ldots + a_{in}x_{in} + y_i \tag{14}$$

In matrix notation, this new equation can be expressed as *X*=*AX*+*Y*, where:

$$A = \begin{Bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{in} \end{Bmatrix} \qquad X = \begin{Bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{Bmatrix} \qquad Y = \begin{Bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{Bmatrix}$$

The *A* matrix shows the structure or the technological characteristics of an economy. The terms in the equation can be rearranged to solve for *X*:

$$X = (1 - A)^{-1}Y = LY \tag{15}$$

where *I* is an identity matrix and $(I\text{-}A)^{-1}$ is known as the Leontief inverse (further identified as *L*), which indicates the inter-industry requirements of the *i*-th sector to deliver a unit of output. In turn, *Y* is a vector of final demand.

As has been said, when industries and consumers are located in different countries or regions, then the traditional IO framework can be expanded, and the technique adopts the name of Multi-Regional Input-Output (MRIO) Analysis. An MRIO model is useful because it captures the underlying structure of several economies and the interdependencies between their different industries through international trade. This method has been frequently used to examine global value chains. The insights obtained from these models are thus not only helpful for research purposes, but also for policy making and economic planning.

In an MRIO framework, the technical coefficient matrix (*A*) accounts for domestically produced goods and services within the different regions and also for the trade that takes place between them. In this sense, the sectoral requirements of region *m* are decomposed into a domestic component and an imports component. The former represents inter-industry relationships within the region, while the latter shows the inter-industry relationships with other sectors located in the *n*-th region.

$$A_m = A_m^D + \sum A_n^I \tag{16}$$

Hence, *A* becomes a square composite matrix of technical coefficients formed by a number of blocks or sub-matrices. The diagonal blocks (i.e. A_{mn}^D, where *m*=*n*) represent domestic IO matrices, which show the inter-linkages between sectors located within regions. Conversely, the off-diagonal blocks (i.e. A_{mn}^I, where *m*≠*n*) represent the sectoral requirements of region *m* from other sectors located in region *n*. These are known as the import matrices. The *A* matrix can thus be expressed as follows:

$$A = \begin{Bmatrix} A_{11}^D & A_{12}^I & \cdots & A_{1n}^I \\ A_{21}^I & A_{22}^D & \cdots & A_{2n}^I \\ \vdots & \vdots & \ddots & \vdots \\ A_{mn}^I & A_{m2}^I & \cdots & A_{mn}^D \end{Bmatrix}$$

As has been said, the *A* matrix is composed of domestic and import sub-matrices. For the sake of clarity, this matrix is shown below in expanded form for a model with two countries, named *m* and *n*, each with *s* sectors. The technology matrix can be expressed in the following way:

$$A = \begin{Bmatrix} a_{11}^{mm} & a_{12}^{mm} & \cdots & a_{1s}^{mm} & a_{11}^{mn} & a_{12}^{mn} & \cdots & a_{1s}^{mn} \\ a_{21}^{mm} & a_{22}^{mm} & \cdots & a_{2s}^{mm} & a_{21}^{mn} & a_{22}^{mn} & \cdots & a_{2s}^{mn} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{s1}^{mm} & a_{s2}^{mm} & \cdots & a_{ss}^{mm} & a_{s1}^{mn} & a_{s2}^{mn} & \cdots & a_{ss}^{mn} \\ a_{11}^{nm} & a_{12}^{nm} & \cdots & a_{1s}^{nm} & a_{11}^{nn} & a_{12}^{nn} & \cdots & a_{1s}^{nn} \\ a_{21}^{nm} & a_{22}^{nm} & \cdots & a_{2s}^{nm} & a_{21}^{nn} & a_{22}^{nn} & \cdots & a_{2s}^{nn} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{s1}^{nm} & a_{s2}^{nm} & \cdots & a_{ss}^{nm} & a_{s1}^{nn} & a_{s2}^{nn} & \cdots & a_{ss}^{nn} \end{Bmatrix}$$

Where elements a_{ij}^{mm} and a_{ij}^{nn} represent the technical coefficients corresponding to the domestic matrices, while elements a_{ij}^{nm} and a_{ij}^{mn} show the inter-country trade coefficients pertaining to the import matrices. As can be appreciated, the size of the *A* matrix grows considerably every time an additional region is included. In a model with *n* nations or regions, each with *s* sectors, the dimension of the technology matrix would be *n*s* by *n*s*. On the other hand, an n-country model would comprise *n* domestic matrices and n^2-*n* import matrices.

In the case of *X* and *Y*, the model must include total output and final demand, respectively, of all sectors located in all regions. Regarding *Y*, it incorporates all the components of final demand (i.e. private and public consumption, gross capital formation and change in stocks) of domestically produced goods and services (Y^D) within region *m*, as well as of imported products and services to final demand (Y^I) from region *n* to be consumed in *m*. Moreover, goods and services produced domestically (*E*), but destined for final consumption in region *n* (i.e. exports) are additionally included in *Y*.

$$X = \begin{Bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{Bmatrix} \qquad Y = \begin{Bmatrix} Y_1 + \sum E_{1n} \\ Y_2 + \sum E_{2n} \\ \vdots \\ Y_n + \sum E_{mn} \end{Bmatrix}$$

In this sense, in an open economy the standard IO equation can be rewritten as:

$$X = (A^D + A^I)X + Y^D + Y^I + E - M \quad (17)$$

Since total imports (*M*) are equal to imports to intermediate demand (A^I) plus imports to final consumption (Y^I),

$$M = A^I X + Y^I \quad (18)$$

then, by substituting equation (18) in (17), exactly the same form of the standard equation (15) is obtained, implying that $Y=Y^D+E$. This implies that it can be used to determine the amount of output (*X*) from any arbitrary demand.

In addition to the MRIO model, this thesis also makes use of a Bilateral Trade Input-Output (BTIO) model. This method does not split the bilateral trade flows into components to intermediate and final consumption. It is particularly useful to build a multi-regional model when import matrices are not available and the modeller has to rely on bilateral trade data. It has also been regularly used to determine the amount of emissions embedded in total trade flows, as opposed to only in final consumption. In this last case, it is better known as an Emissions Embodied in Bilateral Trade (EEBT) model (see: Peters, 2008; Atkinson et al., 2011). Its main difference with respect to an MRIO is that the sectoral requirements of region *m* just include the domestic component, while the imports component is omitted.

$$A_m = A_m^D \quad (19)$$

In this sense, the *A* matrix is sparse, with domestic components situated in the main diagonal and zeros in the off-diagonal sub-matrices:

$$A = \begin{Bmatrix} A_{11}^{D} & 0 & \cdots & 0 \\ 0 & A_{22}^{D} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & A_{mn}^{D} \end{Bmatrix}$$

The inter-industry requirements with respect to sectors located in region *n* are appended to the *Y* vector.

$$Y = \begin{Bmatrix} Y_1 + \sum E_{1n}^{int} + \sum E_{1n}^{final} \\ Y_2 + \sum E_{2n}^{int} + \sum E_{2n}^{final} \\ \vdots \\ Y_n + \sum E_{mn}^{int} + \sum E_{mn}^{final} \end{Bmatrix}$$

where E^{int} represents exports to intermediate (i.e. inter-industry) demand and E^{final} stands for exports to final demand. In this manner, equation (17) becomes:

$$X = A^D X + Y^D + Y^I + E^{int} + E^{final} - M \quad (20)$$

Then, by substituting equation (18) in (20), it can be inferred that the standard equation (15) can be obtained as before, assuming that $Y=Y^D+E^{int}+E^{final}$.

Both the MRIO and the EEBT models can be extended so as to include environmental variables. In this case, a vector of CO_2 emissions is built with data disaggregated into sectors. It is assumed that CO_2 is a function of output (*X*). The emissions generated by sector *i* can be divided by the corresponding output (X_i) in order to obtain a row vector of direct carbon intensities. These intensities can then be expressed as a diagonal matrix ($\hat{C}$). In order to determine the amount of emissions (*C*) associated with a given output (*X*), $\hat{C}$ can be post-multiplied by *X*.

$$C = \hat{C} X \quad (21)$$

By substituting *X* according to equation (15), this is equal to:

$$C = \hat{C}LY \quad (22)$$

In this sense, the model is able to determine the amount of direct and indirect CO_2 emissions that are associated with a certain level of final demand (Y). As can be appreciated, equation (22) can also be rearranged to express final demand as the endogenous variable: $Y = (\hat{C}L)^{-1}C$. This particular inverted form is used in Chapter 5, where it will be explained further.

The term C in equation (22) represents a rectangular matrix of CO_2 emissions, with $i*s$ rows and i columns, where i is the number of countries and s the number of sectors. It can alternatively be expressed in compact form. The matrix is constituted by domestic and trade-related components. In the case of two regions, m and n, this matrix is equal to:

$$C = \begin{Bmatrix} c^{mm} & c^{mn} \\ c^{nm} & c^{nn} \end{Bmatrix}$$

where each component (c) in this matrix stands for a column vector, whose number of rows correspond to the total amount of sectors (s). In this sense, c^{mm} and c^{nn} are the emissions required to satisfy the domestic production of goods consumed within regions m and n, respectively. In turn, c^{mn} are the emissions necessary to manufacture products in m that are consumed in n (i.e. exports from m to n). Accordingly, c^{nm} are the emissions required to produce goods in n that are consumed in m (i.e. imports from n to m). The total sum of the rows in this matrix (i.e. domestic plus exports) yields direct production or territorial emissions. Conversely, the total sum of the columns (i.e. domestic plus imports) represents indirect consumption emissions. The trade balance in emissions for country m, for example, is given by c^{mn} minus c^{nm}, which is exactly the opposite with respect to region n's trade balance. Both approaches return the same amount of total emissions. However, they differ in terms of the entities to which they are allocated (Munksgaard and Pedersen, 2001; Gallego and Lenzen, 2005; Lenzen et al., 2007; Peters and Hertwich, 2008a). From a production perspective, these are assigned to the sectors or industries where the emissions were generated during production. Conversely, from a consumption perspective, these are allocated to the final consumers (e.g. households, firms, government) according to their final demand.

Miller and Blair (2009) state that this same procedure can be applied to virtually any factor associated with inter-industry activity that is assumed to vary linearly with output.

Therefore, the diagonal matrix $\hat{C}$ in equation (21) can be substituted with intensities derived from different variables, such as energy consumption or employment. It is particularly helpful to determine the factor content of trade. In this thesis, direct intensities for value added and for wages paid to skilled and unskilled labour are used apart from CO_2 emissions. When this procedure is used in the case of value added, it is better known as *trade in value added* (Hummels et al., 2001; Daudin et al., 2011; IDE-JETRO and WTO, 2011).

3.2.2.1. Multiplier analysis

Multiplier analysis has been extensively used in the IO literature, as has been recognised by Miller and Blair (2009). According to them, one of its most frequent uses is to assess economic impacts. They are useful, for example, to estimate how exogenous changes in output or income can affect the different sectors of an economy. The notion of the multipliers rests upon the difference between the initial or direct effect of an exogenous change and the total effects caused by that change. The total effects thus envelop the direct and indirect effects (i.e. the effects that occur throughout the whole supply chain). The Leontief inverse or total requirements matrix presented in equation (15) is in fact a matrix composed of direct and indirect output multipliers. Specifically, each of its elements indicates the inter-industry requirements of the *i*-th sector to deliver a unit of output, given a level of final demand. Other types of multipliers can be built with the use of the *L* matrix, like employment, value-added or CO_2. In essence, the diagonal matrix of carbon intensities represented by $\hat{C}$ in equation (22) also represents a type of multipliers, this time for carbon. They can be labelled as direct intensity multipliers (DIMs), since they show how much carbon is directly generated by every unit of output. When this matrix is used in equation (22), it provides a set of weights to *L*, forming total intensity multipliers (TIMs). In this sense, each element in the TIMs matrix expresses how much CO_2 would vary directly and indirectly throughout the whole supply chain given a change in final demand. Equation (22) can then be alternatively expressed as:

$$C = TIMs \cdot Y \qquad (23)$$

As has been said, the *i*-th row of the *C* matrix represents the production-based emissions, while the *j*-th column stands for consumption-based emissions. On the other hand, it must be noted that the TIMs form a square matrix comprised of domestic and trade-related square sub-matrices. In the case of two regions, *m* and *n*, this matrix is equal to:

$$TIMs = \begin{Bmatrix} t^{mm} & t^{mn} \\ t^{nm} & t^{nn} \end{Bmatrix}$$

This matrix thus indicates how much CO_2 is created directly and indirectly by an additional unit of final demand. The elements of the sub-matrices placed in the main diagonal (t^{mm} and t^{nn}) represent intra-regional multipliers, which determine the amount of CO_2 that is generated within regions *m* and *n* (i.e. direct effects) by every unit of final demand. The elements in the off-diagonal sub-matrices, on the other hand, are inter-regional multipliers. These specify the quantity of emissions generated indirectly in regions *m* and *n* throughout the global supply chain (i.e. indirect effects) by the same unit of final demand. The total effects, direct plus indirect, are given by the sum of the columns. For example, the total amount of emissions generated directly within region *m* and indirectly in region *n* by a change in final demand is determined by $t^{mm}+t^{nm}$. This can similarly be calculated for the other region. It is worth noticing, on the other hand, that TIMs can be regarded as the carbon intensity of final demand, since they indicate the quantity of emissions generated per unit of final expenditure.

TIMs were calculated not only for CO_2, but also for value added and wages to skilled and unskilled labour following the same procedure. In this manner, the resulting multipliers indicate the amount of value added and wages that are generated intra- and inter-regionally by every unit of final demand. Apart from being useful to determine the magnitude of the effects, TIMs can also be used to calculate the labour productivity of carbon (LPC). This indicator expresses the quantity of wages associated inter- and intra-regionally with every unit of emissions generated by a dollar of final demand. This is achieved by dividing the labour multipliers by the carbon multipliers.

$$LPC_m = t_{labour}^{mm}(t_{carbon}^{mm} + t_{carbon}^{nm})^{-1} \tag{24}$$

Equation (24), for example, expresses the amount of wages generated in region *m* that are associated with every a unit of CO_2 emitted throughout the entire supply chain. As can be noted, the intra-regional multipliers are multiplied by the inverse of the total carbon multipliers of region *m*. This can equally be repeated in the case of region *n*. Moreover, this same procedure applies for wages paid to skilled and unskilled labour. Another indicator that can be estimated in this manner is the carbon intensity of value added, which can deliver more useful information than the traditional intensities used based on GDP (i.e. CO_2 per unit of GDP), since it allows distinguishing the direct from the indirect effects.

3.2.2.2. BCA analysis

As has been explained, MRIO analysis is used to address the third research question proposed in this thesis, related to the potential implementation of a BCA scheme. This study relies basically on manipulating the *C* matrix as expressed by equation (22). According to what was said in section 3.2.2, this matrix is made of domestic and trade-related components:

$$C = \begin{Bmatrix} c^{mm} & c^{mn} \\ c^{nm} & c^{nn} \end{Bmatrix}$$

If region *m* corresponds to a group of economies subject to legally-binding emissions targets (i.e. Annex B nations), the column vector c^{nm} then represents the emissions embedded in their imports manufactured in region *n*, which could therefore be levied by a BCA scheme. On the other hand, c^{mn} stands for emissions already priced that are embedded in products manufactured in region *m* to be consumed in *n*. These are the exports that can be subject to a rebate (see section 2.3.3).

The tariff rates faced by region *n* depend on the price for carbon (*p*). In order to calculate the tariffs, *p* is multiplied to the amount of emissions embedded in imports. This is then divided by the value of those same imports, expressed in terms of their value added. As has been said, the amount of value added embedded in imports to region *m* can be determined using equation (22). In this sense, the rectangular matrix $V = \hat{V}LY$ expresses the amount of value added created directly and indirectly by a given level of final demand, where $\hat{V}$ represents a diagonal matrix of value added DIMs (i.e. value added per unit of output for every sector). The *V* matrix is also comprised of domestic and trade-related components. The tariff can then be calculated in the following manner:

$$tariff = pc^{nm}(v^{nm})^{-1} \tag{25}$$

where *p* is a scalar (i.e. price for carbon), c^{nm} represents the emissions embedded in imports and $(v^{nm})^{-1}$ is the inverse of the value of those imports.

Finally, the BATs, which were described in section 2.3.3, were calculated as the average DIMs of the 33% most carbon efficient countries under the scheme. Individual nations were ranked, once for every economic sector, according to their DIMs. The BATs were then estimated as the mean carbon intensity of the most efficient tercile.

3.3. Constructing an MRIO

The MRIO model used in this thesis was constructed by the author following the guidelines described by Peters et al. (2011a), based on the GTAP 8 database. As is explained by these authors, an advantage of using this dataset is that it is already balanced and harmonised, so there is no further need to perform these tasks. The data only requires to be manipulated into an MRIO table. However, attention needs to be taken in order to satisfy several accounting identities, according to the UN system of national accounts. The procedure is summarised here, but complete details are provided by the aforementioned authors. In this sense, the total output in region *m* is given by:

$$x^m = Z^{mm} + y^{mm} + t^n + \sum_n e^{mn} \qquad (26)$$

where, x^m is total output in region *m*, Z^{mm} are the domestic inter-industry purchases, y^{mm} are the domestic purchases by final consumers, t^n is the export of international transport services from region *n*, and e^{mn} are the exports of region *m* to region *n*. Since exports can be purchased by either industries or final consumers, then:

$$e^{mn} = Z^{mn} + y^{mn} \qquad (27)$$

Substituting (27) into (26):

$$x^m = Z^{mm} + y^{mm} + t^n + \sum_n (Z^{mn} + y^{mn}) \qquad (28)$$

This equation can be normalised ($A=Zx^{-1}$), which results in a system of linear equations:

$$x^m = A^{mm}x^m + \sum_n A^{mn}x^n + y^{mm} + \sum_n y^{mn} + t^n \quad (29)$$

GTAP 8 comprises data for two years, 2004 and 2007, so two MRIO tables, one for each year, were constructed.

3.4. Data and sources

The construction of MRIO and EEBT models requires a number of national IO tables. Many countries make them available, but assembling them into a multi-regional model requires undertaking a process of balancing and harmonisation. This is a time consuming procedure, since different nations use varying sector classifications, number of economic sectors, years, prices and currencies. Very few sources offer these tables with a certain degree of harmonisation. The World Input Output Database (WIOD) constitutes perhaps the greatest effort to bring together national IO tables and create a harmonised time series. Until now, it has gathered tables for the EU27 plus 13 other major countries, corresponding to 1995 to 2009 (see: Timmer, 2012). The OECD also provides internationally harmonised IO tables for domestic production and imports, as well as bilateral trade data. Some researchers, such as Giljum et al. (2008), believe that their level of harmonisation makes this data more reliable than that offered by other sources. Nevertheless, the range of nations included in the OECD database is limited. It comprises data for 30 of its member countries and 13 non-OECD nations for 43 sectors, covering the years 1995, 2000 and 2005. The Global Trade Analysis Project (GTAP) represents another important source. It also collects national IO tables and offers them along with bilateral trade data with an acceptable level of harmonisation. Different versions have been made available at a regular basis. The most recent one, version 8, contains data for 57 economic sectors corresponding to 109 nation states and 20 aggregated regions (see Appendix A.2 for a complete list) for the years 2004 and 2007. The GTAP datasets have been used in multiple studies, and represent the main data source for this research. GTAP 8 was selected due to the range of countries covered and, more importantly, because the data is already balanced. In other words, the data has been previously calibrated so that global supply equals global demand. This significantly facilitates the construction of multi-regional models.

GTAP 8 also includes data for wages to skilled and unskilled labour for all regions and sectors, which are used in the analyses presented in Chapter 5 and Chapter 6 (see:

Narayanan G. et al., 2012). GTAP 8 also encloses an environmental extension in the form of total CO_2 emissions for each region derived from six energy carriers: coal, crude oil, natural gas, petroleum products, electricity and gas distribution (also see: Narayanan G. et al., 2012). These figures are based on energy statistics published by the International Energy Agency (IEA). This dataset was complemented with national CO_2 annual emissions for cement production taken from the Carbon Dioxide Information Analysis Centre (CDIAC, 2013). It is worth mentioning, however, that CO_2 emissions related to shipping are not well accounted for in GTAP. In addition, CO_2 generated from land use change is not included in GTAP 8. Furthermore, data for non-CO_2 GHGs was not available at this level of disaggregation, especially nitrous oxide (N_2O), methane (CH_4) and fluorinated gases, so this type of emissions was not taken into account in this thesis.

Time series for production and consumption-based CO_2 emissions were provided by Peters et al. (2010). The authors basically extended global estimates for 1997, 2001, and 2004 over the period 1990-2008 using a combination of GDP, emissions, and trade statistics extracted from established global datasets, such as CDIAC (2013) and the United Nations Statistics Division (UNSD, 2013a) (see their paper for precise details about the methodology). These time series comply with the GTAP 8 classification, thus comprising 109 nation states and 20 aggregated regions. It is important to notice that the production and consumption-based approaches yield the same amount of total global emissions, but differ in terms of how emissions are allocated to countries (see section 2.2.2). In this sense, the level of uncertainty related to the consumption-based CO_2 dataset is deemed to be very similar than that of production-based data taken from CDIAC. More about the uncertainty of CO_2 emissions data is covered in the next section.

Data for future CO_2 emissions pathways, as described by the different RCPs, are used in Chapter 7. These datasets are offered in the form of midyear atmospheric CO_2 concentrations and annual emissions (Gt per year). They are derived from the use of fossil fuels from 2000 to 2100 corresponding to 5 regions (see Figure 4, page 23) which, in turn, cover 184 individual countries. Emissions from the RCP3-PD, RCP6 and RCP8.5 pathways were obtained from van Vuuren et al. (2007), Fujino et al. (2006) and Riahi et al. (2007), respectively. Projections for RCP4.5 were taken from Smith and Wigley (2006), Clarke et al. (2007) and Wise et al. (2009).

GDP data at a national level was acquired from the World Bank (2013) and is expressed in constant 2005 international dollars converted with purchasing power parity (PPP) rates. The percentage of people living in urban areas and the proportion of industrial value added with respect to total GDP were also obtained from this same source.

Population figures for individual countries were extracted from the UNSD (2013a) website. Future population projections from 2010 to 2050 corresponding to SSP1, SSP3 and SSP5 were retrieved from the database published by the International Institute for Applied Systems Analysis (IIASA, 2012). These figures are used in Chapter 7.

The Human Development Index (HDI) was taken from the 2013 Human Development Report, published by the UNDP (2013). The dataset encompasses sub-indices corresponding to income per capita, life expectancy, and the observed and expected years of schooling. Data is available for 187 individual countries and eight years (1980, 1990, 2000, 2005, 2007, 2010, 2011 and 2012).

3.5. Strengths and limitations

This section discusses the strengths and limitations of panel data analysis and EE-MRIO analysis. It also talks about the uncertainties that are involved in MRIO models and in the GTAP database.

3.5.1. Panel Data

As was explained in section 3.2.1, one of the major strengths of panel data analysis is its ability to establish robust long-term causal relationships between a dependent and independent variables when more than one observational unit is considered. Apart from this, Baltagi (2005) makes reference to Klevmarken (1989) and Hsiao (2003), who have enumerated other advantages, as well as limitations. Still other benefits and drawbacks are highlighted by Hsiao (2007). All these are listed below:

Advantages:

- Controlling for individual heterogeneity.

- Panel data provide more informative data, more variability, less collinearity among the variables, more degrees of freedom and more efficiency.
- Panel data are appropriate to study the dynamics of adjustment (see section 3.2.1.3).
- Panel data are able to identify and measure effects that are simply not detectable in pure cross-section or pure time-series data.
- Panel data models allow constructing and testing more complicated behavioural models than purely cross-section or time-series data.
- Biases resulting from aggregation over individuals may be reduced or eliminated.

Perhaps the main limitation of panel data analysis is data availability. It is a frequent problem faced by researchers who need to deal with missing observations. When data is not available for several cross-sectional units, the panels are technically referred to as being unbalanced. However, several procedures have been designed to overcome these difficulties. In the case of this study, the methods that are used allow for missing observations without affecting the robustness of the results. Other limitations identified by the aforementioned authors are:

- Design and data collection problems
- Distortions due to measurement errors
- Selectivity problems
- Short time-series
- Cross-sectional dependence (see section 3.2.1.2)

3.5.2. MRIO

When it comes to environmentally-extended IO analysis, this tool offers several advantages over other techniques. In relation to CO_2 emissions accounting, Murray et al. (2010) argue that IO's most important virtue over life cycle assessment lies in its ability to overcome the issues of establishing boundaries and double counting. IO takes into account all the impacts derived from the full upstream supply chain, without leaving anything unaccounted for. On the other hand, the problem of double counting emissions is solved by apportioning the impacts along the entire supply chain. This basically means that it is possible to determine the specific amount of emissions every actor in the economic system is responsible for.

MRIO analysis is also useful in developing scenario analysis. By modifying a number of initial conditions (e.g. increasing demand for inputs by any sector or alterations in final demand in a particular industry), different policy options can be explored and their possible outcomes can be verified. It must be noted, nevertheless, that scenarios produced using MRIO analysis are limited by constraints on how much the economy can be altered. Miller and Blair (2009) also recognise that single and multi-regional IO analyses can be complemented with other techniques, like linear programming, life cycle analysis and econometric models.

However, IO analysis also entails certain drawbacks. One of the most relevant ones is the level of uncertainty that is involved. Since the data contained in IO tables is derived from thousands or millions of data points, it is almost impossible to determine how many errors are involved. And, most importantly, it is difficult to estimate how this uncertainty would propagate through the entire modelling process (Lenzen, 2000).

One other major disadvantage of MRIO analysis is data availability. The amount of resources and time that are necessary to produce IO tables is considerable, so some national governments only publish them sporadically. This makes it difficult to obtain updated figures for all the regions for the same base years that are to be included in a model. This contributes to increase the uncertainty. In addition, the issue of aggregation is also present. Despite the reporting guidelines provided by the UN, some countries do not offer a sufficient level of disaggregation regarding certain economic sectors. This creates a problem of harmonisation and hinders the detail with which the analysis can be undertaken (Wiedmann, 2009).

3.5.2.1. Uncertainties related to MRIO models and GTAP data

There are a number of uncertainties associated with the GTAP database and to the construction of MRIO models in general. These are related to a number of issues, like manipulation due to calibration, balancing and harmonisation, use of different time periods, currencies, country and sectoral classifications and levels of aggregation, accounting for inflation effects, data errors, among others (see: Lenzen, 2000; Lenzen et al., 2004; Peters, 2007; Weber, 2008; Lenzen et al., 2010).

According to Peters (2007), the biggest uncertainty might be the one related to its manipulation. GTAP data is collected from voluntary submissions by individuals or organisations at an international scale, and these receive in return the right to use the dataset. Thus, the data is presented in different country classifications and levels of aggregation. Aguiar and Walmsley (2012) have claimed that of all the contributed tables, 86 did not contain all 57 sectors, so disaggregation was required. Moreover, data generally corresponds to different years. IO tables for some countries, like Hong Kong and Zimbabwe, date from 1988 and 1991, respectively. Only a small fraction of the entire set of domestic IO tables is newer than 2004. Furthermore, the data is often expressed in national currencies. For these reasons, after receiving the data from its original sources, GTAP undertakes a process of harmonisation. The data is initially transformed in order to comply with GTAP classification. It is subsequently valuated by taking into account currency conversions and inflation, so all tables are expressed in a common unit valued at the prices of a base year. Then, it is further calibrated and balanced, making it suitable to be used in a computable general equilibrium model. The precise details of these harmonisation, calibration and balancing processes are not transparent enough. This affects data consistency and generates a degree of uncertainty that is hard to estimate.

Regarding MRIO models in general, Weber (2008) has analysed their uncertainties associated with aggregation issues. By using IO data from the United States and several of its largest trading partners, he determined that aggregation and concordance to a common sectoral classification, the treatment of the rest-of-world (ROW) region, and monetary exchange rates represent the greatest sources of uncertainty. In the particular case of the GTAP EE-MRIO model that is used to produce the results for this thesis, these problems seem to be also present at a certain extent. Some of these have already been mentioned, but it is worth highlighting the ROW issue. Although it does not include a ROW region as such, it does possess 20 aggregated regions that comprise another 126 nations and territories[14]. Due to the reduced size of their economies and the lack of data at a national level, these were aggregated instead of being presented individually. This aggregation, according to Lenzen et al. (2004) and Weber (2008), is likely to result in some errors.

Some other issues further contribute to increase the level of uncertainty that is present in any model of this kind. In general terms, raw macroeconomic and energy data, as is generated by national sources, is already associated with a series of errors. These are seldom estimated by governmental offices of statistics at a national scale, so it is

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[14] See GTAP 8 country classification in Appendix A.2.1.

difficult to determine their magnitude. Guan et al. (2012), for instance, found a discrepancy of about 1.4 gigatonnes of CO_2 for 2010 between the figure reported by China as a whole and the emissions estimates from China's individual provinces and municipalities. Moreover, data from different sources often varies due to differing definitions or methodologies for data collection. For example, GTAP CO_2 data is calculated by using IEA energy statistics. However, it may vary from 10% to 20% at a national level, and maybe even more at a sectoral level, when compared to other sources, such as CDIAC (see: Minx et al., 2008). Significant variations have been found particularly in the case of the United States, China and the EU. In this same respect, Lenzen et al. (2010), while undertaking an uncertainty analysis of the UK's carbon footprint by using an MRIO model, estimated an 89% probability that the footprint might have been significantly larger than originally calculated due to errors related to the carbon multipliers.

In summary, it is almost impossible to know how big the uncertainties are. But, in spite of all these issues, Weber (2008) thinks that the advantages of MRIO models outweigh these problems. Regarding GTAP, it still constitutes one of the most reputable sources and its data is currently being used in numerous studies.

3.6. Summary and further remarks

This chapter presented the methods and data that are used in this thesis. It explained the reasons for following a multi-method approach and for selecting Panel Data analysis and EE-MRIO analysis as the most appropriate techniques to address the research questions outlined in the introductory chapter. It provided a detailed description of these methods and presented the data and their sources. The process to build the MRIO model was also illustrated. This was followed by a discussion about the strengths and limitations of each technique and the last section talked about the uncertainties that are involved in MRIO models and in the GTAP database.

The next chapter focuses on providing answers to the first research question, which deals with the carbon EKC.

Chapter 4
The Consumption-Based Carbon Kuznets Curve

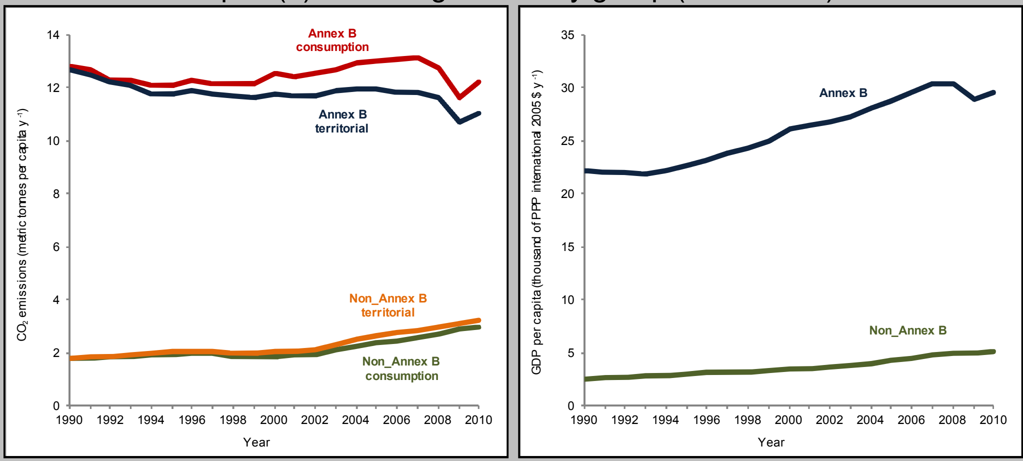
This chapter presents the empirical findings related to the first research question proposed in this thesis (see section 1.2): *Is the EKC for carbon valid from a consumption-based approach?* As was explained in the literature review chapter, if the carbon EKC was to hold true, a possible prescription for attaining higher levels of development and prevent dangerous climate change would be to increase income per capita throughout the world. However, the analyses undertaken so far have yielded mixed findings in relation to CO_2 emissions. The majority of studies have used territorial emissions and only a few have tested the hypothesis from a consumption-based perspective (see section 2.2.3). Authors like Ekins (1997) and Rothman (1998) have suggested that analysing the income-emissions relationship from the consumption-side can deliver more consistent results. This chapter thus analyses this assertion by testing the consumption-based carbon EKC hypothesis using a large set of cross-country data. As was explained in section 3.1, the best method to examine this particular query is panel data analysis. This chapter starts by inspecting the historical trends of CO_2 and GDP per capita according to country groups. Next, the variables used in the study are described in section 4.2. This is followed by the presentation of the results obtained by various econometric methods in section 4.3. Finally a summary of the results is presented in section 4.4.

4.1. Historical trends of CO_2 and GDP per capita

Section 2.2.2 explained the differences between territorial- and consumption-based emissions. Figure 9, which is included in that same section, shows the historical trends of both types of emissions for Annex B and Non-Annex B countries in absolute terms on a yearly basis. Figure 13a, seen below, shows the same data, but this time expressed in per capita terms. The first obvious difference between both graphs is that Non-Annex B per capita emissions have not surpassed those of their counterparts. In contrast to absolute figures, a significant gap exists between both groups of nations. In 1990, territorial- and consumption-based emissions per capita were around 7 times greater in Annex B nations than those of the rest of the world, but this proportion declined in 2010 to 3.4 times for territorial and 4 times for consumption. Despite this *catching-up* by Non-Annex B countries, the inequality in per capita emissions remains high. Another important aspect reflected in the graph is the divergence between both types of emissions. Annex B economies have increasingly become net-importers of CO_2. In 1990, territorial and consumption-based emissions per capita were roughly the same, but the gap became approximately 9.3% larger in 2010. Non-Annex B nations, on the other hand, have gradually become net-exporters of emissions. Their territorial CO_2 per capita was similar to their consumption-based levels in 1990, but the former became almost 8% larger in 2010. This means that the net transfer of emissions (i.e. weak carbon leakage) via international trade grew significantly over time. In terms of their overall levels, Annex B countries observed a decrease of about 13% in their territorial emissions in per capita terms over the period, in some part due to the effects of the 2008/09 financial crisis. However, their consumption-based emissions kept their 1990 levels for most of the time. An opposite effect took place in the rest of the world. Although it is not clearly seen in Figure 13 due to its scale, territorial and consumption emissions per capita rose 70% and 80%, respectively, in 2010 compared to 1990, showing a special acceleration since the first years of the 2000s. This coincides with the period of high economic growth registered in developing economies, particularly in China.

In relation to income per capita, the same levels of inequality are found, as was already shown in Figure 7 and discussed in section 2.2.1. Figure 13b, seen below, displays the same data, but this time for Annex B and Non-Annex B countries. In 1990, income levels in the former nations were about 8.7 times larger. This proportion was reduced to 5.7 times in 2010. In relation to per capita income growth, Annex B nations experienced an improvement of nearly 33% in real terms during the period, while their counterparts' income almost doubled over the same time, reflecting what the UNDP (2013) calls the *rise of the South*.

Figure 13 - Consumption and territorial emissions per capita (a) and GDP per capita (b) according to country group (1990-2010)



(a) (b)

Source: Own figures based on data by UNSD (2013a), CDIAC (2013), (World Bank, 2013)

4.2. Overview of the variables and data

CO_2 emissions and GDP, both expressed in per capita terms, are the basic data inputs used in a carbon EKC analysis, in which the former represents the dependent variable. As explained in section 3.2.1.5, apart from linear and quadratic income per capita terms, a cubic term is also regularly included as an independent variable to check for the possibility of obtaining a statistically significant *N-shaped* curve. In addition, it is also a common practice to use additional independent variables to improve the fit of the regression (see: Stern et al., 1996; Ekins, 1997; Dinda, 2004). In this case, the percentage of people living in urban areas and the proportion of industrial value added with respect to total GDP are included in the functional specification. These two variables are deemed relevant since they can capture signs of structural change. As explained in section 2.2.3, while an economy changes its structure from an agrarian to an industrial regime, more people move to urban areas and income per capita rises. According to the EKC hypothesis, this would be associated with lower environmental degradation rates. Table 11 presents the descriptive statistics for each of the variables used in the analysis.

Table 11 - Descriptive statistics for variables included in the carbon EKC analysis

Statistic	CB	TB	GDP	Urban	Industrial
World					
Mean	5.30	4.70	11,040	58.26	30.90
Median	3.37	3.19	6,547	59.38	29.66
St. Dev.	5.39	4.96	11,657	22.18	10.07
Minimum	-0.36	0.01	62	8.85	6.84
Maximum	35.21	29.80	74,021	100.00	75.38
No. Obs.	2,520	2,520	2,477	2,520	2,349
Annex B					
Mean	12.47	11.80	23,533	71.33	30.74
Median	9.62	8.10	24,567	73.10	29.73
St. Dev.	4.51	4.26	11,823	11.15	6.31
Minimum	2.84	2.63	3,429	47.92	12.97
Maximum	35.21	27.51	74,021	97.46	60.12
No. Obs.	777	777	757	777	742
Non-Annex B					
Mean	2.95	2.76	5,654	52.89	30.96
Median	1.55	1.33	3,326	50.46	29.58
St. Dev.	3.83	3.88	6,159	23.33	11.29
Minimum	-0.36	0.01	62	8.85	6.84
Maximum	25.77	29.80	42,848	100.00	75.38
No. Obs.	1,743	1,743	1,720	1,743	1,607

Note: Data corresponds to time series for the 1990-2010 period CB: Consumption-based emissions and TB: Territorial-based emissions (metric tonnes per capita); GDP is expressed at PPP constant (2005) international dollars; Urban and industrial are expressed as percentages. The average per capita emissions differ between the consumption and territorial approaches at a global scale due to the exclusion of certain regions.
Source: Own table based on data by Peters et al. (2011b), CDIAC (2013), UNSD (2013a) and the World Bank (2013)

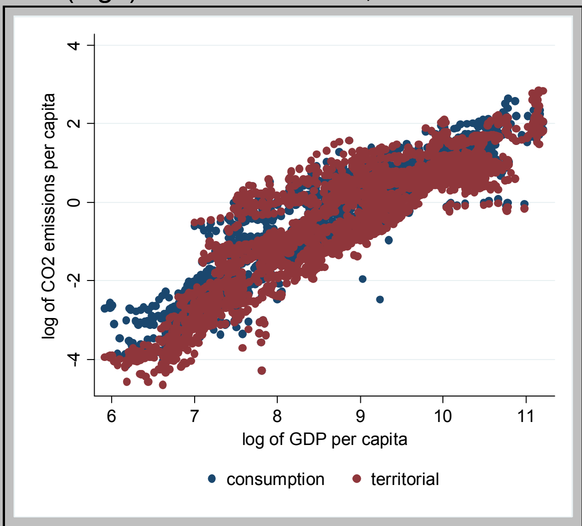
As was explained in section 3.4, the data was obtained from various sources. The country classification is compatible with the GTAP 8 dataset, covering 109 individual countries and 20 regions which, in turn, comprise another 126 nations and territories[15]. In this analysis, each of these 20 aggregated regions is treated as an individual country. It would have been ideal to possess data for every single nation. Unfortunately, the yearly CO_2 figures estimated by Peters et al. (2011b) are only provided in this form. On the other hand, 3 countries and 6 regions had to be excluded, since time series for GDP at purchasing power parity (PPP) per capita were not available for them[16]. Their territorial emissions represent approximately 1.1% of the total. Furthermore, again due to data availability, the panel used in this analysis is still unbalanced for GDP per capita and the share of industrial value added; that is, there are missing values for some countries (see Table 11). This is a common problem found in the majority of large-scale cross-country studies (Mátyás and Lovrics, 1991). In this case, however, the results are not deemed to be affected by this issue. In relation to GDP per capita, missing values represent only 1.7% of the total, and in the case of industrial value added, they represent 6.7%. In addition, the methods that will be used

[15] See GTAP 8 country classification in Appendix A.2.1.
[16] See list of excluded countries in Appendix B.1.1.

in the analysis allow for missing observations without affecting the robustness of the results.

All the variables used in the regressions are expressed in natural logarithms in order to correct their scale, as is the common practice in EKC studies (see: Stern et al., 1996; Ekins, 1997; Dinda, 2004). An initial visual inspection of the main variables can be done in Figure 14, which shows the correlation between the logarithms of territorial and consumption emissions against GDP, both in per capita terms. It should be noticed that data for all countries and all years were pooled together in this graph. As it can be seen, while income grows, both types of emissions also tend to rise. The EKC analysis then basically consists in estimating the best fitting curves for these data points.

Figure 14 - Territorial and consumption emissions per capita versus GDP per capita (logs) for 120 countries, 1990-2010



Source: Own figure based on data by Peters et al. (2011b), CDIAC (2013), UNSD (2013a) and the World Bank (2013)

4.3. Testing the carbon EKC

The following sub-sections offer the results obtained by the various cross-country panel-data methods used in the analysis, which were presented and described in section 3.2.1.

4.3.1. Pooled OLS

As a first approach, conducting an initial OLS regression with pooled data is useful to observe the overall behaviour of the variables included in the analysis in spite of not always being the most suitable method. This implies pooling all the data together and treating it homogeneously. The following table presents the results from these regressions.

Table 12 - Pooled OLS carbon EKC regression results

Coefficient	Territorial		Consumption	
	Quadratic	Cubic	Quadratic	Cubic
β_1	2.93*** (21.94)	9.11*** (6.43)	1.91*** (13.88)	3.89*** (2.66)
β_2	-0.11*** (-15.20)	-0.84*** (-5.08)	-0.05*** (-7.11)	-0.29* (-1.70)
β_3	---	0.03*** (4.41)	---	0.01 (1.39)
Urban	0.01*** (7.64)	0.01*** (8.01)	0.01*** (6.31)	0.01*** (6.48)
Industrial	0.02*** (16.89)	0.02*** (16.88)	0.01*** (9.56)	0.01*** (9.51)
Constant	-18.50*** (-32.72)	-35.78*** (-8.95)	-13.58*** (-23.17)	-19.12*** (-4.60)
R^2	0.85	0.85	0.87	0.87
Turning point	372,174	---	44,390,312	---
Note: t-stats are shown in parentheses. ***, **, * Significant at 0.01, 0.05, and 0.10 levels, respectively				

The quadratic specifications for both territorial- and consumption-based emissions yield significant coefficients, and the quadratic terms display negative values consistent with an inverted-U. However, in both cases, the turning points show out-of-sample income per capita values, with the inflection point being extremely high in the case of the consumption specification. When the turning points lie so far outside the data range, it means that only the increasing part of a possible inverted-U is seen, so in fact the observation is that emissions grow monotonically with income. In relation to the cubic specifications, the coefficient corresponding to β_3 is only significantly different from zero in the case of territorial emissions, suggesting the presence of an N-shaped curve, but it is not significant for consumption-based CO_2. This means that in the case of territorial emissions, both quadratic and cubic specifications can fit the data equally well, although it is difficult to identify which is better just by looking at their R^2s. The *Akaike criterion* (AIC), in this sense, is often used to choose between a set of similar models. As the cubic form possesses a slightly smaller AIC (4165.9) compared to the quadratic one (4182.5), the former would be preferred, but the difference is not large. No turning points, however, could be estimated for the cubic polynomials due to imaginary roots. Table 12 also shows that the *urban* and *industrial* variables are positive and significant across all specifications, reflecting their relevance as explanatory factors of CO_2 emissions.

The OLS results, nonetheless, are inconsistent, as the method assumes homogeneity across countries (i.e. the same coefficients are applied to all nations). Country-specific differences in terms of their intercepts and slopes are not taken into account. Two tests were thus conducted in order to prove the viability of OLS against other techniques. First, an F-test was applied to check for the presence of specific traits fixed to individual countries (i.e. fixed effects). If this was the case, then OLS would not be valid, indicating the need to use a fixed effects model. Second, the Breusch-Pagan Lagrange Multiplier test was performed, which is designed to confirm or reject the validity of OLS against a random effects model. The results derived from both tests can be found in the following table.

Table 13 - F-test and Breusch-Pagan LM test for quadratic and cubic specifications

Test	Specification	Territorial	Consumption	Result
F-test: All fixed effects are null	Quadratic	F(116, 2204)=201.48***	F(116, 2201)=117.04***	OLS not valid
	Cubic	F(116, 2203)=199.71***	F(116, 2200)=116.86***	OLS not valid
Breusch-Pagan LM test for pooled vs random effects	Quadratic	$chi^2(1)$=16820.65***	chi2(1)=14878.73***	OLS not valid
	Cubic	$chi^2(1)$=16646.28***	chi2(1)=14842.55***	OLS not valid
*** Significant at 0.01 level				

The null hypothesis in the F-test states that no fixed country-specific traits exist, and it is significantly rejected for all quadratic and cubic specifications for territorial and consumption emissions. This indicates that OLS is not a valid estimation method. Similarly, the null hypothesis in the Breusch-Pagan test assumes the absence of random individual-specific effects. It is again rejected at a level of significance of 1% for all specifications and types of emissions. Hence, a fixed or random effects model should be used instead of pooled OLS.

4.3.2. Fixed and random effects

Running pooled OLS regressions served as an initial exploratory measure, but they yielded misleading results. As was explained in section 3.2.1.1, the assumption that all countries possess homogenous traits is too restrictive. The fixed effects model thus takes into account that the intercepts may differ across individual countries, but not over time. In other words, the model is designed to differentiate heterogeneous and time-invariant (i.e. fixed) country-specific intercepts. In this sense, it controls for all those unobserved time-invariant characteristics that may affect the generation of CO_2 emissions (e.g. geographical location, area, culture, etc.) and which may bias the results. In a similar fashion, the random effects model also allows for differences across countries in terms of their intercepts, but these variations are assumed to occur randomly. This method is usually utilised when individual observations are known to constitute a random sample extracted from a given population. An advantage of this method is that time-invariant unobserved variables are accounted for in the regression.

However, these unobserved effects must not be correlated with the regressors. If this was the case, then random effects are not valid and a fixed effects model would be required instead. In order to choose between the fixed and the random effects model, the Hausman test is widely used (again, see section 3.2.1.1). Its null hypothesis assumes that the cross-sectional unobserved effects are not correlated with the independent variables. The results are presented in the following table.

Table 14 - Hausman test to select between fixed and random effects

Test	Specification	Territorial	Consumption	Result
Hausman: fixed vs random	Quadratic	$chi^2(4)=509.34$	chi2(4)=49.33	Fixed effects
	Cubic	$chi^2(4)=15.88$	chi2(5)=157.43	Fixed effects
*** Significant at 0.01 level				

The test shows that the null hypothesis is rejected in both specifications and both types of emissions, as the unobserved effects are correlated with the regressors (see Table 14). This indicates that a fixed effects model is more appropriate in all cases and, hence, it was used to estimate a new set of regressions.

Table 15 shows the results derived from the fixed effects model. As in the case of the pooled OLS regressions, the quadratic specifications produced statistically significant coefficients for β_1 and β_2 for both territorial and consumption-based emissions. The signs of the quadratic terms are negative indicating bell-shaped curves or inverted-Us. Once again, the consumption specification peaks at a higher income level than its counterpart, but this time both turning points lie within the sample. Territorial emissions peak at around $17,168 dollars per capita, while consumption emissions do so at around $27,740. In relation to the other variables, *urban* is statistically significant in both types of emissions, but *industrial* is only relevant in the territorial specification. Before drawing any conclusions in this particular respect, further analyses must be done using the additional methods to ensure the viability of this variable. On the other hand, the cubic specifications did not produce statistically significant fits. However, their inflection points were still calculated and these are almost identical to those of the quadratic specifications.

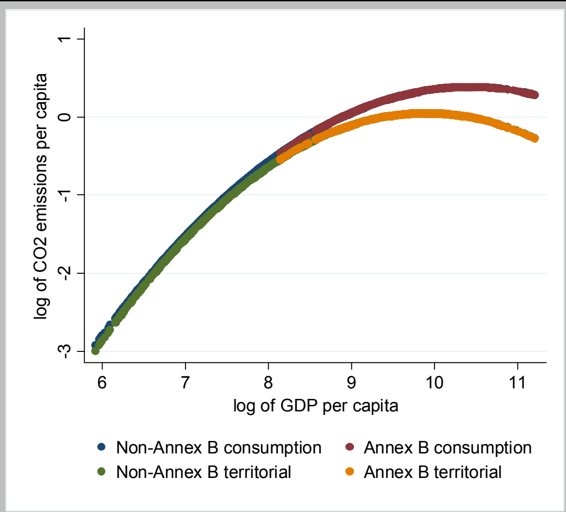
Table 15 - Fixed effects carbon EKC regression results

Coefficient	Territorial		Consumption	
	Quadratic	Cubic	Quadratic	Cubic
β_1	2.84*** (5.40)	1.99 (0.53)	2.97*** (5.35)	2.42 (0.63)
β_2	-0.15*** (-4.69)	-0.04 (-0.10)	-0.14*** (-4.60)	-0.08 (-0.18)
β_3	---	0.00 (-0.23)	---	0.00 (-0.15)
Urban	0.02*** (4.87)	0.02*** (4.84)	0.02*** (3.45)	0.02*** (3.45)
Industrial	0.01*** (2.77)	0.01*** (2.76)	0.00 (1.10)	0.00 (1.09)
Constant	-15.50*** (-6.89)	-13.11 (-1.24)	-15.98*** (-6.59)	-14.46 (-1.32)
R^2	0.79	0.79	0.81	0.81
Turning point	17,168	17,056	28,828	27,740

Note: t-stats are shown in parentheses.
***, **, * Significant at 0.01, 0.05, and 0.10 levels, respectively

Figure 15 shows a visual approximation of the estimated territorial and consumption carbon EKCs. It can be clearly seen that the latter peaks at a higher income level. The gap that exists between both curves represents the magnitude of the weak carbon leakage. In addition, it is interesting to notice that Annex-B nations are situated on the top-ends of the curves, while the great majority of Non-Annex B countries occupy the leftmost and steepest sections. This reflects the disparities between the stages of economic development of both groups. The majority of developing countries possess agrarian regimes and are located at the earlier stages of the EKC.

Figure 15 - Estimated carbon EKCs for territorial- and consumption-based emissions using fixed effects according to country groups (1990-2010)



Source: Own figure

If these results were valid, then countries, on an average basis, would be on track of achieving emissions reductions by becoming wealthier. In order to confirm their consistency and robustness, several tests were applied to the residuals to identify the presence of heteroskedasticity, serial autocorrelation and cross-sectional dependency. If any of these conditions were present, the findings could lead to incorrect conclusions. The results from the tests are presented in the following table.

Table 16 - Heteroskedasticity, autocorrelation and cross-country correlation tests

Test	Specification	Territorial	Consumption	Result
Modified Wald test for groupwise heteroskedasticity	Quadratic	chi^2 (117)=70,230.88***	chi2(117)=62,650.28***	Heteroskedasticity
	Cubic	chi^2(117)=73,706.80***	chi2(117)=59,633.74***	Heteroskedasticity
Likelihood-ratio test for group heteroskedasticity	Quadratic	chi^2(116)=2,306.31***	chi2(116)=2,343.32***	Heteroskedasticity
	Cubic	chi^2(116)=2,306.86***	chi2(116)=2,359.99***	Heteroskedasticity
Wooldridge test for autocorrelation in panel data	Quadratic	F(1,116)=94.05***	F(1,116)=90.43***	Autocorrelation
	Cubic	F(1,116)=93.78***	F(1,116)=90.47***	Autocorrelation
Pesaran's test of cross-sectional independence	Quadratic	13.85***	10.51***	Cross-sectional dependence*
	Cubic	13.67***	10.48***	Cross-sectional dependence*
Note: * Tested without *industrial* variable *** Significant at 0.01 level				

Two tests were applied to detect the presence of heteroskedasticity in the residuals. This condition implies that the variance of the errors is not constant over time. It often affects cross-sectional aggregated data, and may be caused by measurement errors or data quality. The modified Wald test for groupwise heteroskedasticity is used with fixed effects regressions and assumes that the residuals may be homoskedastic (i.e. constant variance) within countries, but may differ across them. Its null hypothesis states that the error variance is constant across nations. The likelihood-ratio test for group heteroskedasticity works in a similar way, but it is based on a generalised least squares (GLS) procedure. Its null hypothesis also presupposes the absence of heteroskedasticity. In both tests, the null hypotheses are rejected in all specifications and types of emissions, indicating that the residual variance is not constant across groups. The next test applied was the Wooldridge (2002) test for serial correlation. If this condition was present, then it would mean that the errors at a certain point in time are to some extent explained by their own past levels, biasing the coefficients. Its null hypothesis assumes the absence of autocorrelation, and it was rejected at a significance level of 1% for all specifications. Finally, the Pesaran (2004) test for cross-sectional independence was applied to identify if country-specific errors are correlated between them, as this can bias the estimated coefficients (Müller-Fürstenberger and Wagner, 2007; Wagner, 2008). This is very relevant, as nations have become increasingly interdependent of each other through international trade and economic and financial integration policies. The null hypothesis, presumes country-specific independent errors. It was rejected in all cases, indicating the presence of cross-country dependency.

The results from all these tests cast doubts on the robustness and validity of the quadratic curves produced with the fixed effects model. Although they might seem attractive from a policy perspective, they lead to wrong conclusions, as they are affected by heteroskedasticity, autocorrelation and cross-country dependence.

4.3.3. Panel-corrected standard errors

The GLS method is broadly used whenever heteroskedasticity is present and when the observations are correlated to some degree. Several variations of the technique have been built upon the GLS framework to allow estimating parameters in the presence of groupwise heteroskedasticity and cross-country dependence. In this case, the Prais-Winsten regression is an appropriate method because, apart from correcting these problems, it also eliminates biases derived from autocorrelation. As has been explained in section 3.2.1.2, this tool has been used in some EKC studies, yielding unbiased and consistent estimators. The results produced by these regressions are presented in the following table.

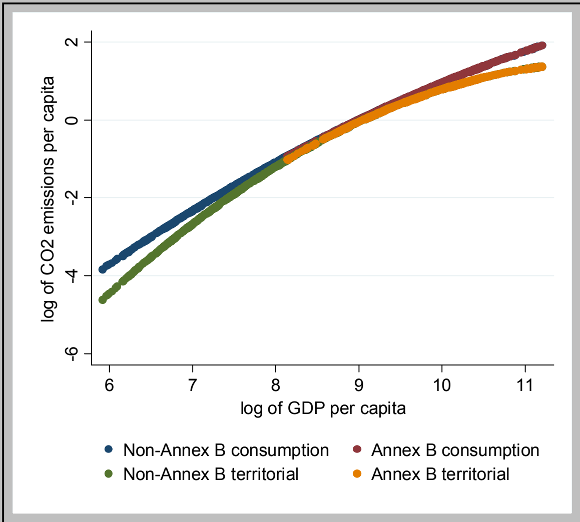
Table 17 - PCSE carbon EKC regression results

Coefficient	Territorial		Consumption	
	Quadratic	Cubic	Quadratic	Cubic
β_1	2.99*** (15.23)	6.40*** (3.06)	1.87*** (8.06)	2.69 (1.42)
β_2	-0.12*** (-11.80)	-0.52*** (-2.11)	-0.05*** (-4.34)	-0.15 (-0.68)
β_3	---	0.02 (1.61)	---	0.00 (0.43)
Urban	0.01*** (6.44)	0.01*** (6.50)	0.01*** (4.58)	0.01*** (4.58)
Industrial	0.01*** (5.39)	0.01*** (5.40)	0.004** (1.99)	0.004* (1.95)
Constant	-18.32*** (-21.09)	-27.84*** (-4.78)	-13.15*** (-13.13)	-15.45*** (-2.91)
R^2	0.72	0.72	0.71	0.71
Turning point	211,151		32,618,691	

Note: PCSE: Panel-corrected standard errors; t-stats are shown in parentheses.
***, **, * Significant at 0.01, 0.05, and 0.10 levels, respectively

The quadratic specifications produced statistically significant coefficients for all variables. The estimated coefficients for the β_2s are negative, evidencing once more inverted-U shapes. As with the previous methods, the turning point is much higher when using consumption data. However, in this case, the turning points are located in an out-of-sample region, which indicates that emissions continue growing monotonically over time. The variables *urban* and *industrial* are significantly different from zero in all the regressions, showing their relevance as explicative factors. On the other hand, the cubic specification is not significant at all in relation to consumption emissions, while the coefficient of term β_3 is statistically equal to zero for territorial CO_2, which confirms the appropriateness of using the quadratic specification. The inflection points for the cubic polynomials were again impossible to calculate due to the presence of imaginary roots.

Figure 16 - Estimated carbon EKCs for territorial- and consumption-based emissions using PCSE regressions according to country groups (1990-2010)



Source: Own figure

Figure 16 shows a visual approximation of the estimated quadratic curves. The first noticeable difference with respect to those calculated with the fixed effects model is that the consumption-based carbon EKC is almost a straight line. The territorial curve shows a slightly higher concavity, but it can equally be said that it grows monotonically with income, as its turning point is significantly higher. The bulk of the Non-Annex B nations are grouped at the bottom left sections of the curves, while their wealthier counterparts are situated in the upper extremes. It is worth highlighting, on the other hand, the gap that exists between both curves at the lower levels of GDP per capita. It is partially due to the restriction of fitting the data to specific polynomial forms. Other more flexible ways of fitting the data, such as non-parametric methods, could have modified these patterns. Nonetheless, it must be stressed that the poorest countries are also net importers of emissions, as can be seen in the bottom left corner of Figure 14. In order to verify this issue, a simple calculation was made. Net emissions transfers (i.e. territorial minus consumption emissions) were averaged for every country in the sample over 1990 to 2010 in order to find those nations that were net exporters during the whole period. This resulted in only 35 countries, which are mainly middle-income nations, while the rest are net importers. The net transfers were then expressed as the proportion of total territorial emissions for each nation and grouped according to income terciles. For the richest tercile, negative emissions transfers represented on average 35.8% of their territorial emissions, while for the poorest tercile they accounted for 38.7%. These rough figures show that many poor nations, not being self-sufficient, have become net importers of carbon embedded in a range of commodities and capital-goods manufactured in other regions. This issue requires further examination, since it has not received an adequate attention in the literature. Some of its implications will be discussed with more detail in Chapter 8.

An examination of the residuals from the two quadratic regressions shows that they effectively do not present problems of heteroskedasticity, autocorrelation and cross-country correlation. However, there are still two issues that must be taken into account and explored. As explained in section 3.2.1.3, non-stationary variables can be cointegrated, and may thus lead to spurious results. It is important to check if this is the case. Furthermore, another condition that must be examined is if the heterogeneity between country-specific slopes influences the results. Fixed and random effects models allow a certain level of heterogeneity across nations, but they still maintain the homogeneity assumption in relation to the turning points. As was mentioned in section 3.2.1.4, studies have found that assuming homogeneous slopes across countries can represent a stringent restriction (e.g. Dijkgraaf and Vollebergh, 2005). In this sense, cointegration and slope heterogeneity are examined next.

4.3.4. Cointegration

In section 3.2.1.3, it was explained that the properties of many econometric techniques require the use of stationary variables in general, so if the condition of stationarity is not confirmed, the results can be biased or spurious. Many time series used in economic analyses are non-stationary; that is, they possess unit roots. Consequently, proper methods need to be used to deal with non-stationary and stochastically trending variables. On the other hand, it is said that if two variables share the same order of integration, they can be cointegrated or share a long-term trend if a linear combination of both (i.e. residuals) is stationary. Unit root tests are then applied to determine the order of integration of the variables that are being used in this analysis.

Three different unit root tests were applied. The first one is the Im-Pesaran-Shin test, which represents a conventional tool widely used for panel-data. The next one is a second-generation test, developed by Pesaran (2007), designed to handle heterogeneous panels with cross-sectional dependence. The third one is the Zivot and Andrews (1992) unit root test used with time series that possess a structural break. This test is useful, as sometimes variables show temporal discontinuities in their trends due to shocks or structural changes, which can complicate assessing their stationarity (see: Romero-Ávila, 2008). All the variables were tested twice, once in their original levels and another in first differences. The results obtained after applying the tests are presented in the following table.

Table 18 - Unit root tests for variables used in the carbon EKC analysis

Variable	Lags	Im-Pesaran-Shin	Pesaran	Zivot-Andrews
		Statistic (t-bar)	Statistic (t-bar)	Statistic (average t-stat)
Territorial	3.29	-0.53	-1.73	31 panels are stationary (-5.44)
Δ Territorial	2.28	-20.68***	-2.10***	98 panels are stationary (-6.03)
Consumption	3.39	-0.12	-1.53	37 panels are stationary (-5.38)
Δ Consumption	2.50	-17.74***	-2.30***	106 panels are stationary (-6.44)
GDP	3.43	9.17	-1.59	38 panels are stationary (-5.91)
Δ GDP	2.64	-12.66***	-1.86*	58 panels are stationary (-5.88)
GDP^2	3.41	10.39	-1.57	38 panels are stationary (-5.80)
Δ GDP^2	2.69	-12.65***	-1.86*	59 panels are stationary (-5.90)
GDP^3	3.40	11.30	-1.55	36 panels are stationary (-5.75)
Δ GDP^3	2.68	-12.02***	-1.85*	57 panels are stationary (-5.89)
Urban	0.94	0.67	-1.53	65 panels are stationary (-8.01)
Δ Urban	1.37	1.00***	-2.39***	92 panels are stationary (-14.12)

Note: Number of panels = 120; ***, * Null significantly rejected at 0.01 and 0.10 levels, respectively
Number of average lags obtained according to AIC provided by the Im-Pesaran-Shin test
Δ: First differences. All variables tested with constant. Industrial not tested due to missing values

The results derived from the Im-Pesaran-Shin and Pesaran tests convey the same message. Their null hypotheses state that all the series in every panel present unit roots. The nulls were accepted for variables in levels, but rejected for differenced variables. In other words, all the variables used are non-stationary in levels, but become stationary when transformed to first differences. This means that all the variables possess an order of integration of 1, which is expressed in statistical notation as I(1). The Zivot-Andrews test presents a more complex message, as it is applied individually to each panel. Its results indicate that for all variables only a small fraction of the panels are stationary in levels in the presence of structural breaks, whereas the majority become stationary when differenced. The rest of the panels might possess higher orders of integration, although this cannot be confirmed as the results could be affected by the small number of years in the sample. This is especially the case with respect to GDP per capita in its linear, quadratic and cubic forms. Consequently, in the case of some panels, cointegration might not be applicable, as GDP and both types of emissions could not share the same level of integration. However, seen as a whole, the three tests point out that cointegration could be present and, therefore, should be tested in order to detect it.

Table 19 - Westerlund's cointegration tests

Statistic	Territorial		Consumption	
	Quadratic	Cubic	Quadratic	Cubic
Pt	-7.56 (0.000)	-4.76 (0.000)	-8.99 (0.000)	-8.81 (0.000)
Pa	-5.11 (0.000)	-1.61 (0.053)	-4.99 (0.000)	-4.40 (0.000)
Note: Reported Z-values and P-values in parentheses; tested with an average of 2 lags, based on AIC with a constant				

The cointegration test developed by Westerlund (2007) is well suited for this dataset, as it allows for country heterogeneity and cross-sectional dependence. It employs two different statistics (i.e. Pt and Pa), whose null hypotheses presuppose no cointegration among all the panels. Both of them are rejected for the quadratic and cubic specifications, with the exception of the cubic polynomial corresponding to territorial emissions, for which the null is nearly accepted at a 5% level of significance. On the whole, however, it can be said that the variables are cointegrated and thus share a long-term trend.

4.3.5. Panel heterogeneity

The evidence suggests that cointegration is present in the income-emissions relationship, which means that both variables follow a common long-term process. This should be evident, as greater levels of affluence and economic activity have regularly led to higher emissions over time. In order to capture this long-term association, the same technique designed by Westerlund (2007) is used. Apart from testing for cointegration, it estimates the short- and long-term coefficients of the various specifications allowing for panel heterogeneity in relation to intercepts, slopes and dynamic processes. Instead of imposing homogenous estimates to the entire panel, individual regressions are run for each individual country according the Mean Group procedure proposed by Pesaran and Smith (1995). Once the unit-specific coefficients are obtained, they are then averaged and their standard errors are computed. The short-run dynamics are modelled with an autoregressive distributed lags function, which allows the estimation of the error correction term. This term shows how fast short-term deviations converge back to their long-term values. In other words, income and emissions usually register increases or decreases on a yearly basis, but their levels tend to return to a common cointegrating trend in the long-run. In order to confirm signs of cointegration, the error correction term must be negative and statistically significant (see section 3.2.1.3). On the other hand, the procedure requires using differenced and lagged differenced series, which reduces the available time periods. For this reason, the variables *urban* and *industrial* were omitted in this analysis, to ensure the robustness of the income effects on the level of emissions. The results from this set of regressions are shown in the following table.

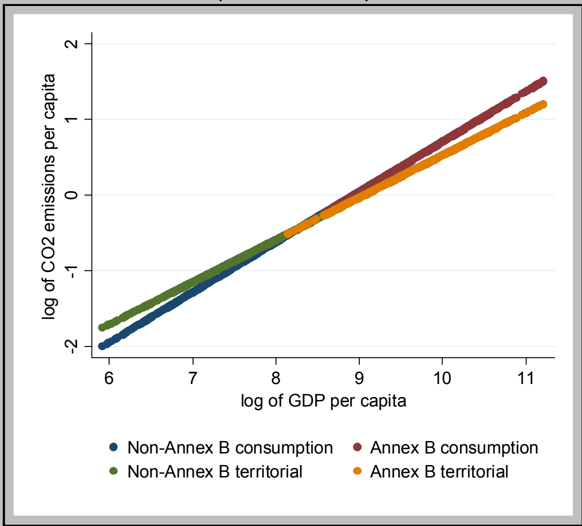
Table 20 - Cointegrating carbon EKC regressions with panel heterogeneity

Coefficient	Territorial			Consumption		
	Linear	Quadratic	Cubic	Linear	Quadratic	Cubic
β_1	0.56*** (4.03)	28.50 (1.39)	-12.51 (-1.56)	0.66*** (5.20)	34.04 (1.06)	-10.78 (-0.88)
β_2	---	-1.58 (-1.51)	10.30* (1.67)	---	-0.97 (-0.92)	5.30 (1.41)
β_3	---	---	-0.77 (-1.60)	---	---	-0.38 (-1.45)
Constant	-5.07*** (-3.96)	-8.18 (-0.28)	4.14 (0.02)	-5.93*** (-5.84)	35.10 (0.42)	-51.35 (-0.94)
EC	-0.49*** (-15.17)	-1.16*** (-14.75)	-1.36*** (-10.18)	-0.59*** (-19.45)	-1.13*** (-17.78)	-1.41*** (-13.15)
R^2	0.93	0.98	0.99	0.58	0.84	0.91
Turning point	---	8,368	3,923	---	41,205,795	3,539

Note: Error correction (EC) term obtained with short-term specification not shown here.
Regressions with an average of 2 lags; t-stats are shown in parentheses.
***, **, * Significant at 0.01, 0.05, and 0.10 levels, respectively

Table 20 shows the averaged unweighted coefficients derived from the individual country-specific regressions. As can be seen, the quadratic specifications yield non-significant coefficients, although the β_2 values display negative signs. This is due to the fact that only 23% of the countries, on an individual basis, presented evidence of a statistically significant inverted-U shape at a 5% confidence level when using territorial emissions and only 15% with consumption-based data. Hence, on average, the quadratic polynomials are deemed as invalid. Still, it is worth noticing that the mean turning point for the consumption curve shows an extremely high level. The same conclusions are derived from the cubic specifications, which produced non-significant estimates, with the sole exception of the β_2 coefficient for territorial emissions. These results made necessary testing an additional specification with just the linear term, which generated significant coefficients in both cases at a 1% confidence level. Thus, the best fitting curves in the long-run when controlling for panel heterogeneity and taking cointegration into account are straight lines, reflecting a monotonic increase of territorial and consumption emissions with higher levels of income.

Figure 17 - Estimated carbon EKCs for territorial- and consumption-based emissions using cointegrating and panel heterogeneity regressions according to country groups (1990-2010)



Source: Own figure

Figure 17 shows the long-term trends of both types of emissions. The consumption-based curve possesses a slightly steeper slope and a lower intercept than its counterpart. Consequently, both curves cross at an income level of approximately $3,955.8 dollars per capita, which corresponds to the middle-income group. In this case, the poorer countries appear to be net exporters of emissions, while in fact they are not. The effect reflected in Figure 16 at low income levels is lost due to the shape of the fitted line. It must thus be remembered that these lines show the average long-run behaviour of all the countries in the sample and that individually they may present different patterns. However, the figure shows that on average the majority of Annex B economies are net importers of CO_2, and that negative emission transfers (i.e. deficits) tend to increase with income via international trade. In other words, the wealthier nations tend to be the largest net-importers. On the other hand, the error correction terms, obtained with the short-term dynamics, were negative and statistically significant in all the different specifications (see Table 20). This confirms that the series are cointegrated. Interestingly, the speed of adjustment from short- to long-run dynamics is somewhat higher for consumption emissions, as the absolute values of the error correction terms are greater by around 20%. This suggests that consumption tends to respond at a faster pace after short-term disturbances in GDP than production.

4.3.6. Income elasticity of carbon

The previous section explained that when the estimations are free from the restriction of parameter homogeneity, the long-term cointegrating relationship between income and emissions is linear. Higher levels of income are thus associated with higher levels of emissions. The slopes portrayed in Figure 17 represent the average carbon intensity over the period. More specifically, they represent the income elasticity of carbon. In order to be more precise and calculate the extent to which income increases when emissions grow by 1%, both the dependent and independent variables must be expressed in growth rates, and this is achieved by applying logarithms and first differences to the time series. For this purpose, a new set of regressions were tested for the linear specifications, but this time taking into account cross-country dependency. While the procedure designed by Westerlund (2007) corrects cross-country correlation with regards to the cointegration-test statistics, the technique does not control for this issue when estimating the individual coefficients. Thus, new regressions were estimated using the same Mean Group method used in the previous section, but adding an additional variable to capture cross-country effects according to the procedure proposed by Eberhardt and Teal (2010). In this sense, regressions were conducted individually on a country by country basis and the coefficients were then averaged. The results are presented in the following table.

Table 21 - Estimated income elasticity of carbon for territorial and consumption emissions

Coefficient	Territorial Linear	Consumption Linear
β_1	0.53*** (8.25)	0.75*** (9.10)
Common dynamic process	0.60*** (5.12)	0.84*** (6.93)
Constant	0.00 (1.11)	-0.02*** (-6.15)
t-stats are shown in parentheses *** Significant at a 0.10 level		

Table 21 shows the estimated average income elasticities of carbon using only the linear specifications. In the case of territorial emissions, the estimated coefficient is almost the same as the one presented in the previous section. In this sense, when income per capita grew by 1% during the period, emissions per capita increased by 0.53%. This figure is almost identical to the one obtained by York (2012). On the other hand, for every 1% rise in income per capita, consumption emissions grew by 0.75%, which is slightly higher than the estimate obtained in the preceding section. This figure had never been estimated in the literature before. Furthermore, the cross-country dependence variable confirms that countries have been profoundly interrelated due, for example, to economic, financial and trade policies.

4.4. Summary and further remarks

This chapter presented the findings related to the consumption-based carbon EKC analysis. Section 4.1 talked about the inequality that exists not only in relation to income per capita, but also with respect to emissions. The gaps, however, have been gradually decreasing over the years. Moreover, Annex B countries have increasingly become net importers of emissions via international trade, exceeding their Kyoto reduction commitments (Peters et al., 2011b). In section 4.2, descriptive statistics were offered for each of the time series used in the analysis. The results obtained with the different econometric methods were then presented in section 4.3. There, it was argued that pooled OLS regressions are not valid, as they impose a strict restriction in relation to country-specific traits. When the income-emissions relationship was examined with the use of the fixed effects method that allows for differing country intercepts, the results favoured the quadratic specifications. Thus, the estimated curves follow an inverted-U shape, and emissions seem to gradually decline after reaching a within-sample income level. This turning point, nonetheless, is always higher for consumption emissions, reflecting the magnitude of weak carbon leakage. Although these estimates may seem attractive from a policy point of view, they are misleading. It was explained that they are affected by heteroskedasticity, autocorrelation and cross-country correlation. When these issues were controlled for using the PCSE technique, the best fitting polynomials were again quadratic. However, both curves show lower concavities with out-of-sample turning points, especially in the case of consumption emissions, which follow almost a straight line. This indicates that emissions tend to grow monotonically with income. An interesting finding, on the other hand, is reflected by the shape of the curves, showing that the poorest nations are also net importers of emissions, as they depend on international trade to obtain the goods and services they require to pursue economic development. In addition, the bulk of Non-Annex B nations are concentrated on the steepest and earlier stages of the curves. In spite of the robustness of these results, the estimated parameters were still restricted by an assumption of slope homogeneity. Freeing the estimates from these limitations and calculating the long-term relationship between income and emissions, proved to be a more appropriate way of obtaining robust results. By following the procedure proposed by Westerlund (2007), the findings indicate that income and emissions shared a linear long-term trend during the period under study, and that consumption adjusts slightly faster to short-term fluctuations in GDP than production. On average, Non-Annex B nations tend to be net exporters of emissions, while the richest nations are the largest net importers. Finally, the average income elasticities of carbon were estimated, finding that the elasticity for consumption emissions was significantly higher, and that nations are deeply interdependent. In summary, the results lead to completely reject any evidence of the EKC hypothesis for CO_2 emissions. All these findings, and their various implications, will be discussed more extensively in Chapter 8.

The next chapter presents the results related to the second research question proposed in this thesis.

Chapter 5
Demand-side mitigation impacts in the developing world

This chapter focuses on providing empirical answers to the second research question proposed in this thesis (see section 1.2): *How much value added and wages paid to skilled and unskilled labour in developing countries are associated with every unit of CO_2 that is mitigated in different sectors through reductions in consumption in industrialised nations?* As was explained in the previous chapter, CO_2 emissions tend to rise monotonically with higher levels of income per capita in the long-run, and this increase is particularly accentuated from a consumption-based approach. The wealthier economies tend to import more CO_2 embedded in the foreign goods and services they consume, and have thus become net importers of emissions. This exposes their substantially greater consumption per capita levels compared to middle- and low-income countries, as well as their growing dependency on resources and products extracted and manufactured in the developing world. As implicitly reflected in the results derived from the carbon EKC analysis, and as argued in section 2.3.1, the pace of technological change has not been enough to compensate for the emissions associated with the rise in population and per capita income. Thus, demand-side mitigation measures oriented to change/reduce consumption are deemed as essential to complement technology-led mitigation actions in order to achieve a 2°C target and prevent dangerous climate change in the long-run. However, in the context of a globalised planet, in which countries are ever more dependent on each other through international trade, changes in demand registered in industrialised nations can bring negative developmental consequences in the global South. By adopting free-market policies and export-led models of growth, many developing countries depend significantly on the revenue and employment generated by their exporting sectors. In this sense, while changes/reductions in final demand in the North can free carbon space and make it available for developing economies, the development process in the latter regions could be affected by lower flows of traded goods and services. This chapter thus examines this trade-off, specifically scrutinising if Northern demand-side mitigation actions, in general, affect the capacity of developing countries to create value added and wages for their labour force. As was explained in section 3.2.2, the best technique to undertake this examination and provide answers to this particular query is the so-called Environmentally-Extended Multi-Regional Input-Output (EE-MRIO) analysis. The chapter begins by providing a brief overview of the variables used in the study in section 5.1. The empirical findings are then presented, starting in section

5.2, which describes the global production structure. This is followed by an examination of the factor content of trade in section 5.3, as well as its carbon content in section 5.4. The labour productivity of carbon is calculated in section 5.5 for different country groups. This indicator shows the amount of wages to skilled and unskilled labour that are associated with every unit of emissions. Section 5.6 then identifies the most trade-dependent nations, which are particularly vulnerable to external economic shocks. Section 5.7 quantifies how much value added and wages to skilled and unskilled labour in developing countries decline when final demand is reduced in industrialised nations. Finally, a summary of the results is presented in section 5.8.

5.1. Overview of the variables and data

Although the characteristics of an MRIO model have been described in detail in section 3.2.2, the particular variables used in this analysis are presented again in a brief manner to assist the reader throughout the exposition. As has been said, the MRIO technique demands a significant amount of data, mainly in the form of national Input-Output (IO) tables. One of the available sources for this information is the Global Trade Analysis Project (GTAP). The most recent version of its dataset, number 8, was used in this study, which comprises records for years 2004 and 2007. The data corresponds to 109 nation states and 20 aggregated regions, which are treated as individual countries. Moreover, the national IO tables for domestic production and imports cover 57 economic sectors[17]. This data was then assembled in the form of two square MRIO transaction matrices, one for each year, by the author of this thesis, representing intermediate demand by industries. Their dimensions are 7,353 (129*57) rows by 7,353 columns. Each of these matrices is accompanied by an additional matrix of final demand for domestic and imported goods, whose dimensions are 7,353 rows by 129 columns (i.e. one column for each country). In addition, there is a row vector of total output and another of value added, which represents the amount by which the value of a sector's output is increased at each stage of production. It is expressed as the total payment received by the owners of the factors of production in the form of wages to skilled and unskilled labour, rents received by land owners, and interest plus profits paid for capital services. Value added is thus analogous to a country's GDP from an income approach. The environmental extension is represented by a row vector of CO_2 emissions disaggregated into economic sectors, derived from the use of coal, crude oil, natural gas, petroleum products and electricity, as well as gas distribution.

[17] See Appendix A.2 for GTAP 8 country and sectoral classification.

Unfortunately, data for non-CO_2 GHGs is not available for GTAP 8, especially nitrous oxide (N_2O), methane (CH_4) and fluorinated gases. This constitutes a limitation of the study, and its implications will be discussed in Chapter 8.

Value added and wages paid to skilled and unskilled workers are used in this examination as proxies for development indicators, as these variables are relevant for promoting economic growth and improving welfare. Due to the methodological nature of MRIO analysis, explained in section 3.2.2, it requires data at a sector-level, which is not available for human-development-related indicators, such as life expectancy, observed and expected years of schooling, etc. Data for number of people employed by country and by sector was also not accessible. This represents a second limitation, also to be discussed in Chapter 8. However, while focusing on value added and wages may provide a partial view of the effects caused by Northern demand-side mitigation actions on the global development process, they can provide valuable insights regarding the magnitude and direction of the potential impacts. It is important to have in mind that the data for wages used in this analysis represent sectoral averages, so it is not possible to take into account wage disparities that exist between the different types of jobs within an individual sector. Moreover, having data for two different years is useful to assess if these effects have changed over the years.

In this analysis, countries are grouped according to the UNDP's 2013 HDI-quartile they belong to, being classified as very-high-, high-, medium-, and low-human-development countries[18]. This simplifies the presentation of the results and allows distinguishing the effects that take place in nations with different levels of development with more detail than by just differentiating them as Annex B or Non-Annex B economies as was done in the previous chapter. However, individual countries will be singled out to illustrate interesting and outstanding cases, or when the interpretation of the results requires doing so.

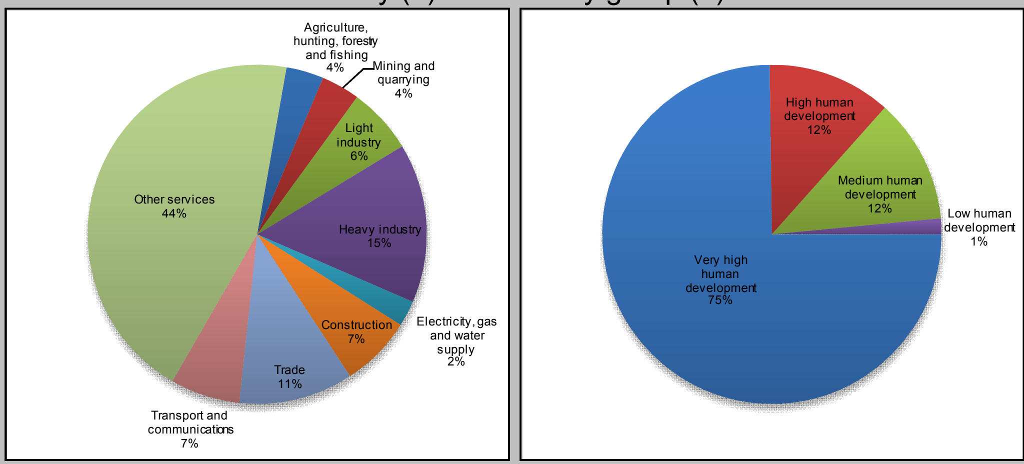
5.2. The global production structure

MRIO analysis has been increasingly used to assess how much CO_2 is associated with the consumption of goods and services throughout the global supply chain. As explained in section 3.2.2, the same procedure can be applied to calculate the amount of value added that is embedded in products and services destined for final

[18] Appendix A.1.2 contains a list of the different countries that compose each group.

consumption. It is important to bear in mind that value added is generated at every stage of production. This procedure thus allows a precise determination of how much value each economic sector in each country contributes during the production process (see section 2.4.2).

Figure 18 - Global structure of value added in 2007 according to economic activity (a) and country group (b)



(a) (b)

Source: Own graphs

The global production structure is represented by the amount of value added that is generated by the production of finished goods and services for domestic consumption and exports according to economic activity. Figure 18a shows that the global production structure in 2007 was largely dominated by services, accounting for around 62% of the total value added (i.e. trade, transport and communications and other services). Agricultural activities and mining contributed with approximately 8%, while industry created slightly more than 21%. The rest corresponded to construction (7%) and electricity, gas and water supply (2%). Viewed from the perspective of country-groupings, shown in Figure 18b, the distribution of value added shows a profound disparity. As has already been noted in section 2.2.1, very-high-human-development nations produced almost 75% of the total value added, even though they possess only 15% of the world population. High- and medium-human-development economies generated jointly nearly 24%, while low-development nations were barely responsible for the remaining 1%. In terms of individual countries, the US was accountable for creating almost one fourth of the world's total value added, while nearly another third was created by the EU27. Meanwhile, the big emerging economies, such as China, India, Brazil, Mexico, Indonesia and others, created approximately 12%. All these shares basically remained unchanged with respect to 2004, and a very similar structure is considered to prevail nowadays.

A portion of the global value added is due to international trade. This is what has become known as *trade in value added*, an indicator that has been deemed as more precise than traditional trade statistics to measure the value of trade flows (IDE-JETRO and WTO, 2011). Almost 15% of the total value added is embodied in trade, but in the cases of agriculture and mining this figure reaches almost 40%. In relation to industry, it is 30%, which is very close to the estimation done by Daudin et al. (2011), while in services it is only 8%.

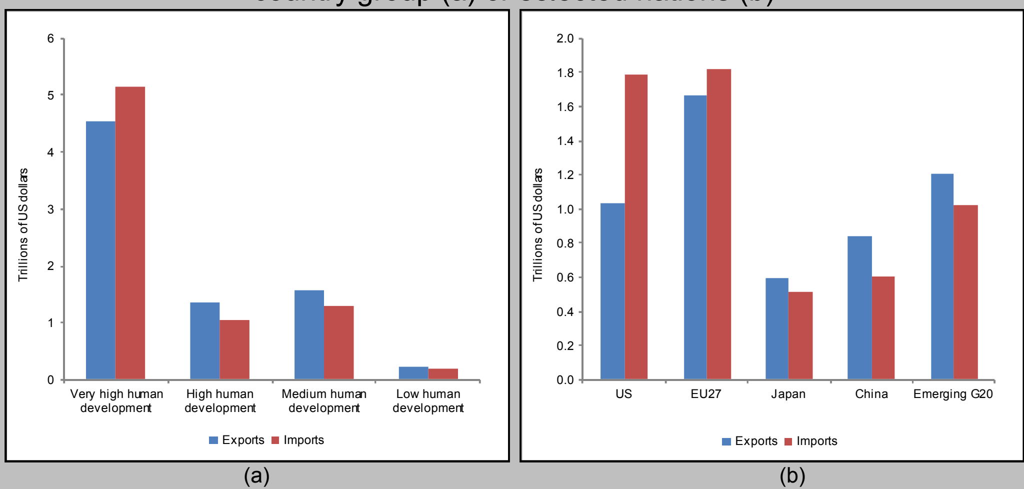
5.3. Factor content of trade

The previous section described the global production structure, showing the general composition of the world economy in terms of economic activities and how much value added is created by each group of countries. It also pointed out the proportion of value added that is embodied in trade flows. The following sections will present a more detailed analysis of the factor content of trade, disaggregating into sectors the amount of value added that is traded. The same is done for skilled and unskilled labour, also from a sectoral perspective.

5.3.1. Trade in value added

Figure 19a presents the value added embodied in exports and imports for the different country groups in 2007. Very-high-human-development nations are, on the whole, net importers of value added, since the total value of their imports is higher than the total value of their exports. Said differently, the amount of value added that they create domestically, and which is embodied in their exports, is lower than the value added incorporated in their imports, which is generated in foreign regions. In this sense, these economies tend to create wealth in the rest of the world through international trade. As can be seen in the graph, the rest of the country groups are net exporters of value added. However, it is important to notice that the least developed nations barely manage to achieve a trade-balance surplus. As was explained in the previous chapter, many of these countries are not self-sufficient and rely on foreign trade to acquire commodities and capital-intensive goods that are necessary for their development process. In individual terms (see Figure 19b), the US is the largest net importer of value added in the world, having an overall deficit of nearly 750 billion dollars. Its shortfall against China alone is close to 150 billion, and with respect to the EU27 it is approximately 120 billion. The trade deficit with China is thus reduced by around 45% when using this method than when employing traditional trade statistics, which report a deficit of 275 billion (UNSD, 2013b). However, the deficit grows around 11% in relation to the EU27 from a reported 109 billion utilising the traditional approach (UNSD, 2013b). These findings are consistent with those obtained by IDE-JETRO and WTO (2011) and Stehrer (2012). Moreover, the US deficit increased around 28% in real terms with respect to 2004. The EU27 is also an important net importer of value added, with a deficit of nearly 150 billion dollars, which grew in real terms more than 60% since 2004. It is worthy to mention that, within this group, the UK was the second largest net importer after the US, possessing a deficit of 125 billion. Meanwhile, Japan is one of the very-high-development nations with a trade surplus, which amounts to around 80 billion. China, on the other hand, a medium-human-development country, is the largest net exporter of value added in the planet, with a surplus of 230 billion dollars, of which almost two thirds are against the US. Its surplus increased 1.7 times with respect to 2004. The other important net exporters are the big emerging economies of the G20 (i.e. Argentina, Brazil, India, Indonesia, Mexico, Russia, Saudi Arabia, South Africa and Turkey), which together hold a surplus of 180 billion, observing a rise of 20% compared to three years earlier. These nations, which mainly belong to the medium- and high-development groups, are key players in the global supply chain. They possess large exporting capacities, providing not only raw materials, but also more elaborate intermediate and finished manufacturing goods to foreign markets.

Figure 19 - Value added embodied in exports and imports in 2007 according to country group (a) or selected nations (b)



Source: Own graphs

An analysis of the sectoral composition of national and regional trade balances has not been sufficiently undertaken in the existing trade-in-value-added literature, which has mainly focused on manufacturing. Undertaking this analysis reveals important characteristics of the global production structure. It allows, among other things, determining "*who produces what and for whom*", to employ a phrase by Daudin et al. (2011). The trade balances according to country group, but this time disaggregated into sectors, are displayed in Figure 20a. Positive numbers indicate that a country has a trade-balance surplus in a given sector. That is, it generates more value added within its own territory by producing goods for external markets. Conversely, negative numbers show that nations have a trade-balance deficit in a certain sector by importing more value added from foreign regions via imported goods. In relation to agricultural activities, very-high-development economies are net importers, as they are the only group that presents a deficit in value added. In contrast, the rest of the countries are net exporters, since they register surpluses, which are small in the cases of high- and low-development nations, but much bigger in the case of the middle-human-development group. When it comes to mining and quarrying, it is clear that high-development nations constitute the main net exporters, since they encompass the major oil and gas producers, like Bahrain, Russia, Saudi Arabia, Venezuela, Oman, etc. In this activity, the least developed countries also hold an important surplus. The very-high-development group, on the contrary, represents the big net importer of mining goods and consequently possess a significant deficit. Regarding light industry[19], medium-development nations constitute the main net exporters, and more specifically China (see Figure 20b), who belongs to this classification. The very-high-development nations, in turn, are the main net importers of light-industry goods. This latter group, on the other hand, possesses an important trade surplus in heavy, capital-intensive industry. A smaller surplus is achieved by the middle-development group, again mainly due to China. The rest of the world is, hence, a net importer of heavy-industry products. Moreover, with regards to services, the very-high-development group stands as the main net exporter, while the rest of the world presents deficits. An opposing pattern is observed in the transport sector, in which the very-high-development economies are net importers and the rest of the world presents trade-balance surpluses.

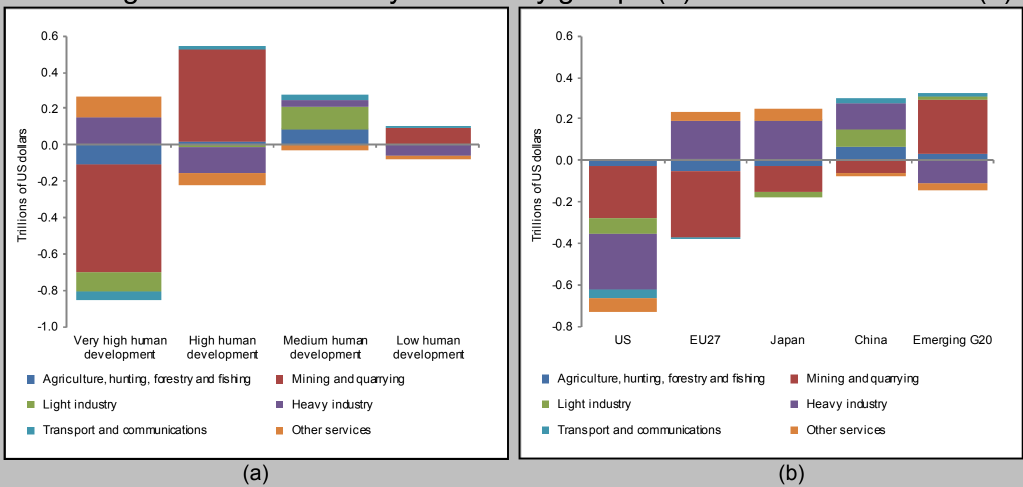
In terms of individual nations (Figure 20b), the US holds deficits in every sector, reflecting its strong dependency on all types of imports. The EU27, along with Japan, are important net exporters of heavy-industry goods and services. China, on the other hand, achieves surpluses in agriculture and in light and heavy industry, but is a net

[19] See Appendix A.2.3 for a list of the economic sectors that are classified as light and heavy industries.

importer of mineral resources. The major emerging economies of the G20 specialise in the extraction of these resources, as well as in agricultural activities, but require importing capital-intensive goods and services.

These trade patterns reflect to some extent the flows described by the Prebisch-Singer hypothesis (Prebisch, 1950; Singer, 1950). It can be appreciated that the periphery (i.e. the developing world) specialises in the extraction of material resources and the production of labour-intensive goods. The so-called global South is a net exporter of value added embodied in agricultural, mining and light-industry goods. On the other hand, the core (i.e. industrialised nations) is a net exporter of capital-intensive products, as well as in services. China, however, has managed to break this pattern due to its rapid industrialisation process, managing to become an important net exporter of value added embodied in light- and heavy-industry goods.

Figure 20 - Sectoral composition of trade balances in value added in 2007 according to economic activity for country groups (a) and selected nations (b)



Source: Own figures

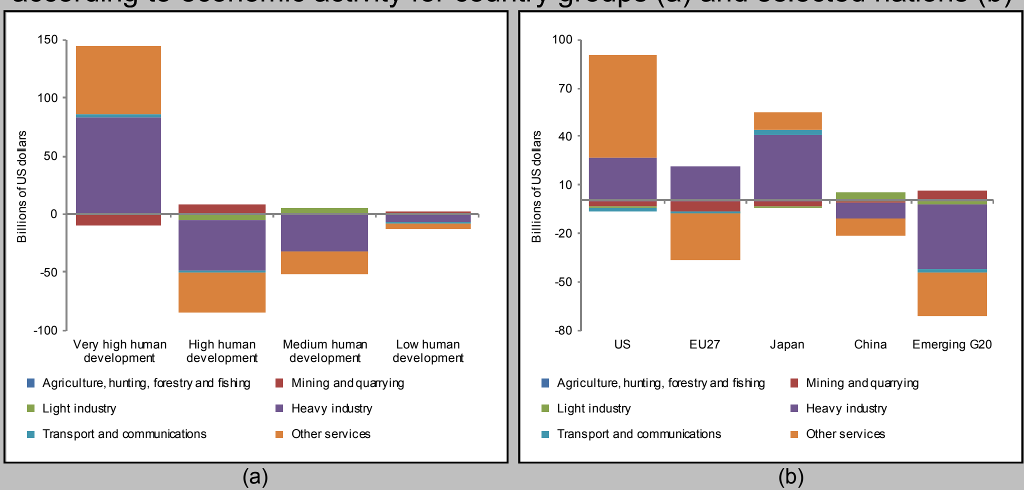
5.3.2. Trade in skilled and unskilled labour

The analysis of the sectoral composition of the regional trade balances in value added offers a more detailed view of the global production structure, as it allows identifying which regions represent net exporters or net importers of different types of goods and services. A more exhaustive examination requires focusing on the payments to labour, one of the components of value added. As has been explained, the revenues associated with this factor of production serve as a proxy for economic development in this thesis, as they contribute to economic growth and to improve a society's level of well-being. Wages received by skilled labour will be examined first.

A portion of the total wages paid for labour services are due to international trade. Around 10% of the wages to skilled labour are embodied in trade flows, but this figure rises to nearly 40% in agricultural and mining activities, and around 28% in the case of industry. In services, it represents approximately 7%.

Looking at total figures, very-high-human-development countries are net exporters of skilled labour embodied in trade, with a trade-balance surplus in 2007 of around 130 billion dollars. The rest of the world, in turn, constitutes a net importer. However, looking at the sectoral composition reveals how the balances are formed with more detail, reflecting the global division of labour. Skilled labour is embodied primarily in the heavy industry and services sectors, as can be seen in Figure 21a. These graphs must be interpreted in the same way as the previous ones, which presented total value added. The magnitude of the trade-balance surplus in the case of the very-high-development group is significant, reflecting an evident global disparity. The types of products and services that are intensive in skilled labour usually encompass more technology and physical capital, and thus yield much more value for every unit that is produced. The developing world has still not achieved this level of economic development and, hence, of productivity. In consequence, it relies on the wealthier economies for skilled-labour-intensive products and services. However, the high-human-development group holds a small surplus in the mining sector, and the medium-development group also possesses one in light-industry activities, mainly due to China (see Figure 21b). The low-development countries, on the other hand, have deficits in every sector.

Figure 21 - Sectoral composition of trade balances in skilled labour in 2007 according to economic activity for country groups (a) and selected nations (b)



Source: Own figures

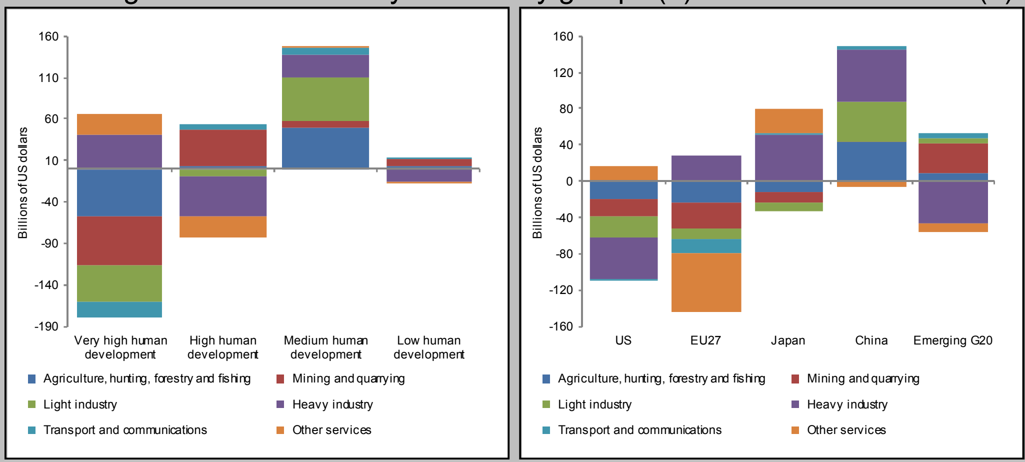
In terms of individual countries, the US is the world's largest net exporter of skilled labour embodied in trade. Its surplus grew around 20% in real terms from 2004 to 2007, ranging from nearly 70 billion dollars to 83 billion, respectively. This country, however, presents small deficits in mining, light industry and transport, as seen in Figure 21b. The US is followed by Japan, the second largest net exporter, who presents a very similar pattern, although its surplus in services is much smaller. Surprisingly, the EU27 as a group is a net importer of skilled labour in the services sector, which reflects its reliance on other high-development countries, especially the US. Nonetheless, in terms of its individual members, Germany, the UK, Denmark, Finland, Sweden and others have significant surpluses in this sector. The EU27, in turn, is a net exporter of skilled labour in heavy-industry products. In relation to developing nations, México is the biggest global net importer of skilled labour, followed by China, Russia and most of the emerging economies of the G20. China just possesses a small surplus in the light-industry sector, although it managed to reduce its total deficit by around 17% since 2004, which reflects its increased investments in human capital. In contrast, the emerging economies of the G20 possess significant deficits in heavy industry and services, with just a small surplus in mining. This condition has aggravated over time, as their general deficit grew almost 25% in real terms during the same period.

International trade also contributes to generate wages to unskilled labour, of which approximately 13% was embodied in trade flows in 2007. This number goes up to 23% with regards to agriculture and mining, while it represented 28% in industrial activities. In the services sector, unskilled labour embodied in trade accounted for nearly 8%.

Focusing on total figures, the only net exporters of unskilled labour are the middle-human-development countries, holding a surplus of around 145 billion dollars in 2007, while the rest of the nations are net importers. The very-high-development group registered a deficit of nearly 113 billion. The sectoral composition, on the other hand, shows a more complex scene than the one displayed by skilled labour, as unskilled workers are distributed along a wider range of economic sectors, as shown in Figure 22a. However, they are still mainly concentrated in agriculture, mining and light industry. Very-high-development countries are net importers of unskilled labour in all sectors, except in heavy industry and services, in which they still maintain an advantage. The next group, formed by high-development nations, is a net exporter in agriculture, mining and transport, but possesses deficits in the rest of the sectors.

Middle-development economies, in turn, enjoy trade-balance surpluses in every sector, but this effect is strongly influenced by China, who belongs to this group. Finally, the least developed nations are net importers of unskilled labour in light and heavy industry, as well as in services.

Figure 22 - Sectoral composition of trade balances in unskilled labour in 2007 according to economic activity for country groups (a) and selected nations (b)



(a) (b)

Source: Own figures

Regarding individual nations, the US is the largest net importer of unskilled labour in the world, with a total deficit in 2007 of around 90 billion dollars, which worsened in real terms approximately 37% compared to 2004. This country only manages to be a net exporter in the services sector, as can be seen in Figure 22b. The US is followed by France and the UK, with deficits of 39 billion and 28 billion, respectively. The EU27, as a whole, is a net importer of unskilled labour in all sectors, except in heavy industry, while its total deficit increased by 13% with respect to 2004. Japan is a net exporter in heavy industry, as well as in services and transport. In relation to the developing world, China is the biggest net exporter of unskilled labour in the globe, which has constituted one of its main comparative advantages and a pillar of its development strategy. Moreover, its total surplus almost doubled in real terms in three years. It only possesses a small deficit in the services sector. The rest of the big emerging economies, on the other hand, are net exporters in all sectors, except in heavy industry and services. Their deficit in these activities worsened significantly since 2004, increasing nearly 80% in real terms. This reflects a weakening of these particular sectors and, hence, of their industrialisation processes.

These results complement those obtained in the previous section, offering a more detailed view of the global production structure and the international division of labour.

The global South specialises in low-capital- and unskilled-labour-intensive goods related mainly to agriculture, mining and light-industry. The North, on the other hand, focuses on producing high-capital- and skilled-labour-intensive products and services.

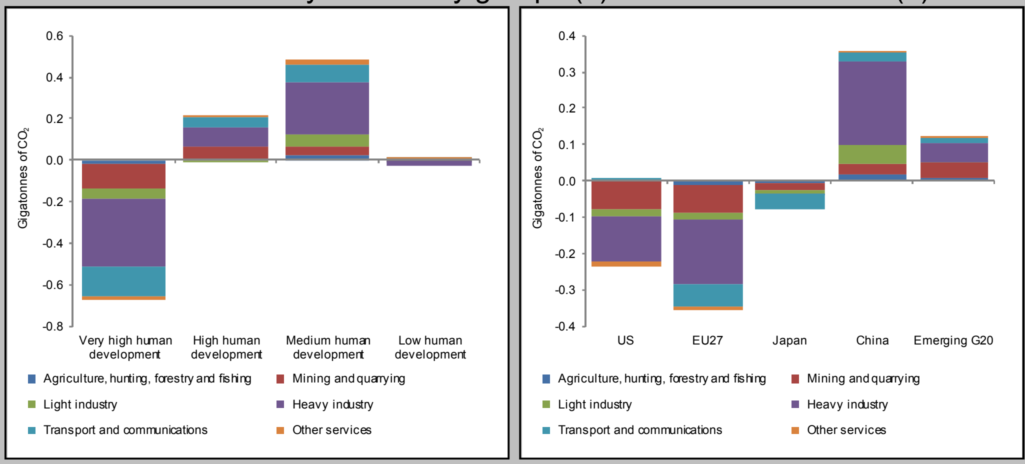
5.4. Carbon content of trade

Many studies have focused on calculating the carbon content of trade (e.g. Peters and Hertwich, 2008a; Davis and Caldeira, 2010; Peters et al., 2011b) (see section 2.2.2). However, the sectoral composition of national or regional trade balances of CO_2 is not always examined in detail. This is done here in the same manner as in the previous section, inspecting the sectoral shares of the trade balances.

The analysis shows that around 21% of CO_2 was embodied in trade flows in 2007. However, the amount in agricultural and mining goods was nearly 37%, while it was 29% in relation to industrial products. Services, on the other hand, accounted for close to 18%.

In the case of CO_2, the division between nations is clear-cut, as shown in Figure 23a. The very-high-development economies are net importers of emissions, while most of the rest of the world is a net exporter. The former group did not possess a trade surplus in any economic activity in 2007, registering an overall deficit of 677 Mt. In turn, high- and medium-development nations did not hold trade deficits in any sector. A different picture, however, is presented by the least developed economies, who are net importers of emissions in agriculture, as well as in light and heavy industries. These findings coincide with those presented in the previous chapter (see section 4.3.3). As said, many of the poorest nations are not self-sufficient and thus import CO_2 embodied in a range of commodities and industrial goods produced in foreign regions.

Figure 23 - Sectoral composition of trade balances in CO_2 in 2007 according to economic activity for country groups (a) and selected nations (b)



(a) (b)

Source: Own figures

The largest surpluses and deficits corresponded to the heavy-industry sector, followed by mining and light industry. Concentrating on individual countries, the results indicate that the US is the largest net importer of emissions, with a total trade deficit of 505 Mt, which almost maintained its same level since 2004. The EU27 is a net importer in every sector as shown in Figure 23b, with an overall deficit of 814 Mt, which increased almost 8% in three years. The UK stands out within this group, as it was the second largest net importer of emissions in 2007 with a deficit of 204 Mt. It was followed by Japan, with a deficit of 164 Mt. Regarding developing nations, China is the largest net exporter of CO_2, registering an emissions surplus of 1.1 Gt, which was almost 38% larger than its 2004 levels. This surplus is mainly created by its industrial sectors. The big emerging economies also held an important surplus in 2007 of 322 Mt, but it diminished almost 33% since 2004. This decline could have been due to a relocation of industries to China, more than to technological improvements. It is also interesting to notice that in the heavy-industry sector, the G20 developing countries are net importers of value added, but are net exporters of emissions. This evidences their high carbon intensity and low productivity in this particular sector.

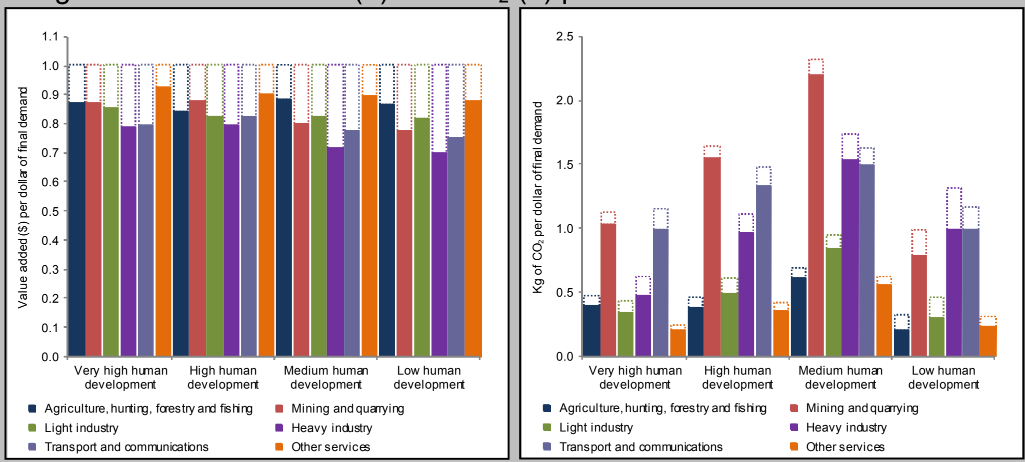
These results and those presented in the previous section can now be interpreted together. As said, the global South specialises in low-capital- and unskilled-labour-intensive goods, and these have high carbon contents. The North focuses on producing high-capital- and skilled-labour-intensive goods and services, produced with *cleaner* technologies.

5.5. Labour productivity of carbon

The chapter so far has focused on analysing the global production structure, as well as the factor and carbon content of trade from a sectoral perspective. This section, in turn, presents the *labour productivity of carbon* for the different country groups and different economic sectors. This measure indicates the amount of wages to skilled and unskilled labour that are associated with every unit of emissions. Apart from being an efficiency indicator, it is also useful to determine to what extent wages could decrease within a given region by every kilogram of CO_2 that is mitigated along the supply chain due to reductions in final demand.

In order to calculate the labour productivity of carbon, multiplier analysis is used. As a reminder to the reader, this consists in examining the matrix of *total intensity multipliers* (TIMs), which was described in section 3.2.2.1. As was explained there, each element of the Leontief matrix represents an output multiplier, which basically indicates how much output is augmented in a given sector by every dollar of final demand. Another characteristic of this matrix is its ability to differentiate between the direct effects of an additional unit of final demand on a given sector and the associated indirect effects that are triggered throughout the economy. In an MRIO context, the Leontief matrix can identify the direct effects that occur in a specific sector within a region and the indirect effects that take place throughout the global supply chain in other regions derived by an additional dollar spent either on finished domestic or imported goods. When the Leontief matrix is pre-multiplied, for example, by a diagonalised matrix of carbon intensities (i.e. CO_2/total output), the result is a matrix of carbon TIMs. Each element of this matrix thus indicates how much CO_2 is created directly and indirectly by an additional unit of final demand. The elements of the regional sub-matrices placed in the main diagonal represent intra-regional multipliers, which determine the amount of CO_2 that is created within a region (i.e. direct effects) by every dollar of final expenditure. The elements of the off-diagonal import sub-matrices, on the other hand, are inter-regional multipliers, which specify the quantity of emissions generated in other regions along the supply chain (i.e. indirect effects) by the same dollar of final demand. In this section, TIMS were calculated not only for CO_2, but also for value added and wages to skilled and unskilled labour. In this manner, the resulting multipliers indicate the amount of value added, wages and CO_2 that are generated intra- and inter-regionally by every dollar of final demand. To calculate the labour productivity of carbon, the labour multipliers are divided by the carbon multipliers, and the resulting indicator expresses the quantity of wages associated inter- and intra-regionally with every unit of emissions generated by a dollar of final demand. The value added multipliers are not directly used to determine the labour productivity of carbon, but they offer interesting insights, as will be explained. These and the CO_2 multipliers are presented first in Figure 24.

Figure 24 - Value added (a) and CO_2 (b) per dollar of final demand in 2007



(a) (b)

Note: Solid bars represent intra-regional multipliers, while dashed bars represent inter-regional multipliers.

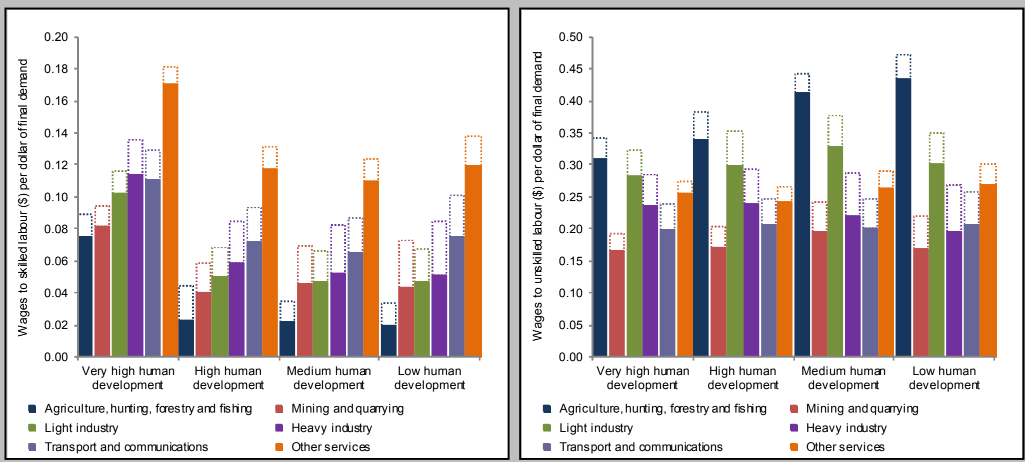
The graphs above contain a lot of information, so it is advisable to examine them attentively. Figure 24a presents the multipliers for value added. It is important to notice that these multipliers add up to 1, since one dollar of final demand generates exactly one dollar of value added, given the income-expenditure identity of GDP. In other words, a dollar spent by someone represents a dollar earned by someone else in the form of income. The interesting aspect of this graph is the magnitude of the intra- and inter-regional multipliers. For example, for every dollar spent in 2007 in final agricultural goods produced in very-high-human-development countries (see first blue bar), 87 cents were generated within the region (i.e. solid portion of the bar) and an additional 13 cents throughout the global supply chain in other regions of the world (i.e. dashed portion of the bar). The remaining bars in the graph should be read following the same logic. It can be seen that the inter-regional multipliers for the services sector are proportionally the smallest (i.e. around 10% on average), since only a small fraction of services is traded. The inter-regional multipliers for heavy industry are much higher (i.e. 25% on average), reflecting the geographical fragmentation of the global production process. For instance, every additional dollar of final expenditure in heavy-industry products manufactured in very-high-development economies generates nearly 79 cents within the region and an extra 21 cents in foreign nations. Focusing on the overall average values for each region, it is found that the least developed countries possess the lowest intra-regional multipliers. For every dollar spent on goods and services produced within the region, only 80 cents on average are kept internally, while 20 cents are captured by other nations. This reflects their weak internal structures and their dependency on foreign regions for intermediate goods. The highest intra-regional multipliers correspond to the very-high-development nations with an average of 85 cents per dollar of final demand. The difference with respect to the least developed group might seem small, but these can be significant if it is taken into account that trillions of dollars of final demand are involved. In this sense, least developed economies capture less value domestically for every dollar of final expenditure than the other country groups.

Figure 24b shows the same type of multipliers, but this time for CO_2 emissions. In this case, they can be interpreted as the *carbon intensity of final demand*, since they indicate the amount of emissions generated per dollar of final expenditure. This graph must be read in the same way as the previous one. For instance, every dollar spent on finished agricultural goods produced in very-high-development nations (see again first blue bar), creates 0.40 kg of CO_2 within the region and an additional 0.07 kg externally along the supply chain. The differences between sectors in this case are more notorious. The most carbon-intensive activity on average across regions is mining, followed by heavy industry and then transport. In turn, the less carbon-intensive sector is services. In relation to regions, the most carbon intensive on average is the medium-development group (1.32 kg/$), which includes China, followed by high-development nations (0.94 kg/$), then the least developed countries (0.76 kg/$) and, finally, the very-high-development economies (0.67 kg/$). Analysing the different types of multipliers also offers interesting insights. The highest inter-regional multipliers proportionally correspond to the least-developed economies, followed by very-high-development nations. On average, around 24.7% and 18.3%, respectively, of the emissions per dollar of final demand for products produced in those regions occur outside their territories along the supply chain. This reflects the high carbon intensity of the intermediates used in their production processes, which are manufactured or incorporated in other regions. For instance, one dollar spent on an average good or service produced in least developed nations generates 0.57 kg of CO_2 internally, and an additional 0.18 kg externally. In contrast, around 12.5% and 9.5%, on average, of the emissions associated with a dollar of final demand for goods and services produced in high- and medium-development nations are generated in other geographical regions.

The information contained in both graphs in Figure 24 can be used to determine the simultaneous effects of an additional dollar of final demand on both the generation of value added and CO_2 emissions. For example, focusing on the low-development group, it can be said that one dollar of final demand spent on heavy-industry products generates 1.3 kg of CO_2 emissions along the supply chain and close to 70 cents of value added within the region. Accordingly, it could equally be said, along the same lines, that for every unspent dollar in this sector, 1.3 kg of CO_2 could be mitigated, but 70 cents of the payments to the factors of production would be lost.

In addition to the TIMS calculated for value added, two more sets of intra- and inter-regional multipliers were estimated for wages to skilled and unskilled labour. A summary of them is presented in Figure 25.

Figure 25 - Wages to skilled (a) and unskilled labour (b) per dollar of final demand in 2007



(a) (b)

Note: Solid bars represent intra-regional multipliers, while dashed bars represent inter-regional multipliers.

As has been said, skilled labour is mainly concentrated in the services and heavy-industry sectors, as seen in Figure 25a. Consequently, these activities possess on average the highest multipliers across regions (9.6 and 14.3 cents per dollar), along with transport (10.1 cents). In contrast, the lowest multipliers for skilled labour correspond on average to agriculture and mining with 5.0 and 7.3 cents, respectively. Regarding country groupings, very-high-development economies obtain on average the higher amount of wages per dollar of final demand across sectors (12.5 cents). The rest of the groups register very similar average levels of around 7.9 cents. The smallest intra-regional multipliers, on the other hand, correspond to least developed countries. Around 70% (5.8 cents) of the wages to skilled labour for every dollar spent on an average good or service produced in the region are generated internally, and 30% (2.3

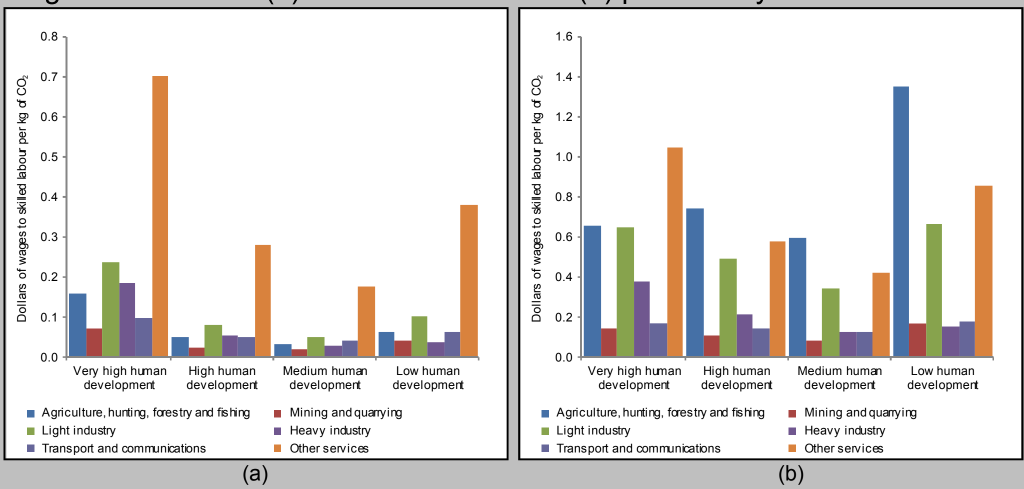
cents) are created elsewhere. This reflects their scarcity of skilled labour and their dependency on other regions to acquire different types of goods. The largest intra-regional multipliers, on average, are held by the very-high-development group, where nearly 80% of the wages to skilled labour are generated internally (10.8 cents). The average intra-regional figures for the high- and medium-development nations are 75% (5.9 cents) and 72.5% (5.6 cents), respectively.

The multipliers for unskilled labour (see Figure 25b) show an opposing picture, as the highest values across regions on average correspond to agriculture (40.9 cents per dollar of final demand) and light industry (35.0 cents per dollar), followed by heavy industry and services (28.2 cents each). In relation to regions, the least- and medium-development groups hold the largest average total multipliers across sectors (31.1 cents per dollar each), followed by high-development (28.9 cents) and very-high-development economies (27.5 cents). Analysing the different types of multipliers reveals that the smallest intra-regional effects correspond once more to the low-development group. Around 80% (26.1 cents) of the wages to unskilled labour for every dollar spent on an average good or service produced in this region are generated internally, and an additional 20% (4.9 cents) are captured externally along the supply chain. Although the nations in this group possess high total multipliers, the intra-regional effects evidence once again their inability to be self-sufficient. Very-high-development nations, in contrast, generate on average 86% (24.0 cents) internally and 13.9% (3.5 cents) externally. Intra-regional figures for the high- and medium-development groups are 85.1% (24.8 cents) and 83.3% (26.8) on average, respectively.

The information provided by both graphs in Figure 25 can now be combined with the figures contained in Figure 24b, to assess the joint effects of a reduction of one dollar of final demand on CO_2 emissions and skilled and unskilled labour. Focusing on the agricultural sector, for example, it can be said that for every unspent dollar in goods produced in low-development nations, around 0.32 kg of CO_2 could be mitigated along the supply chain, but nearly 43 cents would be lost in wages to unskilled labour within the region, along with an additional 1.9 cents to skilled labour. The effects related to the rest of the sectors and regions can thus be read in the same manner.

The multipliers that have been presented here were used to calculate the labour productivity of carbon. As explained, dividing the labour multipliers by the CO_2 multipliers allows determining the amount of skilled and unskilled labour associated with every kg of emissions. As the within-regional effects on labour are specifically of interest to this study, intra-regional labour multipliers are divided by the total CO_2 multipliers. In this sense, the resulting indicator expresses the quantity of wages within a region that are associated with a kg of CO_2 emitted along the entire supply chain.

Figure 26 - Skilled (a) and unskilled labour (b) productivity of carbon in 2007



Source: Own graphs

The skilled-labour productivity of carbon is much higher in the services sector, as can be seen in Figure 26a. In very-high-development economies, nearly 70 cents of wages are created within their territories for every kg of CO_2 emissions emitted throughout the entire supply chain. In low-development countries, almost 38.5 cents are generated by the same amount of emissions. This figure actually constitutes the global average across regions for services. The next most productive sector is light industry where, across regions, 11.7 cents are associated on average to every kg of CO_2. This sector is followed by agriculture and heavy industry, with an average of 7.5 cents each. Transport comes next with 6.1 cents, and finally mining with 3.9 cents. The most productive region in skilled labour, on the other hand, is the very-high-development group, with an average across sectors of 24.1 cents. Low development nations possess an average of 11.5 cents, while high- and medium-development countries have averages of 8.9 and 5.7 cents, respectively.

When it comes to unskilled labour (see Figure 26b), the most productive sector in very-high-development nations is services, generating a little more than 1 dollar of wages internally per kg of emissions emitted along the supply chain. Agricultural activities are, in turn, the most productive sector in the low-development group, with around 1.3 dollars. This result, however, has to be taken with caution, considering that non-CO_2 emissions are not included in the analysis. This figure could thus be much lower. On average, the most productive activity across regions is agriculture, with 0.84 dollars per kg, followed by services (0.73), light industry (0.54), heavy industry (0.22), transport (0.15) and mining (0.13). When it comes to regions, the most productive group is the one formed by the least developed nations, with an average across sectors of 0.56 dollars per kg of CO_2. They are followed by the very-high-development economies, which possess an average of 0.51 dollars. High- and medium-development countries hold averages of 0.38 and 0.28, respectively.

As has been said, apart from representing measures of productivity, the figures presented can also be useful to determine the sensitivity of regions and sectors to demand-driven mitigation actions. For instance, mitigating one kilogram of CO_2 by reducing the demand of agricultural imports from low-human-development nations could yield losses of 1.4 dollars in wages to unskilled labour and 6 cents to skilled labour. Understanding these figures is important, as they represent the underlying mechanism that explains the impacts on skilled and unskilled wages in the global South derived from changes in final demand registered in the North. An analysis of these impacts is presented in section 5.7.

5.6. Trade-dependent countries

Before presenting the impacts on value added and wages in the developing world caused by mitigation-induced changes in final demand, the analysis of trade in value added is undertaken once again in this section to identify those countries that are more dependent on trade.

Some economies are especially dependent on foreign markets. These are generally low- or medium-developed countries, small nations, small-island states and fossil-fuel producers with either limited or weak domestic markets, limited factor endowments, low industrialisation levels, an outward-market orientation, or a mix of these factors. Table 22 shows the 15 most trade-dependent countries or regions. They generate more value added through their exports of goods than what they produce in their own internal markets. The content of value added included in their exports thus surpasses that of their domestically-consumed products and services. Five of them correspond to low- and medium-human-development countries or regions. According to the analysis, Malaysia is the most trade-dependent nation. The value added that it produces through its exports is approximately 1.6 times greater than what it obtains domestically. Nearly

60% of its exports are destined for the US, the EU, Japan and China. A similar situation is found in Vietnam, who possesses a mixed economic regime similar to China's, and represents one of Asia's most open economies. This country acquires almost the same amount of value added through trade than what it creates internally. In the cases of Angola, the Democratic Republic of Congo, Tajikistan, Turkmenistan, Uzbekistan, Iraq, Jordan, Lebanon, Syria and Yemen, these countries had either weak economic structures or had endured internal periods of social and political unrest. Although some of them possess vast resource endowments, such as oil and natural gas, they have been unable to strengthen their internal economies and depend heavily on foreign markets. On the other hand, a second group of countries are formed by oil-exporting nations with high-human-development status, such as Kuwait, Saudi Arabia, Oman and Bahrain. Their economies are mainly based on the oil extracting industry. Their exports' content of value added augmented from 2004 to 2007 as a result of rising oil prices, which explains why the rankings of two of these nations increased during the period. Saudi Arabia, for example, was the twentieth most trade-dependent country in 2004, but moved up to sixth place in 2007. The next group is formed by small states and small-island states, whose economies are highly dependent on exports, due to their limited territories and their clearly defined outward-market orientations. This is the case of Malta, Singapore, Luxembourg, Hong Kong and Mauritius which, except for the last one, enjoy very-high-human-development levels. Surprisingly, the last country in the list is Ireland, whose exports generate nearly 1.4 times more than its internal market. It depends strongly on the rest of the EU members and the US. From all these countries, only three (i.e. Malta, Luxembourg and Vietnam) registered deficits in their value-added trade balances, indicating a dependency on imports as well. Overall, it can be said that all these countries and regions are highly vulnerable to external shocks in foreign final demand. The 2008/2009 crisis can provide some insights in this respect. Malaysia's economy was growing at a rate of 6.3% before the crisis (World Bank, 2013), mainly fuelled by its manufacturing sector, producing exports for the US and the EU. But during the second half of 2009, its growth dropped to minus 6.2% and 3.9% in the first two quarters of 2009, respectively. Manufacturing employment fell 7.8% from 2008 to 2009, which led to an increase in poverty (Abidin and Rasiah, 2009). Moreover, Ireland's vulnerability to external shocks may represent a significant factor of its most recent economic downturn. It was one of the first EU member countries to receive bailout funds after the crisis.

Table 22 - Countries with the largest dependencies on international trade in 2007

Rank	Rank in 2004	Country	VA embodied in exports as % of domestic VA	Trade balance *	% of exports to US	% of exports to EU27	% of exports to Japan and China
1	1	Malaysia	163.06%	52,587	20.27%	20.11%	19.53%
2	2	Malta	160.08%	-1,391	12.72%	48.03%	8.75%
3	6	Kuwait	152.24%	41,996	13.09%	16.79%	18.68%
4	4	Ireland	141.01%	59,445	17.80%	58.80%	4.33%
5	21	Angola and DR of Congo	136.80%	19,155	36.00%	14.48%	22.97%
6	19	Saudi Arabia	136.80%	120,027	18.38%	19.41%	19.61%
7	8	Singapore	124.42%	27,412	15.32%	24.24%	16.27%
8	7	Oman	121.56%	7,255	7.10%	10.25%	42.81%
9	9	Tajikistan, Turkmenistan and Uzbekistan	118.95%	11,254	7.91%	31.33%	4.63%
10	11	Luxembourg	101.86%	-3,567	10.02%	66.61%	3.00%
11	5	Bahrain	99.54%	2,848	13.02%	24.68%	7.92%
12	14	Hong Kong	97.52%	14,156	19.41%	24.64%	29.25%
13	17	Iraq, Jordan, Lebanon, Syria and Yemen	94.10%	6,928	21.98%	29.48%	7.77%
14	20	Vietnam	90.50%	-6,844	21.86%	24.53%	17.62%
15	18	Mauritius	88.20%	257	14.22%	52.81%	5.94%

Note: * Trade balance expressed in millions of dollars. VA: Value added.

5.7. Demand-side mitigation impacts on value added, skilled and unskilled labour

This chapter has already described the global production structure and the sectoral composition of the trade balances for value added, CO_2 emissions and wages to skilled and unskilled labour. These results constitute the background that helps to understand how the developing world could be affected by mitigation-induced changes in final demand registered in developed nations. The analysis on the labour productivity of carbon is specifically useful, as it represents the underlying mechanism that explains the impacts. This section quantifies how much value added and wages to skilled and unskilled labour in developing countries fall when final demand is reduced in industrialised nations. As a reminder to the reader, the first stage of this analysis, described in section 3.2.2, consists in determining the extent to which final demand for imports, either in a given sector or across-the-board, are required to be reduced in very-high-development economies in order to mitigate 1% of their total consumption emissions. The second stage then involves calculating how much value added and wages to skilled and unskilled labour would fall in the different developing-country groups caused by those reductions in final demand. This made necessary reformulating the traditional IO equation to express final demand as the endogenous variable, as was explained in section 3.2.2. A reduction of 1% was applied to the exogenous CO_2 emissions that correspond to the imported goods and services purchased by the very-high-development group, focusing on certain sectors or across-the board, in order to estimate the new level of final demand associated with the new level of consumption-based emissions. These reductions were weighted according to the share that each developing country holds in relation to the very-high-development group's total imports. The results were used next to find the associated reductions in value added and wages to skilled and unskilled labour that take place in the rest of the country groups.

Table 23 shows the results from this analysis. The first column from left to right shows the sectors where mitigation-driven demand reductions are undertaken in order to cut very-high-development countries' total consumption emissions by 1%. The second column shows the required decline in total final demand to attain the specified emissions reduction. The last three columns show how much value added and wages to skilled and unskilled labour fall in the developing world as a consequence of the decrease in final demand. The rows, on the other hand, show the different economic sectors. In each case, it is assumed that the 1% reduction in total consumption emissions is achieved just by reducing imports from that specific sector. The last row, however, shows a special case, in which the cut in emissions is accomplished through across-the-board reductions in imports. Focusing on individual sectors is useful, as it allows determining the vulnerability of the different developing-country groups in each case. Furthermore, it is important to keep in mind that all the figures in the table represent group averages.

Table 23 - Demand-side mitigation impacts on value added, skilled and unskilled labour, according to country group

Sector where mitigation-driven demand reductions are undertaken to reduce VHD's total consumption emissions by 1%	Required reductions in total Final Demand in VHD economies to achieve the CO_2 reduction	Impacts on total Value Added in the developing world	Impacts on total wages to Skilled Labour in the developing world	Impacts on total wages to Unskilled Labour in the developing world
Agriculture, hunting, forestry and fishing	-1.7%	High: -3.4% Medium: -6.2% Low: -7.2%	High: -0.2% Medium: -0.2% Low: -0.3%	High: -5.1% Medium: -9.9% Low: -11.6%
Mining and quarrying	-1.2%	High: -4.3% Medium: -2.4% Low: -5.6%	High: -0.7% Medium: -0.5% Low: -1.0%	High: -1.6% Medium: -1.1% Low: -1.8%
Light industry	-1.5%	High: -3.0% Medium: -5.9% Low: -2.8%	High: -1.4% Medium: -3.7% Low: -1.6%	High: -3.9% Medium: -7.7% Low: -2.7%
Heavy industry	-1.8%	High: -5.3% Medium: -6.4% Low: -0.7%	High: -2.3% Medium: -3.6% Low: -0.4%	High: -5.0% Medium: -6.4% Low: -0.6%
Transport and communications	-1.6%	High: -12.0% Medium: -12.6% Low: -11.4%	High: -4.7% Medium: -4.9% Low: -6.5%	High: -2.7% Medium: -2.6% Low: -3.0%
Other services	-4.8%	High: -13.2% Medium: -16.1% Low: -13.3%	High: -13.6% Medium: -19.8% Low: -24.5%	High: -11.5% Medium: -13.1% Low: -14.1%
Across-the-board	-0.34%	High: -0.98% Medium: -1.03% Low: -1.07%	High: -0.45% Medium: -0.67% Low: -0.66%	High: -0.73% Medium: -0.95% Low: -0.69%

Note: Impacts refer to region-wide declines in total value added and total wages to skilled and unskilled labour in high-, medium- and low-development nations derived from reductions in final demand for imports in the specified sectors. These reductions take place in very-high-development nations, which are required to mitigate their total consumption emissions by 1%. VHD: Very-high-human-development economies. Countries are classified according to the UNDP's 2013 classification.

The first case corresponds to the agricultural sector. If 1% of very-high-development countries' consumption emissions were to be mitigated just by reducing their agricultural imports, their final demand would need to fall by 1.7%. This would cause losses in developing nations in terms of value added and wages, especially in least developed countries, which turn out to be the most affected group. Their total value added, which is analogous to their GDP, would decline around 7.2%. Moreover, total wages to skilled and unskilled labour would suffer a decrease of 0.3% and 11.6%, respectively, significantly affecting their exporting sectors. Medium-development nations would experience similar losses, while the high-development group would be the least affected.

In relation to mining, very-high-development nations would need to reduce their final demand by 1.2% in order to mitigate 1% of their total consumption emissions. Least developed countries would be again the most affected, losing around 5.6% of their value added. However, wages to unskilled labour would not fall as much, as in the case of agriculture, dropping only by 1.8%. Skilled labour, however, would register a slightly larger decrease of 1%. The next most affected group corresponds to the high-development countries which, as has been said, constitute the big oil and gas producers. Their value added would fall by 4.3% and their wages to skilled and unskilled labour by 0.7 and 1.6%, respectively. Medium-development nations, in this case, would register the smallest impacts.

Regarding the light-industry sector, a 1.5% reduction in total final demand is required in industrialised nations to bring their total consumption emissions by 1%. Medium-development economies, to which China belongs, would become the most affected group. Their total value added would fall 5.9%, while the wages to skilled and unskilled labour would drop by 3.7% and 7.7%, respectively. High-development nations are the second most affected group, registering a decline of 3% in value added, with drops of 1.4% and 3.9% in wages to skilled and unskilled labour, respectively. Low-development countries, in turn, are the least affected.

Heavy industry displays a very similar picture to the case of light industry. A 1.8% reduction in final demand is required to achieve the emissions cut in very-high-development economies. Once again, the most affected group corresponds to middle-development nations with similar reductions as those that take place in light industry. Moreover, least developed countries again experience the smallest impacts.

When it comes to transport, a 1.6% reduction in final demand in very-high-development economies produces considerable losses of total value added in all country groups, which range from 11.4% in least developed countries to 12% in high- and 12.6% in medium-development nations. In this case, the wages to skilled labour register larger losses, being the low-development group the most affected with a fall of 6.5%. This last group is also the most impacted in relation to unskilled labour, experiencing a decline of 3%.

Achieving the emissions cut in services requires a much larger reduction in final demand in industrialised nations, given the sector's lower carbon intensity and the small fraction of output that is traded. Consequently, final demand would need to drop by 4.8%. The consequences to the developing world are significant, since these nations are not specialised in these activities, as was explained in the previous sections. Medium-development economies are the most affected in terms of total value added, observing a drop of 16.1%. However, in relation to wages, the low-development group would suffer the biggest declines of 24.5% and 14.1% in skilled and unskilled labour, respectively. The rest of the countries would also suffer considerable losses.

Finally, when the same emissions reduction is achieved by cutting imports across-the-board, the required decline in total final demand is much smaller (0.34%), as the effect is distributed along all the sectors. The low- and medium-development groups would register similar impacts. In the case of value added, they would experience falls of 1.07% and 1.03%, respectively, while in wages to skilled labour they would suffer drops of 0.66% and 0.67%. Medium-development nations, in turn, suffer the biggest cuts to wages to unskilled labour (0.95%).

These results reveal that mitigation-induced reductions in demand registered in developed countries can free carbon space and make it available to the developing world. Nonetheless, these actions can also produce significant consequences in the developing world in terms of losses in payments to the factors of production. Low-development nations are particularly vulnerable to lower levels of imports in the agricultural and mining sectors. The medium-development group, in turn, is more vulnerable in the case of the industrial sectors. Finally, when it comes to services, all groups are particularly vulnerable. Lower levels of value added and wages, and consequently of GDP per capita, motivated by reductions in final demand for imports, can thus produce significant developmental consequences in the developing world via international trade.

5.8. Summary and further remarks

This chapter provided answers to the second research question proposed in this thesis. The empirical results derived from the EE-MRIO analysis show, on the one hand, how much value added, skilled and unskilled wages are associated in developing countries to every kilogram of CO_2 that is mitigated in different sectors through reductions in consumption in industrialised nations. On the other hand, the examination allowed quantifying the magnitude and direction of the potential losses in terms of value added and wages that could affect the global South if industrialised nations were to undertake demand-side mitigation measures. Overall, a significant amount of information was presented in this chapter. A brief summary of the main results is thus offered in this final section.

The global production structure, presented in section 5.2, reflects that the world's economy is largely dominated by services. Moreover, the global distribution of value added shows a profound disparity. Very-high-human-development nations produced in

2007 almost 75% of the total value added, in spite of possessing only 15% of the world population. The US was accountable for creating almost one fourth of the world's total value added, while nearly another third was created by the EU27. Least developed countries, in contrast, barely generated 1% of the total.

In that same section, it was argued that *trade in value added* offers a more precise measure of the value of trade flows than traditional trade statistics. The US trade deficit with China, for example, is reduced by around 55% when using this method than when employing traditional trade statistics, but its deficit with the EU27 grows around 12%. These differences are explained by the fact that traditional trade statistics consider that a product is entirely manufactured in the country of origin. In contrast, trade in value added takes into account the geographical fragmentation of production. It measures the precise value that each sector in each country along the global supply chain contributes during the production process.

In section 5.3, it was explained that very-high-development economies tend to create wealth in the rest of the world through international trade, since they are net importers of value added. This reflects their larger levels of consumption and their dependency on the developing world to obtain resources and a wide range of products. The rest of the world, in contrast, is a net exporter of value added.

The same section, along with section 5.5, showed that the global South specialises in low-capital- and unskilled-labour-intensive activities, while their economies are highly carbon intensive. The North, on the other hand, focuses on producing goods that are highly intensive in capital and skilled labour. Moreover, they possess much cleaner technologies, making their economies less carbon intensive. This situation supports to a certain extent the validity of the Prebisch-Singer hypothesis (Prebisch, 1950; Singer, 1950), as the periphery (i.e. the developing world) is structurally constrained and depends significantly on the core (i.e. industrialised nations) to obtain more elaborate capital- and technology-intensive goods.

Section 5.5 argued that examining the labour productivity of carbon can be useful to determine the sensitivity of regions and sectors to demand-driven mitigation actions, since it indicates the amount of wages to skilled and unskilled labour that are associated with every unit of emissions. Moreover, it represents the underlying mechanism that explains the impacts on skilled and unskilled wages in the global South derived from changes in final demand registered in the North. Its calculation required calculating intra- and inter-regional multipliers of CO_2 and wages to skilled and unskilled labour. The analysis showed that, on average, the smallest intra-regional multipliers for value added and wages corresponded to least developed nations, revealing their weak internal structures and their inability to capture more revenue per dollar of final demand within their domestic markets. In contrast, the largest intra-regional multipliers are held by the industrialised and very-high-development group, whose economies capture internally more value and wages than any other region. However, when it comes to CO_2 emissions, high- and medium-development nations possess the largest intra-regional multipliers, evidencing their high carbon intensities. Moreover, the analysis on labour productivity of carbon shows that these regions are the least productive, generating less wages for every kilogram of CO_2. The most productive in terms of skilled labour, in turn, are the least developed nations.

Section 5.6 presented the most trade-dependent economies, which are generally low- or medium-developed countries, small nations, small-island states and fossil-fuel producers with either limited or weak domestic markets, limited factor endowments, low industrialisation levels, an outward-market orientation, or a mix of these factors. These countries are highly vulnerable to external shocks in foreign final demand, as evidenced, for example, by Malaysia's response after the 2008/09 crisis.

Finally, the analysis showed that the developing world can suffer potential impacts in relation to losses in value added and wages derived from demand-side mitigation measures undertaken by very-high-development nations. While these actions can free carbon space, a decline in value added and wages can lead to negative developmental consequences in the developing world via international trade. Understanding the vulnerability of different country groups to lower levels of different kinds of imports is important to better inform policy decisions. For instance, the study revealed that low-development nations are particularly sensitive to a decrease in agricultural and mining imports. The medium-development group, in turn, is more vulnerable in the case of the industrial sectors. Mitigation-driven reductions in final demand oriented towards those sectors can thus put at risk their developmental processes. The implications and limitations of all these results will be further discussed in Chapter 8.

The next chapter will focus on the case of Border Carbon Adjustments, and thus provides answers to the third research question proposed in this thesis.

Chapter 6
The case of Border Carbon Adjustments

The objective of this chapter is to offer empirical answers to the third research question proposed in this thesis (see section 1.2): *How much value added and wages paid to skilled and unskilled labour in developing countries are associated with CO_2 emissions that would be captured in different sectors through the implementation of border carbon adjustments in industrialised nations?* The previous chapter showed that mitigation-induced reductions in final demand for imports undertaken in developed nations can contribute positively to cut CO_2 emissions and free carbon space. Nonetheless, these actions can significantly lower the revenue that developing countries obtain via international trade. A lower amount of exports in the global South implies the creation of less value added and wages to skilled and unskilled workers domestically. As a consequence, the development process in many developing economies can be impaired. Understanding the underlying mechanisms behind this trade-off and its effects on different types of countries is important in an ever more globalised world. As the inter-dependence of nations is intensified by an increasing volume of traded goods and services, it is more likely that policy decisions made in one region of the planet can produce significant effects on others. This can be the case of border carbon adjustments (BCAs). As was explained in section 2.3.3, discussions are happening in some Annex I countries (e.g. US, EU, Australia) about their potential adoption. It is argued that these policy instruments are essential to ensure the competitiveness of their industries and thus level the playing field with respect to nations not bound to legal emissions-reduction commitments. Moreover, it is deemed that they can help to reduce strong carbon leakage. The US, in particular, has been considering this option more seriously, expressing that it will not implement an emissions trading scheme without a provision for BCAs. Nonetheless, as discussed in section 2.3.3, these measures can produce direct effects on the producer-side. If BCAs lead to a reduction in final demand for imports, then, according to the results presented in the previous chapter, they could potentially distort trade flows and have negative impacts on welfare in the developing world. The academic literature on the topic has pointed out this possibility. However, existing studies have not focused on estimating the amount of emissions that could be captured with this policy tool from different country groups in the global South, and analyse which of these groups could potentially be most affected. This chapter thus seeks to provide these answers. Once again, the technique used for this purpose is EE-MRIO analysis. Section 6.1 starts by describing the specific variables used in this study. The empirical findings are then presented, starting in section 6.2, which examines the potential scope for BCAs. There it is shown that the amount of emissions that could be captured is influenced by a number of issues, such as GATT's provision of non-discrimination, the ability to differentiate between emissions caused by intermediate and final demand, and nation and sectoral exemptions. This is followed in section 6.3 by the quantification of BCAs for different country groups, where it is argued that the estimated tariff rates can potentially cause disruptions in trade flows due to their magnitude. Section 6.4 then focuses on identifying which country groups could be particularly affected by changes in final demand for imports caused by the BCAs. Finally, section 6.5 offers a brief summary of the results.

6.1. Overview of the variables and data

This analysis, once more, makes use of the MRIO framework already described in detail in section 3.2.2, and additionally employs the Emissions Embodied in Bilateral Trade (EEBT) model, also presented in that section. Moreover, the study involves the same variables utilised in the previous chapter. However, in this case, only data for 2007 is used, since no comparisons over time are considered. The GTAP 8 dataset formed the basis to assemble the MRIO and EEBT models, consisting of large square transactions matrices that represent the structure of the global economy. They include 129 countries and regions, each encompassing 57 economic sectors. These matrices are accompanied by another one representing final demand and additional row vectors for value added and wages to skilled and unskilled labour. The environmental extension is given by a row vector of emissions which, as has been said, do not include non-CO_2 GHGs. This constitutes a limitation to be discussed in Chapter 8, as many of the existing emissions trading schemes (i.e. Kyoto Protocol, EU ETS, etc.) cover a range of GHGs apart from CO_2. Moreover, emissions from aviation are not included, which started to be covered in the EU ETS since 2012.

As was done in the previous chapter, countries will be classified according to the UNDP's 2013 HDI-quartile they belong to. As said, this simplifies the interpretation and presentation of the results and allows differentiating the effects on nations with different levels of development.

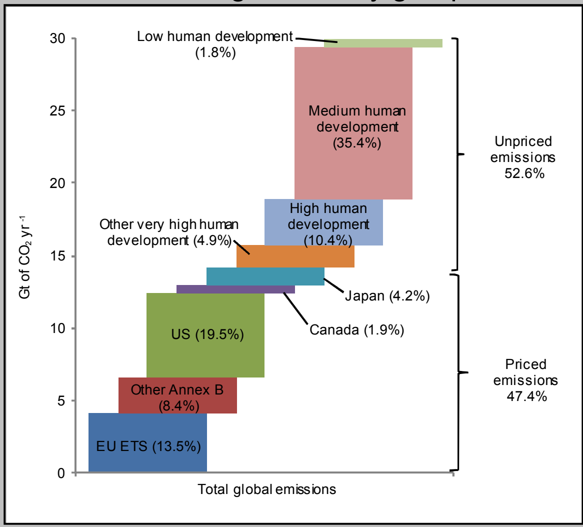
6.2. Potential scope for BCAs

Section 2.2.2 of the literature review chapter describes how emissions have evolved over time in Annex B and Non-Annex B nations. Figure 9, which appears in that same section, shows that the latter group's territorial emissions surpassed those of their counterparts by the mid 2000s. In 2007, 47.4% of the total global emissions corresponded to countries that have adopted quantified legally-binding emissions-reductions pledges and that are thus subject to carbon pricing, as can be seen in Figure 27. This group includes the majority of industrialised countries and economies in transition. However, in strict terms, the actual estimate is approximately 20% lower. The reason is that the US, despite being traditionally listed as an Annex B nation, has not ratified the Kyoto Protocol and has consequently not been obliged to undertake quantified reductions[20]. A more precise estimate of the proportion of emissions subject to carbon pricing is thus 28%, constituted by emissions from the EU members which, apart from being Annex B parties of the Protocol, also belong to the EU ETS[21]. They generated 13.5% of the global emissions. The rest of Annex B nations emitted jointly the remaining 14.4%, including Canada and Japan, who have decided not to participate in the second phase of the Kyoto Protocol corresponding to the period 2013-2020, along with New Zealand and Russia. In turn, more than half of the global emissions in 2007 were emitted in Non-Annex B countries. Very-high-human-development economies, which do not possess binding targets, such as Hong Kong, Korea, Singapore and oil producers, like Bahrain, Qatar and the United Arab Emirates, contributed with 4.9%. The bulk of unpriced CO_2 emissions were mainly generated in the developing world. Medium-human-development economies, to which China belongs, produced 35.4% of total emissions. The high-development group emitted 10.4%, while least developed countries, in contrast, were responsible for only 1.8%.

[20] In proper terms, the US is only an Annex I country or party to the UNFCCC (see footnote 9).

[21] The exceptions are Cyprus and Malta, which belong to the EU ETS but are not Annex B nations.

Figure 27 - Total global emissions in 2007 according to country group



Source: Own figure

Without the US, Canada, Japan, New Zealand and Russia, the proportion of priced emissions would be less than one fifth of the total. For the purpose of this study, emissions from these nations will be considered as being subject to carbon pricing along with all the other Annex B countries, as it is expected that they will adopt some kind of reduction targets in future international climate negotiations. In addition, the purpose of this study is to assess the effects on the developing world derived from the hypothetical implementation of BCA schemes in all Annex B economies, including the US[22]. Under this assumption, it can be said that the amount of priced emissions would have been 14.2 Gt in 2007; that is, 47.4% of the total.

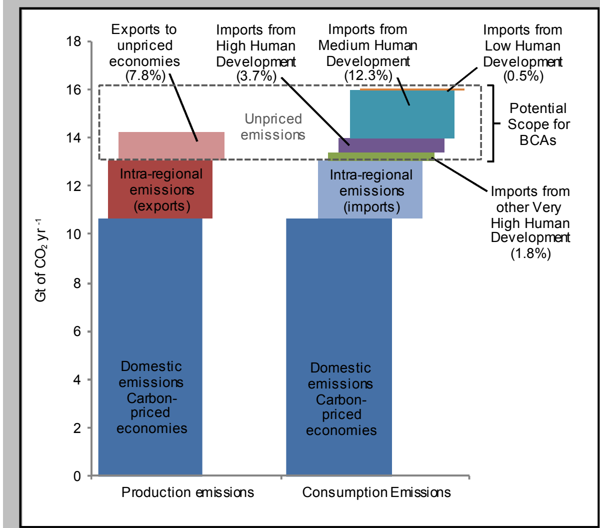
The production emissions from the countries subject to carbon pricing (i.e. carbon-priced economies) is thus formed by the emissions embodied in the goods and services they consume domestically and by the emissions embedded in their exports, as is represented by the first column in Figure 28. Consumption emissions, on the other hand, are comprised by the domestic component, plus the emissions embodied in their imports. These are represented by the column at the right. As can be seen in the graph, these carbon-priced economies (i.e. Annex B) are net importers of CO_2, since their consumption emissions are larger in magnitude.

A BCA scheme just focuses on those emissions that are traded with unpriced economies. It can be appreciated in Figure 28 that in the carbon-priced region a portion

[22] See Appendix A.2.4 for a list of countries considered to be under the BCA scheme in this analysis.

of the emissions embodied in their exports and imports is traded intra-regionally and, therefore, would not be covered under the scheme. In contrast, the fraction of emissions traded with regions not bound to reduction commitments constitutes the hypothetical amount of emissions that could be included in such a scheme. They are portrayed in Figure 28 as the area within the dotted lines. In other words, this portion of emissions represents the *potential scope for BCAs*. As explained in section 2.3.3, exports destined to unpriced economies would be subject to a rebate, since they are not consumed in the region of origin. These represent 1.1 Gt or 7.8% of total production emissions. In contrast, the amount of CO_2 that is embodied in imported goods from nations without binding targets would be taxed according to a given carbon price. These constitute approximately 2.9 Gt or 18.3% of total consumption emissions. The larger fraction corresponds to the medium-human-development group, which includes China, and amounts to 12.3%.

Figure 28 - Potential scope for BCAs given production and consumption emissions in 2007

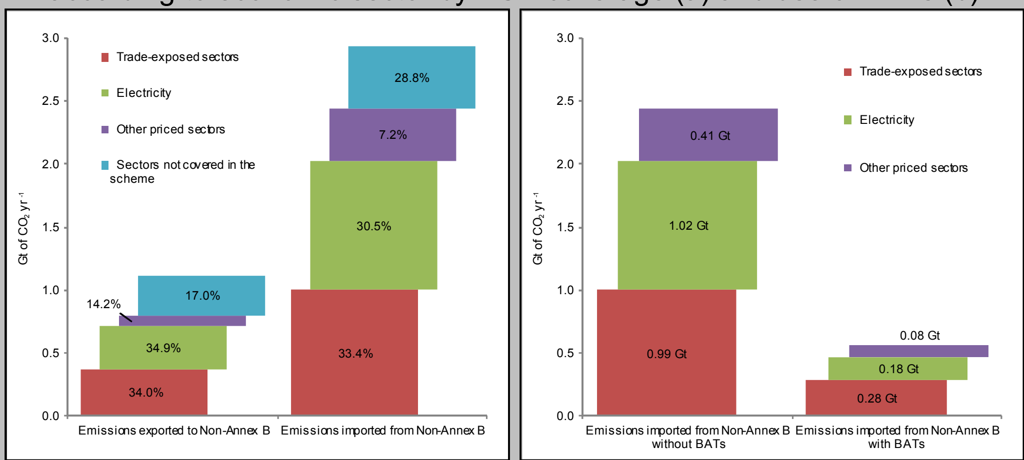


Source: Own figure

The potential scope for BCAs is, however, influenced by a number of issues, such as GATT's provision of non-discrimination, which includes the principle of *best available technology* (BAT) (see: Ismer and Neuhoff, 2007), as well as the composition of intermediate and final products, and sectoral and country exemptions. As will be explained, the amount of emissions that could be captured by a BCA scheme can be significantly reduced when these factors are taken into account.

In order to comply with GATT's provision of non-discrimination, and thus ensure that imports receive a fair and similar treatment than domestic products, not all types of imports can be levied (see section 2.3.3). BCAs can only be applied to comparable products that are covered domestically in the region of consumption by the emissions trading scheme[23]. In this manner, around 17% of the emissions embodied in remitted exports and 28.8% of the emissions embedded in imports would not be included in the scheme, as is shown in Figure 29a. These emissions correspond to economic sectors not covered in the Kyoto Protocol and the EU ETS, and which are consequently not priced. Regarding the emissions that could be potentially taxed, 34.0% of exports and 33.4% of imports correspond to carbon-intensive and trade-exposed sectors (i.e. lime and cement, basic iron and steel, refined petroleum, aluminium, inorganic basic chemicals, and pulp and paper), which are considered by Stephenson and Upton (2009) as particularly at risk from foreign competition and strong carbon leakage. These are the emissions that are most likely to be taxed by future BCA schemes. On the other hand, a significant amount of emissions, 34.9% in exports and 30.5% in imports, corresponds to the on- and off-site generation of electricity. Although a fraction of electricity is traded between countries, the majority of these emissions are embodied in the products that are consumed. In order to tax these emissions and enhance the scope of the BCAs, it would be necessary to calculate the amount of electricity used during the production process. However, this would increase the complexity of administrating the scheme, apart from requiring a precise and updated carbon accounting method. The rest of the emissions that could be covered correspond to other light- and heavy-industry sectors; that is, 14.2% of CO_2 embodied in remitted exports and 7.2% contained in imports.

Figure 29 - Share of unpriced emissions embodied in exports and imports according to economic sector by BCA coverage (a) and use of BATs (b)



(a) (b)

Source: Own graphs

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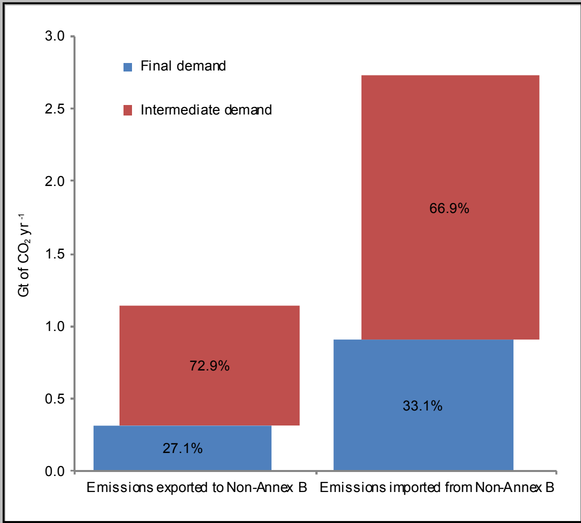
[23] See Appendix A.2.4 for a list of the economic sectors that are assumed to be covered by the BCA scheme in this analysis.

GATT's provision of non-discrimination would also require not taxing imports in excess of the domestic rates, even if their carbon content is greater. This implies the application of carbon equalisation measures, such as using BATs. In this sense, imports are assumed to have been manufactured with at least the best *clean* technology existent in the region of consumption. The determination of an appropriate BAT is, however, problematic. Monjon and Quirion (2010), for example, suggest utilising product-specific benchmarks, like the ones developed under the EU ETS framework for industry products. In the case of this analysis, finding suitable and homogeneous BATs for each sector is complicated, as all Annex B countries are aggregated into a single region. In reality, each individual country or bloc of nations would possess a specific BAT. The standards used in the US would, for instance, differ from those that are relevant in the EU or in Japan. With the purpose of illustrating the effects of applying BATs in the whole region and to simplify the examination, these were calculated for each economic sector as the average carbon intensity of the 33% most carbon efficient countries under the scheme. In other words, individual nations were ranked, once for every economic sector, according to their carbon intensities (i.e. CO_2/total output). The BAT rates were then estimated as the mean carbon intensity of the most efficient tercile. This procedure was preferred over the option of selecting those countries with the minimum carbon intensities for each sector. As an example, it was identified that some nations present very low carbon intensities in the production of mineral products. This is the case of Luxembourg and Malta. However, these countries are not significant producers or possess comparative advantages in this particular sector. Hence, their carbon intensities cannot be considered as representative of high-yielding and efficient industries in the mineral sector. By using the mean carbon intensity of the most efficient terciles, this problem is avoided, along with others derived from country-heterogeneity. In this way, a more representative estimation of the best available technologies in the region is ensured.

As can be seen in Figure 29b, when applying BATs to each sector, the results reveal that the scope for BCAs would decrease significantly. The scheme would capture nearly 75% less emissions from Non-Annex B nations. This evidences, on the one hand, the high carbon intensities registered in the developing world with respect to Annex B economies; and, on the other hand, the implications that using the BAT principle have in terms of the effectiveness of BCAs. The objectives of the scheme are to address competitiveness issues and avoid strong carbon leakage, but these can be compromised with the use of BATs. By capturing just one fourth of the total amount of potential emissions, the playing field between nations is only levelled partially. Moreover, the stimulus to encourage the adoption of cleaner technologies in high carbon-intensity regions is weakened.

Figure 30 - Unpriced emissions embodied in exports and imports according to intermediate and final demand



Source: Own figure

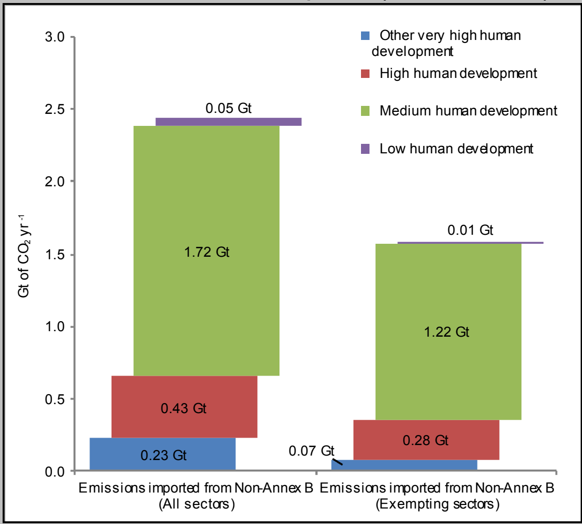
Another factor that can limit the scope of BCAs, and which has been briefly discussed in the case of electricity, is the challenge of obtaining a precise measure of the carbon content and origin of the different constituent parts that integrate a certain product. In order to achieve a clear differentiation between emissions caused by final and intermediate demand, the EEBT model was used in this examination. Its main difference with respect to an MRIO model is that intermediate demand for imports is extracted from the transactions matrix, leaving just domestic IO tables on the main diagonal. Intermediate demand for imports is then appended to the final demand matrix (see section 3.2.2). This allows distinguishing the amount of emissions that are generated due to inter-industry requirements between regions and those derived from the final consumption of goods.

The results obtained from the EEBT analysis reveal that the major flows of traded CO_2 emissions are associated with intermediate demand; that is, 72.9% of exports and 66.9% of imports, as can be seen in Figure 30. Estimating the amount and origin of emissions that are embodied in intermediate goods can be simpler in the case of intensive primary commodities, but this can become a challenging task with regards to more elaborate products, such as electronic or mechanical components. In the case of finished goods, such as cars or heavy equipment, the complexity is even greater.

Consequently, estimating the exact carbon content and origin of different goods requires a robust administrative system and an adequate and regularly updated carbon accounting procedure. However, this would elevate the costs and difficulty of managing a BCA scheme effectively. Winchester (2012), for example, points out that the risk of not implementing a robust system, capable of precisely determining and updating the carbon content of different products, can lead to BCAs being viewed as fixed import or anti-dumping tariffs, irresponsive to improvements in carbon intensity. This, in turn, could generate trade disputes within the WTO. Moreover, just focusing on certain intermediate commodities and final goods would reduce the scope of the scheme which, as has been explained, is already at risk of being significantly diminished by the application of the BAT principle.

Country and sectoral exemptions constitute one more factor that can influence the scope of BCAs. Certain proposals, such as the ones initiated in the US, contemplate exempting least developed countries, as long as they are responsible individually for less than 0.5% of global GHGs (see: Monjon and Quirion, 2010; Winchester et al., 2011). Furthermore, criteria have also been proposed to exclude those activities that contribute with less than 5% of the total imports in a given sector of the consuming country or region (see: van Asselt and Brewer, 2010; Cosbey et al., 2012). As is shown in Figure 28, the implications of excluding least developed countries from the scheme, in terms of its effectiveness, are minimal. The CO_2 captured from these nations amounts to barely 0.5% of total consumption emissions in the carbon-priced region. However, exempting sectors based on the 5% criterion reduces the amount of captured emissions by approximately 35%, as shown in Figure 31. The most drastic decreases take place, proportionally, in least developed nations, with a decline of about 78.9%. The lower changes occur in the medium-human-development group, which includes China, with a fall of 29.1%.

Figure 31 - Reduction in BCA scope (unpriced emissions embodied in imports) due to sectoral exemption (5% criterion)



Source: Own figure

As has been explained, the potential scope for BCAs is influenced by a number of factors. From a hypothetical amount of emissions that could be captured by the scheme, the actual quantity that could be covered is determined by issues like GATT's provision of non-discrimination, the proper estimation of emissions embedded in intermediate and final goods, as well as country and sectoral exemptions. All these aspects can significantly reduce the effectiveness of BCAs. Given these results, the next step consists in quantifying the magnitude of the BCAs for each of the regions in the developing world.

6.3. Quantification of BCAs

Quantifying effective tariff rates that the consuming region would impose to different Non-Annex B country groups requires determining a carbon price. The term *effective* here denotes the ability of the tariff rates to level the playing field between carbon-priced and unpriced nations. Atkinson et al. (2011, p. 572) suggest using an illustrative price of $50 dollars per tonne of CO_2, arguing that it is compatible with "*a fairly ambitious*" emissions reduction target for highly-developed economies. Although the carbon price would be required to augment more in the future to encourage yet deeper reductions, the proposed price is useful to show the scale that BCAs could reach in the case of different regions. The first step to calculate the tariff rates is to multiply the amount of emissions embodied in imports by the carbon price. Then, the result is divided by the value of those imports, expressed in terms of their value added, which was estimated in section 5.3.1 and presented in Figure 19. In basic terms, this consists in multiplying the carbon price by the *carbon intensity of value added*. The resulting rate, in this sense, represents the proportion by which the monetary value of the imports would increase due to the BCA. This, in consequence, would translate into a rise in the price paid by consumers for the imported goods. The same procedure is followed, on the other hand, to calculate the rebate rates for the remitted exports. These rates show the fraction of value added that is returned to the producers who were already taxed, since their products are being consumed in unpriced economies.

Table 24 shows the average tariff and rebate rates faced by different country groups, depending on sectoral coverage and the implementation of the BAT principle. In the case of imports, if all sectors were taxed, regardless of their treatment by the operating emissions trading scheme, the medium-human-development group, which includes China, would face the largest rates of about 8.9% on average, since it is the most carbon intensive region. It must be remembered that the rates are directly proportional to the carbon intensity of the region of origin. In turn, very-high-development nations with no binding targets would meet an average rate of 2.9%, similar to that of least developed nations (2.8%). The high-development group would confront a tax burden of 3.7%. When only the priced sectors are taken into account (i.e. sectors covered in the scheme), which represents the benchmark case in this analysis, the tax rates increase due to the higher carbon intensity of the sectors involved. The rates then vary from 2.9% in the low development group to 12.3% in medium-development economies. On the other hand, when only emissions associated with intermediate demand are considered, the rates go down by almost half when compared to the benchmark. However, here the decrease is not so marked for least developed nations (i.e. 2.9% to 2.0%), which have a lower share in the production of intermediate goods. The next row in the table shows the rates that are relevant when the 5% criterion is applied to exclude certain sectors. The rates go down with respect to the benchmark, especially favouring least developed nations (0.6%) and the very-high-development group (1.3%). The following case involves excluding the emissions from electricity embodied in imports, which particularly lowers by half the rate faced by the medium-development group (6.9%), while the lowest rate corresponds to very-high-development nations (2.1%). The last option in the table encompasses applying BATs in all priced sectors. This reduces the rates significantly for the medium-development group, whose imports face a burden of 1.2%, almost a tenth of the tariff without BATs. Similarly, the rest of the country groups also result notably favoured by this principle.

Table 24 - Average tariff rates on imports and rebate rates on exports by taxing embodied CO_2 at $50 per tonne

Sectoral coverage	Other very high human development *	High human development	Medium human development	Low human development
Imports				
All sectors	2.94%	3.70%	8.98%	2.81%
Only priced sectors (benchmark)	4.10%	4.00%	12.31%	2.95%
Priced sectors including intermediate demand only	2.40%	2.91%	7.34%	2.06%
Priced sectors using 5% criterion	1.34%	2.54%	8.73%	0.62%
Priced sectors excluding electricity	2.12%	3.08%	6.93%	2.46%
Priced sectors including BATs and electricity	1.18%	0.89%	1.28%	0.65%
Exports				
All sectors	3.06%	3.37%	2.87%	2.48%
Only priced sectors (benchmark)	3.75%	4.50%	3.90%	3.69%
Priced sectors including intermediate demand only	3.64%	3.26%	3.15%	1.66%
Priced sectors excluding electricity	2.22%	2.77%	2.26%	2.34%
Note: * Refers to very-high-development nations without binding targets				

Regarding exports, shown in the lower part of Table 24, the differences between the rates across the various country groups are not so marked. When all sectors are included in the scheme, the rebate rates vary from 2.4% for remitted exports to least developed countries, to 3.3% for those destined to the high-development group. As in the case of imports, considering only the priced sectors causes the rates to rise, ranging from 3.6% for least developed nations to 4.5% for high-development economies. Excluding emissions from final demand, on the other hand, decreases the rate with respect to the benchmark, again particularly for exports to the least-development group. Finally, leaving out emissions from electricity causes the rates to fall by approximately 1.5% on average across the country groups.

In individual terms, the ten countries that would face the largest import tariffs are mainly medium- and low-human-development nations. South Africa and China would face the highest rates of 13.8% and 10.2%, respectively, when only the priced sectors are considered. They are followed by Tajikistan, Turkmenistan and Uzbekistan, which were identified in the previous chapter as some of the most trade-dependent nations (see Table 22 in section 5.6). Zimbabwe would also carry a significant tariff burden of around 9.1%. The rest of the countries in the table would confront rates that range from 7.9% to 6.1%.

Table 25 - The 10 countries or regions with largest tariff rates

Country	Tariff rate Priced sectors *	Tariff rate All sectors **
South Africa	13.87%	15.07%
China	10.20%	11.11%
Tajikistan, Turkmenistan and Uzbekistan	9.77%	17.52%
Zimbabwe	9.13%	11.37%
Egypt	7.93%	11.51%
Mongolia	7.85%	11.20%
Kazakhstan	7.82%	8.94%
Kyrgyzstan	7.73%	11.66%
India	7.09%	7.82%
Venezuela	6.19%	6.79%
Note: * Refers to sectors covered under the scheme; ** refers to all sectors regardless of their treatment by the operating ETS.		

The rates produced by this analysis have the potential to distort trade flows and affect welfare levels in developing countries, as the price flexibility assumption is not expected to hold in reality (see section 2.3.3). It is difficult, however, to ascertain to what extent consumer prices would increase beyond the estimated tariff rates and, more importantly, how the new price levels would impact the demand for imports in the region under the scheme. The MRIO model used in this analysis just encompasses a partial equilibrium of the global economy. Prices are not included and, consequently, the market-clearance condition (i.e. the point where global supply equals global demand through a change in prices) required to achieve a general equilibrium cannot be modelled. This constitutes a limitation in this research, which will be discussed in Chapter 8. However, it is possible to determine the amount of value added and wages to skilled and unskilled labour that are associated with an assumed decline in final demand for imports caused by the implementation of BCAs in the priced sectors.

6.4. Potential impacts to the developing world

As has been said, some of the tariff rates presented in the previous section can potentially cause disruptions in trade flows due to their magnitude. Without the adoption of the BAT principle, regions like the middle-development group would face tariffs as high as 12.3% on average. These rates can imply a negative effect on economic growth and employment creation in the developing world, particularly in the exporting sectors. As has been said, this study is unable to precisely estimate how consumer demand in the region of consumption would respond to the higher prices of imports. However, the same procedure as the one used in the previous chapter (see section 5.7) can be used to explore the impacts in different developing-country groups, in terms of losses in value added and wages to skilled and unskilled labour, due to a certain decline in final demand. In this sense, this examination assumes that BCAs cause a fall in final demand for imports associated with the sectors covered in the scheme. It is also assumed that imports from each developing region drop proportionally to their share of the total. Results are estimated for a fall representing an overall decrease of 1% of total final demand in the consuming region. The amount of consumption-based emissions compatible with this new level of final demand is then estimated. After that, it is calculated how much value added and wages to skilled and unskilled labour would decrease in the different developing-country groups owing to those reductions in final demand.

The results from this analysis are presented in Table 26. When total final demand in the region under the scheme (i.e. carbon-priced) declines by 1%, due to a lower demand for imports corresponding to carbon-priced sectors, consumption emissions are cut by 2.7%. This leads, however, to decreases in total value added and total wages to skilled and unskilled labour in the producing regions. Medium-development economies would be the most affected with a reduction in value added or GDP of 2.8%. In a similar fashion, their wages to skilled and unskilled workers would suffer cuts of 1.6% and 2.8%, respectively. The high- and low-development groups would face similar cutbacks. In the case in which only the trade-exposed sectors are included in the BCA scheme, a decline of 1% in total final demand leads to a reduction of 5.5% in consumption emissions. CO_2 falls more in this scenario, as the entire reductions in final demand occur in a smaller number of carbon-intensive sectors. In terms of value added, the high- and medium development groups are the most affected, with similar reductions of 2.4% and 2.3%, respectively. In relation to wages, medium-development economies observe the largest falls with 1.2% for skilled labour and 1.9% for unskilled labour. Overall, the least impacted region corresponds to the low-development group due, ironically, to its limited industrialisation levels.

Table 26 - Impacts on value added and wages to skilled and unskilled labour caused by BCA-induced reductions in final demand

Sectors which register a decline in final demand for imports	**Reductions in consumption CO_2 compatible with the new level of final demand**	**Impacts on total Value Added**	**Impacts on total wages to skilled labour**	**Impacts on total wages to unskilled labour**
Priced sectors	-2.71%	High: -1.55% Medium: -2.81% Low: -1.15%	High: -0.73% Medium: 1.68% Low: -0.81%	High: -1.35% Medium: -2.86% Low: -1.23%
Only trade-exposed sectors	-5.53%	High: -2.43% Medium: -2.30% Low: -1.11%	High: -0.92% Medium: -1.29% Low: -0.65%	High: -1.57% Medium: -1.90 Low: -0.74%

Note: The reduction in final demand for imports takes place in the region under the BCA scheme. The assumed reduction corresponds to imports from the sectors mentioned in the first column and amounts to 1% of total final demand. The impacts refer to decreases in total value added and total wages to skilled and unskilled labour registered in the developing world. High-, medium- and low-human-development countries correspond to the UNDP's 2013 classification.

It must be noted that the objective of a BCA scheme is not to abate emissions, but to address competitiveness issues and avoid carbon leakage, issues that were not analysed here. Nonetheless, BCAs can indirectly achieve emissions reductions by influencing producer and consumer behaviour. The cuts in CO_2 correspond in this analysis entirely to BCA-induced decreases in final demand for imports (i.e. demand-side mitigation).

The results show that the regions which would face the largest tariff rates would also experience the largest impacts in terms of losses in value added and wages. This would translate into lower rates of economic growth and employment and, ultimately, into an associated decline in well-being. The precise impacts, however, are uncertain, as the model used does not consider general-equilibrium effects. The changes in prices could actually lead to a substitution for other types of imported products or for imports from less carbon-intensive regions. Yet, the present analysis provides a useful insight about the potential consequences in the developing world of a BCA scheme from a partial-equilibrium perspective.

If the BAT principle was applied, the impacts are found to be much smaller, as the import prices would increase slightly more than 1%. However, once again, it is not possible here to determine their precise effects on consumer prices. On the other hand, if the revenue obtained by the BCA scheme was returned to the producing regions in the form of development aid or technology transfers, then the impacts on the developing world could be mitigated. This issue, however, was also not modelled.

6.5. Summary and further remarks

This chapter offered empirical answers to the third research question proposed in this thesis. In basic terms, it focused on the case of BCAs and showed how they can potentially distort trade flows and exert a negative impact on welfare in the developing world. As has been said, understanding these effects is relevant, as discussions are happening in several Annex B nations about their possible implementation.

The results presented in this chapter in section 6.2 show that the potential scope for BCAs is influenced by a number of factors. Hypothetically, 7.8% of total production emissions that are embodied in exports, and 18.3% of total consumption emissions that are embedded in imports could be captured by such a scheme. However, this range is potentially reduced by complying with GATT's provision of non-discrimination. Around 17% of the emissions embodied in remitted exports and 28.8% of the emissions embedded in imports would not be included, as they are related to non-priced economic sectors in the consuming region. Moreover, when applying the BAT principle, the scheme would capture nearly 75% less emissions from Non-Annex B nations. This could potentially diminish the effectiveness of BCAs. On the other hand, the capacity to precisely quantify the emissions embedded in intermediate and final goods was shown to be challenging. The results reveal that more than two thirds of emissions are associated with intermediate demand. Finally, exempting economic sectors according to their contribution to final imports in the consuming region can potentially reduce the amount of emissions captured by about 35%.

In section 6.4, it was explained that by adopting a carbon price of $50 dollars per tonne, medium-development economies could face average tariff rates of 12.3% when only priced sectors are taken into account. These rates, however, vary according to the same issues mentioned in the previous paragraph. When only the emissions associated with intermediate demand are considered, for example, the rates go down by almost half when compared to the benchmark. It was also found that excluding emissions from electricity embodied in imports, favours particularly the medium-development group. More importantly, when BATs are applied, the rates drop significantly. The medium-development group, for instance, registers a rate ten times lower. In individual terms and without BATs, medium- and low-human-development nations would face the largest import tariffs. Specifically, South Africa and China would carry the heavier burdens with rates of 13.8% and 10.2%, respectively, when the priced sectors are considered.

The results presented in section 6.4 also reveal that the regions which face the largest tariff rates would also experience the largest impacts in terms of losses in value added and wages. In the analysis, it was assumed that if BCAs were to cause a 1% decline in final demand in the consuming region, medium-development economies could lose around 2.8% of their GDP. In a similar fashion, their total wages to skilled and unskilled workers would suffer cuts of 1.6% and 2.8%, respectively. Similar effects would register in the rest of the country groups. However, it was shown that low-development nations would tend to be the least affected, due to their limited capacity to produce those goods covered in the scheme.

Finally, the chapter argued that although the results reflect a partial equilibrium perspective, it provides valuable insights regarding the potential consequences that the unilateral implementation of BCAs in Annex B nations could bring to the developing world. All these matters will be discussed further in Chapter 8.

The next chapter will focus on providing answers to the fourth research question proposed in this thesis.

Chapter 7

Carbon and development spaces: Developing within limits

The aim of this chapter is to offer the empirical findings related to the fourth and last research question proposed in this thesis (see section 1.2): *To what extent can human development be improved in the developing world within the limits of the available carbon space as defined by the RCP pathways given the continuity of the status quo?* As has been expressed in the introductory chapter, humanity's greatest challenge is to improve development levels around the world within the limits of the available carbon space. However, this space is dwindling at a fast rate. The results offered in Chapter 4 show that CO_2 emissions have tended to rise monotonically with higher levels of affluence, and this increase has been even more pronounced from a consumption-based perspective. As countries become wealthier, their populations consume more goods and services produced domestically and in foreign regions. In this sense, they become accountable for a higher amount of emissions associated with their consumption. Industrialised economies have thus turned into net importers of emissions via international trade, as their consumption-based emissions have expanded at a faster rate than their territorial ones over the years. Emerging economies have also significantly increased their annual territorial and consumption emissions, while they transit from the agricultural to the industrial phases of their economic development process. The rates of technological change and deployment until now, however, have not outpaced the influence of affluence and population as drivers of emissions. Technological-induced mitigation measures must therefore be complemented with demand-side actions in order to achieve a 2°C target and avoid dangerous climate change. As illustrated in Chapter 5, reductions in demand in wealthy nations can contribute to free carbon space, much needed in the global South. Nonetheless, globalisation has intensified the interdependencies between nations. Consequently, as is explained in that same chapter, a lower demand for imports can distort trade flows and affect economic growth rates in developing nations. This would put at risk their development process and the well-being of their societies. For this reason, demand-side actions and measures that can influence demand, like BCAs, must be analysed and implemented adequately to avoid negative consequences in the South, as was explained in Chapter 6. This is relevant, as there is a pressing need for developed economies to achieve deeper reductions through technological and demand-side measures and thus make more carbon space available to less developed nations. The longer it takes industrialised countries to take significant and sustained actions, the less carbon space will be left for the poorest regions. As was mentioned in the literature review chapter, a solution to climate change should not be attained at the expense of reducing the development opportunities of the global South (see section 2.1.3). An equitable use and fair sharing of the carbon space is vital to overcome the challenge. It is uncertain, however, to what extent human development could be improved with the remaining carbon budget in different regions of the planet. Among the scenarios that are to be used in the Fifth Assessment Report (IPCC, 2013), the so-called RCP3-PD, also known as RCP2.6, describes an emissions concentration pathway that is likely to maintain global warming below the 2°C threshold in the long-run (van Vuuren et al., 2007). By using this pathway as a quantification of the available carbon space, the present chapter thus seeks to investigate to what extent human development levels in different country groups can be improved within its limits given the continuity of the *status quo*; that is, according to the current model of economic development. This analysis, however, does not attempt to produce an accurate prediction of future human development levels, explore alternative pathways or rearrange the sharing of the carbon space between nations in order to achieve this goal. Rather, the analysis offers an insight about the magnitude of the challenge. The findings, moreover, can help to build more equitable and comprehensive future emission pathways that focus on enhancing development within biophysical limits, as well as to inform global and regional climate negotiations. The chapter starts in section 7.1 by providing an overview of the variables and data used to carry out the analysis, which is based on cross-country panel-data regressions. The carbon space is quantified in section 7.2, describing the individual budgets assigned to different country groups. The historical human-development trends for each of these groups are then presented in section 7.3, highlighting the potential improvements that can be attained in the future. The carbon elasticity of human development corresponding to the period under study is calculated for each country group in section 7.4. These elasticities are then used in section 7.5 to extrapolate the HDI into the future according to the emissions pathways described by the different RCPs. Finally, a brief summary of the main findings is offered in section 7.6.

7.1. Overview of the variables and data

The present analysis makes use of the 2013 UNDP's human development index, which comprises 187 individual countries. As a reminder to the reader, the purpose of this indicator is to measure and monitor the progress of the development process across nations (see section 2.1.2). It is basically constituted by sub-indices corresponding to income per capita, life expectancy, and the observed and expected years of schooling[24]. The index ranges from 0 to 1, and countries are ranked according to their index scores and are then divided into four tiers or quartiles. This classification has been used in the previous two chapters of this thesis. HDI data is only available for eight years, which are: 1980, 1990, 2000, 2005, 2007, 2010, 2011 and 2012. The gaps between these years were filled in by projecting the HDI scores at a country-level according to average annual growth rates. This allowed having sufficient annual observations to apply the panel data regression methods described in section 3.2.1. Not having done so would have prevented running some statistical tests and obtaining robust results (see: Mátyás and Lovrics, 1991).

Along with the HDI data, two separate databases for CO_2 were employed to estimate the carbon elasticity of human development for different country groups. The first one corresponds to that used in Chapter 4, which is formed by territorial and consumption-based emissions from fossil fuels and cement production, as provided by Peters et al. (2011b). Per capita values were then calculated using population figures obtained from UNSD (2013a). This dataset ranges from 1990 to 2010 and involves 129 countries and regions according to the GTAP 8 classification. This information is useful, since it allows comparing how both types of emissions relate to human development. The second dataset was built only with territorial CO_2 emissions also from fossil fuels and cement production in absolute levels and in per capita terms. It covers a longer time period, from 1980 to 2010, and includes all the 187 HDI countries. This particular dataset was used to complement the analysis and, more specifically, to verify if a longer time series and a larger number of observable units (i.e. countries) produced results that are consistent with those obtained with the first dataset.

As has been said, the RCP3-PD pathway is used as a representation of the available carbon space compatible with a 2°C target, measured from a territorial perspective. Its corresponding data was taken from van Vuuren et al. (2007). Moreover, emissions projections from RCP8.5, developed by Riahi et al. (2007), were utilised to assess the business as usual (BAU) scenario. Emissions from RCP4.5 (Smith and Wigley, 2006; Clarke et al., 2007; Wise et al., 2009) and RCP6 (Fujino et al., 2006) were employed to explore two additional intermediate pathways. Data for the period 2010-2050 was taken

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[24] See Appendix B.1.2 for a more detailed explanation about the methodology to calculate the HDI.

from all scenarios, which is offered in the form of midyear atmospheric CO_2 concentrations and annual emissions (Gt per year). The data comprises 5 regions (see Figure 4) which, in turn, cover 184 individual countries. Future per capita emissions associated with the RCP3-PD were calculated with population estimates for each country up to 2050 extracted from the SSP1 pathway, the most sustainable scenario to be used in the IPCC Fifth Assessment Report (see Table 2 for a description of the SSPs). In the case of RCP8.5, its associated per capita emissions were determined using population figures related to SSP3, the less sustainable pathway. In turn, population projections from SSP5, which correspond to a conventional development scenario, were used to calculate per capita emissions for RCP4.5 and RCP6. Population figures for these SSPs are published by IIASA (2012).

The first part of the analysis consists in estimating the historical carbon elasticity of human development for different country groups with the use of panel-data-regression methods. These estimates are then used in the second part of the examination to extrapolate HDI into the future according to the emissions pathways indicated by the different RCPs. A detailed list of descriptive statistics of all the variables used in the analysis for each country group can be found in Appendix B.1.2. Table 27, presented below, offers a summary of the most relevant variables for the whole set of countries.

Table 27 - Descriptive statistics for HDI and territorial and consumption emissions (absolute and per capita)

Statistic	HDI	Territorial CO_2	Consumption CO_2	Territorial CO_2 per capita	Consumption CO_2 per capita
Mean	0.61	136.45	200.02	4.54	6.06
Median	0.64	9.70	36.25	1.72	3.56
St. Dev.	0.19	550.33	646.66	6.74	7.01
Minimum	0.18	0.03	-1.24	0.01	-0.36
Maximum	0.95	8,286.14	6,976.28	68.62	56.51
No. Obs	4,210	4,889	2,625	4,889	2,625
Period	1980-2010	1980-2010	1990-2010	1980-2010	1990-2010

Note: HDI corresponds to the UNDP's Human Development Index (2013). Territorial and consumption emissions are expressed in megatonnes of CO_2 per year. Per capita emissions are expressed in metric tonnes of CO_2 per year. Source: Own table based on data by CDIAC (2013), Peters et al. (2011b), UNDP (2013) and UNSD (2013a)

As was the case in Chapter 4, several nations had to be excluded from the analysis, due to an insufficient number of observations for HDI or CO_2. Hence, four regions were removed from the consumption-emissions dataset and 17 countries from the longer set of territorial emissions[25]. Notwithstanding these exclusions, the final cross-country panels are unbalanced, because some countries in both datasets still present missing observations. However, these are sparse and represent a small fraction of the total.

[25] See list of excluded countries in Appendix B.1.2.

Hence, they are not deemed to affect the robustness of the results, as was shown in the carbon EKC analysis (see section 4.2).

7.2. The carbon space

The available carbon space is defined in this thesis as the total amount of future cumulative emissions that is likely to achieve a 2°C target and thus avoid dangerous climate change in the long-run. As has been said, the RCP3-PD (or RCP2.6) represents a pathway that is potentially compatible with such a goal. This scenario was described in section 2.1.1 of the literature review chapter, and it can be appreciated graphically in Figure 2 (page 19). It corresponds to a level of radiative forcing of between 2.6 and 3 Wm^{-2}. The acronym *PD* stands for *peak and decline*, as it considers that yearly emissions will peak in 2020 and then will show a sustained decline until becoming negative from the 2070s onwards. The atmospheric CO_2 concentration, in turn, will peak around 2050 at a level of about 450 ppm, which corresponds to a total of approximately 630 Gt of carbon emitted since the beginning of the industrial era. In 2012, the atmospheric concentration was around 394 ppm. Consequently, in line with the RCP3-PD, the available carbon space from 2013 to 2050 amounts to roughly 249 Gt of carbon[26], as can be seen in Figure 32a. Beyond 2050, the carbon space does not expand much, reaching 260 Gt in 2100, since it is assumed that emissions will start to be absorbed rather than emitted into the atmosphere from the mid-2070s. The present analysis, however, just focuses on the period up to 2050.

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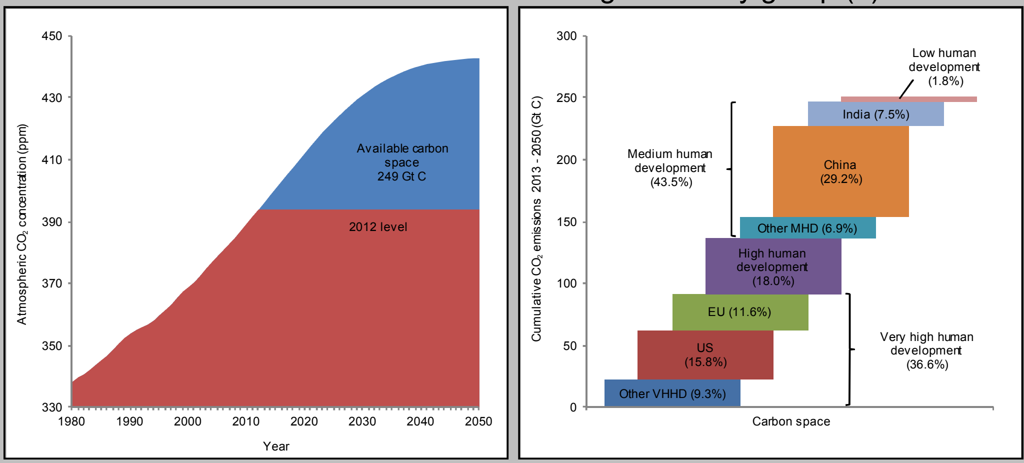
[26] This figure just considers emissions from fossil fuels and cement production. The carbon space would amount to 275 Gt if CO_2 derived from land-use change was also accounted for.

Figure 32 - The available carbon space: Atmospheric CO_2 concentration (a) and cumulative emissions according to country group (b)



(a) (b)

Note: VHHD: Very-high-human development; MHD: Medium-human development. Source: Own graphs based on van Vuuren et al. (2007)

The RCP3-PD pathway entails the achievement of significant abatement efforts across different regions. It allows global emissions to continue increasing until 2020 at an average annual growth rate of 0.5%; a figure that is much lower than the current trend of 2.5% (from 2005 to 2010). Nonetheless, it requires Annex I nations (i.e. industrialised OECD countries and most economies in transition) to attain early reductions of around 0.8% on an annual basis on average before 2020. From that year on, Annex I nations need to undertake steep cuts of nearly 80% in 2050 with respect to 2000. Asian countries, on average, would require accomplishing a reduction target of about 20% for the same period, followed by Latin American economies with a 10% cut. Middle East and African nations, in turn, would be required to stabilise their emissions in relation to their existing levels in 2000. In per capita terms, this implies achieving significant mitigation rates across all country groups, as can be seen in Figure 4 (page 23). Taking into account optimistic growth population rates, such as the ones specified by SSP1, which considers that the global population will peak at around 8.5 billion people in 2050, the developing world (i.e. Non-Annex B nations) would need to cut its per capita emissions by more than half during the period. This consequently entails carrying out considerable mitigation efforts worldwide.

Given the aforementioned emissions cuts, regional and country-specific carbon budgets can be identified. Very-high-human-development countries would hold more than a third (36.6%) of the entire carbon space, as is shown in Figure 32b. This group includes the US, the nation with the second largest budget, which amounts to 11.6% of the total. The EU 27 would possess 15.8% of the carbon space, while the rest of the countries in the group would use the remaining 9.3%. The high-human-development cluster, in turn, would be entitled to 18.0%. Medium-human-development nations, in contrast, would seize 43.5%, but this is largely due to China. This country would hold by itself the largest portion of the carbon space in the world; that is, almost another third (29.2%). This group also includes India, the world's most populated country by mid-century with around 1.5 billion people, and which would possess the third biggest share (7.5%). In fact, the emerging economies of the G20 (i.e. Argentina, Brazil, India, Indonesia, Mexico, Russia, Saudi Arabia, South Africa and Turkey), plus China, would use almost half of the whole carbon space. The least developed countries, on the other hand, would be constrained to utilising the remaining 1.8%. As can be appreciated, the RCP3-PD pathway allocates the larger carbon budgets to the current major polluters, rather than to those who possess the lowest development levels. This allocation can thus be expected to limit development opportunities.

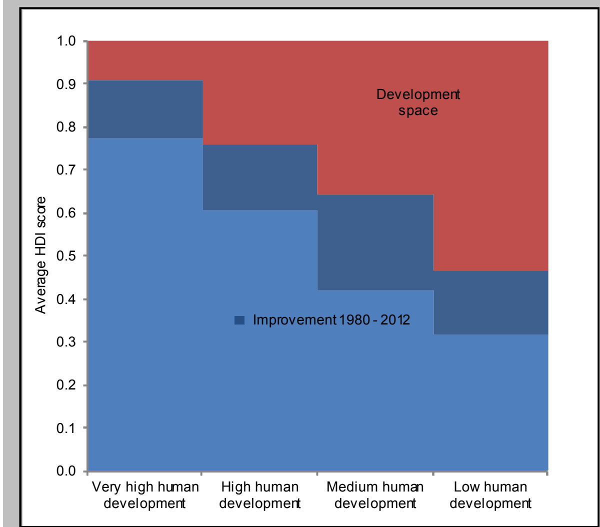
The carbon space clearly increases if it is measured using emissions pathways that lead to higher levels of radiative forcing, such as RCP4.5, RCP6 and RCP8.5. The available space from 2013 to 2050 is almost equal in the case of the first two pathways, since they share almost the same trajectory up to 2050, as can be seen in Figure 2 (page 19). Their cumulative yearly emissions are equivalent to slightly more than 400 Gt of carbon, with a corresponding atmospheric CO_2 concentration that reaches approximately 500 ppm. In relation to RCP8.5, the carbon space amounts to around 550 Gt for the same period, with an atmospheric concentration that would reach almost 600 ppm in 2050. This last pathway could likely (i.e. >66% probability) lead to average rises in global temperature as high as 3.8°C to 5.7°C by 2100 (see Figure 2, page 19).

7.3. The development space

The development space is defined in this thesis as the extent to which human development opportunities can be enhanced across the world. Figure 5 in section 2.1.2 (page 31) shows the historical trends that HDI has followed since 1980 in different regions of the planet. Asian countries have seen the largest advances in human development from 1980 to 2012, as their HDI registered an increase of 33.5%. Latin American nations experienced a rise of about 26.0%, followed by Middle Eastern and African countries with a similar expansion of 24.1%. The growth in developed nations was lower, reaching 17.7%. Transition economies, on the other hand, recorded the lowest increase of 7.3%. The UNDP (2013) has highlighted these improvements across the developing world, labelling the phenomenon as *a rise of the South* (see section

2.1.2). Nonetheless, there is still a considerable space to improve development levels, as can be seen in Figure 33. Very-high-human-development economies, which house approximately 15% of the global population, attained an average HDI score of 0.90 in 2012. This score is twice as high as that of the least developed group, which advanced nearly 48% since 1980. Medium-development countries showed a record growth of 52.6% during the last three decades, but they still need to expand their current HDI levels by another 40% to attain the scores enjoyed by the topmost group. As is discussed in section 2.1.2, the pace of improvement has been accelerating in recent years, but this progress has been uneven. Almost 70% of the people in the planet live in the medium- and low-human development nations. Some of these countries are lagging significantly behind and still need to meet many of their Millennium Development Goals (MDGs).

Figure 33 - The development space: HDI average scores per country group, 1980-2012



Source: Own figure based on data by UNDP (2013)

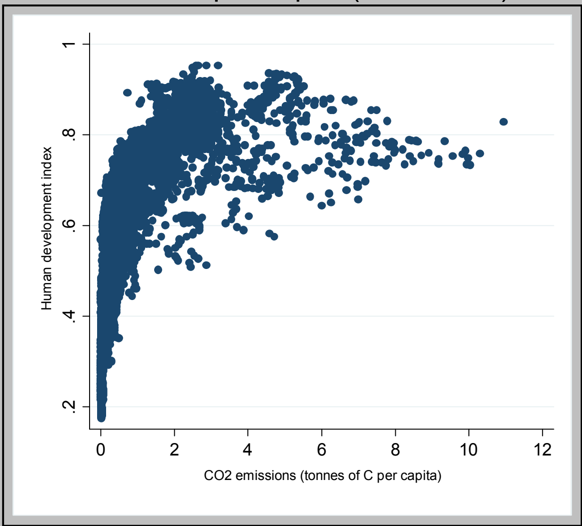
Figure 33 shows a graphical representation of the development space, as expressed by the HDI. The dark blue areas represent the improvements attained from 1980 to 2012 by the different country groups. The red area, in turn, symbolises the potential improvements in human development that can be achieved in the future.

7.4. The carbon elasticity of human development

Energy use has been essential to accomplish higher levels of economic expansion, which have translated into greater levels of human development. As shown in Table 4, section 2.2.1 (page 43), developed countries consume around 205 gigajoules on average per person per year, compared to 33 in least developed nations. Energy consumption has, nonetheless, entailed billions of tonnes of carbon being emitted into the atmosphere, as a considerable amount of energy is obtained from fossil fuels. In addition, carbon has also been freed as a consequence of land use change in response to the need to acquire more land for agricultural activities. Human development and CO_2 emissions, in this sense, have shown to be correlated over time (see section 2.1.3).

The relationship between these two variables, however, is not linear. It rather follows an asymptotic curve. At low levels of HDI, an increase in CO_2 emissions delivers more than proportional increments in human development. As countries become more developed, the relationship starts showing diminishing marginal returns. This means that at higher HDI levels more emissions are required to accomplish smaller improvements in human development. This pattern can be seen in Figure 34, in which data for all years and all countries were pooled together using territorial emissions. As has been said, the first part of the analysis consists in estimating the carbon elasticity of human development for different country groups. This elasticity, in other words, expresses how much CO_2 emissions have been required to achieve improvements in human-development levels during the period in the regions under study.

Figure 34 - Relationship between the human development index and territorial CO_2 emissions per capita (1980-2010)



Source: Own figure based on data by CDIAC (2013) and UNDP (2013)

7.4.1. Functional forms

Existing studies have used different functional forms to express the relationship between HDI and CO_2 emissions. It is common to describe the relationship in terms of a logistic curve, following the approach proposed by Preston (1975), who examined the links between life expectancy and economic development. This particular form, for example, was adopted by Costa et al. (2011) to analyse the correlation between HDI and CO_2 per capita. Other authors have utilised semi-logarithmic forms (e.g. Pasternak, 2000) or have included a quadratic term as is usually done to assess the EKC (e.g. Dietz and Rosa, 1997; Rosa et al., 2004). In this analysis, two functional forms are tested, as is explained in section 3.2.1.6. The first one corresponds to a hyperbolic saturation curve, which was used by Steinberger and Roberts (2010) and Steinberger et al. (2012), according to which HDI for country *i* at time *t* is expressed as:

$$HDI_{it} = HDI_{sat} - \exp\,(A) \times {CO_2}_{it}^{\beta} \qquad (30)$$

where the HDI_{sat} term represents the asymptote or saturation value, *A* is a constant and *β* is expected to be negative, while CO_2 represents carbon emissions per capita per year for country *i* at time *t*. As stated by Steinberger and Roberts (2010), this form offers some advantages, since it produces a slightly better fit than other functional forms, is invertible and allows data weighting. However, the asymptote value has to be determined *a priori* from the data. In line with the aforementioned authors, it is estimated here as HDI_{sat}=1.1*max(HDI). In addition to this functional form, a simplified log-log version is also tested, in which the only difference is that the saturation term is excluded. The curvature of the function is, in this manner, not bounded, producing a slightly steeper slope at high levels of HDI.

$$HDI_{it} = \exp\,(A) \times {CO_2}_{it}^{\beta} \qquad (31)$$

Both functional forms can be easily linearised by applying logs to both the left- and right-hand side terms of the equations, which results in: $ln(HDI_{sat} - HDI_{it})=A+\beta*ln(CO_{2it})$ and $ln(HDI_{it})= A+\beta*ln(CO_{2it})$. Panel data regression methods can then be applied using these linear forms in order to estimate the parameters *A* and *β*. In the latter function, *β* is expected to be positive and represents the carbon elasticity of human development.

It must be kept in mind that these functional forms do not imply a direct causality between the variables. Apart from energy consumption, human development is determined by a number of economic, social and institutional factors (see: Binder and Georgiadis, 2010). The present analysis does not seek to delve any deeper into the causal relationship between human development and per capita emissions, but rather to assess its degree of association over time in relation to countries with different HDI levels.

7.4.2. Statistical tests

In line with the procedure followed in Chapter 4, a series of statistical tests were carried out to assess the viability of using pooled OLS regressions, as well as to identify the presence of heteroscedasticity, autocorrelation and cross-sectional independence in the saturated and unbounded specifications for territorial and consumption CO_2 data.

Table 28 - Statistical tests for the HDI-CO_2 per capita relationship according to functional specification and type of emissions used in the analysis

Test	Specification	Territorial	Consumption	Result
F-test: All fixed effects are null	Saturated	F(30,3951)=339.02***	F(20,2296)=326.32***	OLS not valid
	Unbounded	F(30,3951)=291.36***	F(20,2296)=170.54***	OLS not valid
Breusch-Pagan LM test for pooled vs random effects	Saturated	$chi^2(1)$=30778.63***	$chi^2(1)$=12852.26***	OLS not valid
	Unbounded	$chi^2(1)$=30612.48***	$chi^2(1)$=13136.17***	OLS not valid
Modified Wald test for groupwise heteroskedasticity	Saturated	$chi^2(170)$=1.6e+07***	$chi^2(125)$=1.6e+05***	Heteroskedasticity
	Unbounded	$chi^2(170)$=9.9e+06***	$chi^2(125)$=1.5e+05***	Heteroskedasticity
Likelihood-ratio test for group heteroskedasticity	Saturated	$chi^2(169)$=2784.75***	$chi^2(124)$=1790.99***	Heteroskedasticity
	Unbounded	$chi^2(169)$=3275.25***	$chi^2(124)$=2364.07***	Heteroskedasticity
Wooldridge test for autocorrelation in panel data	Saturated	F(1,169)=76341.92***	F(1,122)=13979.59***	Autocorrelation
	Unbounded	F(1,169)=33277.31***	F(1,122)=17215.17***	Autocorrelation
Pesaran's test of cross-sectional independence	Saturated	379.04***	282.44***	Cross-sectional dependence
	Unbounded	375.60***	279.31***	Cross-sectional dependence
*** Significant at 0.01 level				

As can be seen in Table 28, the results derived from the F (fixed effects) and the Breusch-Pagan Lagrange Multiplier tests indicate that a pooled OLS regression is not a suitable method, since country-specific effects are present. Their null hypotheses are rejected in both cases at a level of significance of 1% for all specifications (i.e. saturated and unbounded) and types of emissions (i.e. territorial and consumption). Moreover, the two heteroskedasticity tests reveal that the residual variance is not constant over time. In both the modified Wald test and the likelihood-ratio test, the null hypotheses are rejected in all cases. On the other hand, the Wooldridge test points out that the errors are serially correlated and bound to produce biases in the estimated coefficients. Its null hypothesis is rejected at a significance level of 1% for all specifications and types of emissions. The same can be said about the Pesaran test for cross-sectional independence, which shows that country-specific errors are correlated between panels.

Unit root tests were also applied to determine the order of integration of the variables. As has been explained in section 3.2.1.3, two variables can be cointegrated if they share the same order of integration. Table 29 presents the results from these tests. According to the Im-Pesaran-Shin test, territorial and consumption emissions are stationary in levels (i.e. not differenced variables) in the case of some panels. However, the Pesaran (2007) test, which accounts for heterogeneous panels with cross-sectional dependence, indicates that both variables are I(1); that is, they possess an order of integration of 1. The alternative hypothesis, which states that some panels are stationary in first differences, is accepted at a 1% level of significance. These results are consistent with those obtained in Chapter 4 in relation to the same variables. In the case of HDI, both tests point out that its order of integration is 2. In other words, the variable must be differenced twice before becoming stationary across the whole set of panels. The results thus suggest that HDI and CO_2 emissions are not cointegrated, since they do not share the same order of integration. In order to verify this assertion, the Westerlund (2007) test was applied. It reveals that the variables are in fact not cointegrated in both functional specifications when using both types of emissions. The null hypotheses of no cointegration among all the panels are accepted. The complete results can be checked in Table 33, which appears in Appendix B.1.2.

Table 29 - Unit root tests for variables used in the analysis

Variable	Lags	Im-Pesaran-Shin	Pesaran
		Statistic (t-bar)	Statistic (t-bar)
Territorial	1.38	-3.05***	-1.86
Δ Territorial	1.31	-52.36***	-31.58***
Consumption	1.22	-1.88**	2.06
Δ Consumption	1.10	-37.71***	-6.25***
HDI	2.39	4.24	7.62
Δ HDI	1.17	6.21	5.55
ΔΔ HDI	1.12	-43.43***	-2.08***

Note: Number of panels=170 and 125 for consumption emissions; ***, ** Null significantly rejected at 0.01 and 0.05 levels, respectively. Number of average lags obtained according to AIC provided by the Im-Pesaran-Shin test.
Δ: Number of differences. All variables tested with constant.

7.4.3. Results

Although the existence of cointegration has been ruled out in the relationship, the presence of heteroskedasticity, autocorrelation and cross-sectional dependence precludes the use of fixed and random effects models. Consequently, as was done in the case of the carbon EKC analysis, the GLS Prais-Winsten regression method is used to correct these problems and produce robust standard errors. Moreover, a panel-specific first order autoregressive term is included in the specifications to address serial correlation.

Table 30 shows the estimated coefficients derived from the regressions. The βs are significant in all cases and display the expected signs. These are negative for the specification that considers a saturation term and positive for the unbounded function. In the latter case, the βs represent the carbon elasticity of human development.

At a global level, consumption-based emissions display slightly higher elasticities (0.172) than territorial emissions (0.159), and this difference is statistically significant. Moreover, consumption emissions are more closely correlated with HDI, as evidenced by their higher goodness of fit (i.e. R^2). The HDI-emissions relationship at a global level is, in this manner, better described when emissions related to consumption are used. Overall, these have tended to deliver slightly more benefits in terms of human development than territorial emissions, although this does not always apply for individual regions, as will be explained. These findings, in general, are consistent with those obtained by Steinberger et al. (2012).

When using the longer territorial emissions dataset for the period 1980-2010, the estimated coefficients are statistically significant and similar than those reported here for both specifications. These results can be checked in Table 34 in Appendix B.1.2.

The fitted curves produced by the specification that includes the saturation term and that pertaining to the unbounded function are similar in shape for the global dataset, as can be seen in Figure 35a (page 195). However, the former presents a steeper slope at low levels of CO_2 per capita, while the latter shows a slightly steeper slope at high levels. The same pattern was identified when using both types of emissions. It was found, nonetheless, that the differences in the slopes are minimal when the curves are estimated at a regional scale, although these are not shown here in graphic form. Hence, the βs calculated with the unbounded specification can be deemed as acceptable approximations of the carbon elasticity of human development for each of the country groups.

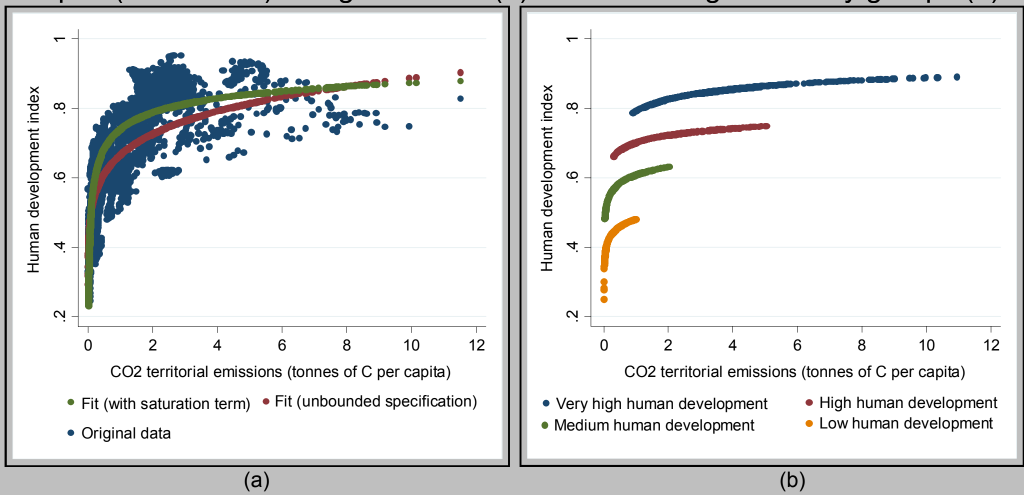
Table 30 - Prais-Winsten regression results according to specification and types of emissions for all countries (1990-2010)

Region	Coefficient	Territorial		Consumption	
		Saturated	Unbounded	Saturated	Unbounded
Global	β	-0.246*** (-23.88)	0.159*** (134.93)	-0.272*** (-21.44)	0.172*** (301.67)
	A	-1.178*** (-35.67)	-0.372*** (-26.92)	-1.138*** (-41.17)	-0.399*** (-34.02)
	R^2	0.668	0.741	0.729	0.773
Very high human development	β	-0.172*** (-31.32)	0.046*** (24.14)	-0.206*** (-31.89)	0.058*** (33.69)
	A	-1.443 (-38.08)	-0.220*** (-20.89)	-1.363*** (-40.89)	-0.244*** (-24.1)
	R^2	0.863	0.778	0.851	0.779
High human development	β	-0.072*** (-19.19)	0.035*** (13.51)	-0.091*** (-17.4)	0.044*** (13.71)
	A	-1.060*** (-32.76)	-0.363*** (-23.42)	-1.059*** (-34.02)	-0.364*** (-24.37)
	R^2	0.925	0.886	0.939	0.885
Medium human development	β	-0.062*** (-33.34)	0.057*** (48.41)	-0.075*** (-21.48)	0.068*** (29.2)
	A	-0.819*** (-55.34)	-0.503*** (-46.17)	-0.822*** (-56.81)	-0.503*** (-46.76)
	R^2	0.869	0.899	0.939	0.943
Low human development	β	-0.049*** (-10.87)	0.092*** (10.14)	-0.052*** (-6.71)	0.093*** (7.02)
	A	-0.577*** (-59.45)	-0.674*** (-44.23)	-0.565*** (-33.08)	-0.705*** (-25.85)
	R^2	0.803	0.904	0.790	0.899

Note: t-stats are shown in parentheses. *** Significant at a 0.01 level. The estimated *β*s are statistically different between territorial and consumption specifications. The null that *β*(saturated)=*β*(unbounded) is rejected at a 0.01 level in all cases, except for the low-human-development group in relation to both specifications.

As can be appreciated in Table 30, the elasticities have been larger on average in those regions that possess lower levels of human development. Least developed countries, for example, registered an elasticity of 0.092 for territorial emissions, while very-high-development nations observed a value of 0.046. These values reflect the position that these economies have occupied along the curve during the period; and this, in turn, exposes their level of economic development. The less developed nations are situated in the steeper segments of the curve, where small increments of CO_2 provide higher improvements in human development, which explains their larger elasticities. However, while countries become more industrialised during their economic development process and their levels of consumption and income per capita rise, they tend to generate more emissions. These rising emissions, in turn, gradually deliver lower marginal improvements in standards of living over time. Very-high-development nations, in this sense, have been positioned along the higher and flatter segments of the curve that correspond to low elasticity values. This situation is illustrated graphically in Figure 35b, which shows the estimated (i.e. fitted) unbounded curves for each country group. As can be seen, each group has occupied a distinct and clear position along the curve. It can thus be implied that as long as the current model of economic development is followed, based on resource- and carbon-intensive economic growth, nations will continue moving along the curve according to this pattern. In other words, improvements in HDI will continue being associated with rising emissions, unless this relationship can be decoupled. In fact, relative decoupling has occurred, but this will be further discussed in the following section.

Figure 35 - Estimated curves for HDI against CO_2 territorial emissions per capita (1990-2010) at a global level (a) and according to country groups (b)



Source: Own graphs

The carbon elasticity of human development is slightly higher at a regional level when it is estimated with consumption emissions. Least developed nations, however, constitute the exception. Their territorial and consumption elasticities are equal from a statistical point of view, reporting a value of 0.09. The same applies to the βs estimated using the saturated specification. This suggests that both types of emissions have contributed in a similar way to enhancing their HDI levels. Nevertheless, their consumption curve lies slightly below their territorial one. This small gap, which is not presented here in graphic form, is due to a lower estimated value for A (i.e. constant) in the consumption specification, which is significantly different in statistical terms from the territorial one. This gap was previously found by Steinberger et al. (2012) and complements the results obtained in chapters 4 and 5. As was explained there, many of these nations are not self-sufficient, particularly in the industrial and services sectors (see sections 4.3.3 and 5.3.1), and require importing a range of goods from other regions to satisfy their needs. The gap between the curves, in this sense, shows that still more emissions are required in these countries to enhance their standards of living when international trade is taken into account. The rest of the regions, on the other hand, display larger elasticities with consumption emissions, and the differences with respect to the territorial elasticities are statistically significant. In the case of the very-high- and high-human-development groups, the consumption elasticities are almost 20% larger, while their consumption curves lie above their territorial ones. These countries, consequently, obtain more human development benefits via international trade. Regarding middle-development economies, which include China, the estimated *A*s (i.e. constants) are equal from a statistical point of view when using both types of emissions, but the slope of the consumption specification is slightly higher. This indicates that, on average, these nations have also started to gain benefits from trade, although in a lesser extent than their more developed counterparts.

At a regional scale, the saturated specification yielded, in general, a better goodness of fit across the country groups. On the other hand, the R^2s are very similar when using territorial and consumption emissions. The medium-development group constitutes the exception. In this case, consumption emissions produced a better fit.

In summary, the main findings presented in this section show that the carbon elasticities of human development reflect the stages of economic development that each country group has gone through during the period under study. Furthermore, international trade has tended to deliver on average more development benefits to the more developed economies. This is evidenced by the higher elasticities obtained for these countries with the use of consumption-based emissions. This type of emissions, moreover, correlates better with HDI on a global scale, although the differences are minimal at the regional level.

7.5. Extrapolating HDI according to the RCPs

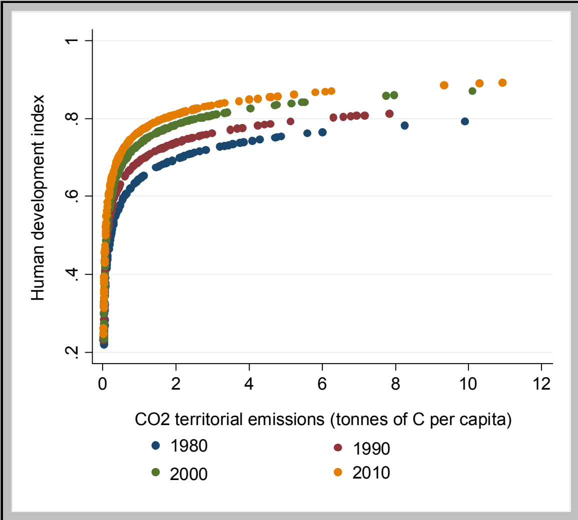
The second part of the analysis, as has been explained, consists in extrapolating HDI into the future by using the already estimated carbon elasticities of human development and the annual emissions described by the different concentration pathways. As has been said, RCP3-PD is of special interest, since it specifies the amount of cumulative emissions that are potentially compatible with the 2°C threshold in the long run. RCP8.5, on the other hand, illustrates the business- or *development-as-usual* pathway. The two remaining RCPs, 4.5 and 6, in turn, represent intermediate scenarios.

The results presented in the previous section evidence the positive and monotonic relationship that exists between the HDI and CO_2 emissions, as described by the functional forms introduced in section 7.4.1. In other words, HDI has generally expanded over time with rising emissions, and the extent to which this expansion has occurred in different regions is given by the carbon elasticity of human development.

However, these specific forms also imply an opposite outcome; that is to say, HDI can fall with decreasing emissions. This possibility is patent under the RCP3-PD, which entails a significant decline in CO_2. If HDI levels depended entirely on an emissions-intensive model of economic development that is unable to achieve any decoupling with the use of technological, economic or social measures, then, *ceteris paribus*, attaining the 2°C target could constrain or undermine the opportunities to improve living standards among the global society. These reductions in HDI were calculated here so as to illustrate this outcome. It must be kept in mind that these figures were obtained by applying the historical carbon elasticities of human development and using the RCP3-PD yearly emissions without introducing any measure of decoupling. As can be appreciated in Table 31 (page 199), least developed nations would be the most affected group, observing a decline of 11.59% in their HDI levels, which would drop on average from 0.466 in 2012 to 0.412 in 2050; attaining a level similar to the one that existed in the early 2000s. Very-high-human-development economies, in turn, would constitute the second most affected region, due to the scale of their required cuts, registering an average fall of 7.92%, going down from 0.905 to 0.833. Medium-development countries, which possess a significant share of the carbon space, would exhibit a plunge of 5.70%, with HDI levels dropping from 0.640 to 0.603. Meanwhile, high-development nations would represent the least affected group with a fall of 3.43% (from 0.758 to 0.731). These crude estimates reveal, on the one hand, the vulnerability of least developed nations to changes in emissions due to their level of economic development, depicted by their position along the curve. On the other hand, these numbers illustrate the importance of achieving considerable decoupling rates in order to significantly improve living standards across the world within the limits imposed by a 2°C target.

Steinberger and Roberts (2010) have revealed the existence of an ongoing process of decoupling between HDI and CO_2 emissions. This process is illustrated in Figure 36, which shows that the fitted correlation curves have been shifting upwards over time. This shift is analogous to a certain extent to the one described by Preston (1975) in relation to income per capita and life expectancy. This process of decoupling indicates that countries not only move along the curve during the different stages of economic development, but they also tend to move continuously upwards, obtaining more development benefits with the same amount of emissions. Following Preston's line of reasoning, it can be said that this behaviour is due to technological improvements, as well as national, regional and global development policies, such as the MDGs.

Figure 36 - Estimated correlations between HDI and territorial CO_2 emissions from 1980 to 2010



Source: Own figure

In order to take this decoupling process into account, the regression parameters (i.e. *β*s and *A*s) were estimated again, but this time including a dynamic saturation value instead of a fixed one, like was done in the previous section. In this case, the asymptote was determined *a priori* as $HDI_{sat,gt}$=1.1*max(HDI_{gt}); that is, it is given by the maximum HDI value achieved in country group *g* at time *t*, multiplied by the 1.1 factor. The saturation value was then projected for each country group up to 2050 according to its historical average annual growth rate, limiting the maximum HDI value so it does not exceed the unity. This procedure allows the estimated parameters to reflect the upward shift of the HDI-emissions relationship that takes place over time. As can be seen in Table 31, the saturation value (i.e. maximum HDI) grew on average 0.58% annually in high-development nations, followed by very-high- (0.40%), medium- (0.26%) and low-development countries (0.23%). This suggests that the process of decoupling has been more emphasised in those economies that possess higher levels of human development.

The parameters utilised to carry out the projections were estimated with territorial emissions, since the RCPs do not include consumption-based figures. The results derived from the regressions that involve the dynamic saturation term can be consulted in Table 35, which is included in Appendix B.1.2. Yearly per capita emissions related to each RCP were then used along with the projected saturation values in order to obtain future HDI scores up to 2050. The results are presented in Table 31.

It can be appreciated that HDI manages to grow across all country groups under the RCP3-PD when considering the historical rates of decoupling. Very-high- and high-development economies register improvements on average of 10.08% and 26.43%, respectively, in 2050 with regards to 2012. Their mean HDI levels thus achieve a value that is close to 1, while utilising slightly more than half of the available carbon space (see Figure 32 in section 7.2). However, the HDI in medium-development countries shows a more modest progress, rising 8.43%, as can be seen in Figure 37a. It advances from 0.640 in 2012 to 0.694 in 2050 by using 43.5% of the carbon space. Least developed nations, on the other hand, remain stagnant throughout the whole period, barely observing an expansion of 1.55%. This is illustrated in Figure 37b. Their HDI scarcely grows from 0.466 to 0.474 with the use of 1.8% of the carbon space. The lower expansions experienced by these two latter groups reflect their larger carbon elasticities and lower rates of decoupling. It must be kept in mind that these projections imply the continuity of the *status quo*; that is, the persistence of the existing economic, social, institutional and technological conditions, which is entrenched in the allocation of remaining carbon space by the RCP3-PD.

Table 31 - Percentage change in HDI according to different RCPs

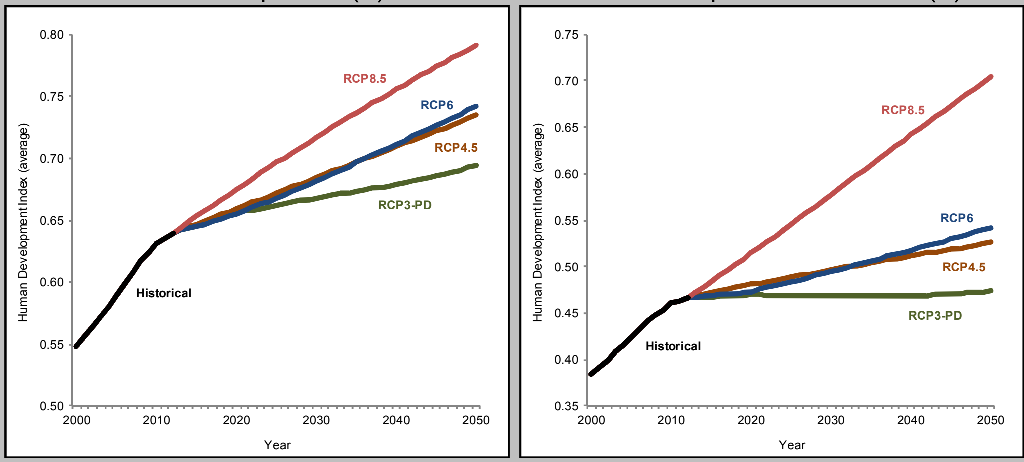
Region	RCP3-PD (no decoupling)*	RCP3-PD*	RCP4.5*	RCP6*	RCP8.5*	Dynamic saturation value (growth)**
Very high human development	-7.92%	10.08%	10.19%	10.30%	10.41%	0.40%
High human development	-3.43%	26.43%	29.30%	30.73%	31.44%	0.58%
Medium human development	-5.70%	8.43%	14.79%	17.49%	23.64%	0.26%
Low human development	-11.59%	1.55%	12.77%	17.74%	50.92%	0.23%
Cumulative emissions (Gt, 2012-2050	249.22	249.22	404.75	399.63	552.46	---
Temperature increase (year 2100)***	1.3°C to 1.9°C	1.3°C to 1.9°C	2.0°C to 2.9°C	2.5°C to 3.6°C	3.8°C to 5.7°C	---

Notes: * Refers to percentage change in 2050 with respect to 2012. ** Average annual growth rates. *** Temperature ranges refer to likely average increase by the end of the century with respect to pre-industrial levels (see: Rogelj et al., 2012; IPCC, 2013). Projections were estimated using a dynamic saturation term except for RCP3-PD (no decoupling).

According to RCP8.5, which is more closely in track with the current emissions trajectory (see: Peters et al., 2013), very-high and high-human development countries achieve elevated levels of HDI that are close to 1. They register average improvements of 10.41% and 31.44%, respectively. The rest of country groups also experiences a significant expansion under this pathway. Medium-development economies attain an HDI level of 0.791 in 2050, which is a score similar to the one currently held by the best ranking high-development nations (see Figure 37a). This represents an enhancement of 23.64% with respect to 2012. Nonetheless, they utilise almost twice the emissions (259 Gt) specified in the RCP3-PD to attain this level. Low development countries, in turn, observe a considerable advancement of 50.92%. Their average HDI score rises to 0.704 in 2050, which is almost the current level enjoyed by some high-development economies (see Figure 37b). This expansion requires almost three times the amount of cumulative emissions (12.21 Gt) than those stipulated in the RCP3-PD. This figure is relatively small when compared to the cumulative emissions used by the rest of the country groups, and can thus be regarded as a positive sign. This suggests that the standards of living can be significantly improved with a moderate amount of emissions in least developed nations, although this fact has to be taken with caution. These countries currently possess very low levels of emissions per capita (i.e. 0.11 tonnes on average in 2010), and the projections assume that their historical carbon elasticity of human development will maintain the same level in the future. However, under the current patterns of economic development, it is expected that the elasticity will decrease as they become more industrialised and income rises, implying a faster rise in emissions and lower improvements in HDI.

The improvements achieved under RCP4.5 and RCP6 in each of the country groups are very similar, since both pathways share almost the same annual emissions trajectories up to 2050 (see Figure 2, page 19). Once again, the two most developed groups attain HDI levels that are close to the unity, as can be seen in Table 31. Growth rates of 10.19% and 10.30% on average are registered in very-high-development economies for RCP4.5 and RCP6, respectively. In turn, high-development countries observe average rises of 29.30% and 30.73%. In medium-development nations, both pathways lead to mean HDI levels of around 0.740, which is equivalent to the current level of the high-development group. Least developed nations, on the other hand, register lower expansion rates of 14.79% and 17.49%. Their HDI, in this sense, reaches scores of about 0.540 in 2050. Nonetheless, human development would continue improving beyond 2050 under the RCP6 pathway, as emissions would continue growing until peaking in 2080 (see Figure 2, page 19).

Figure 37 - Projected HDI values according to different RCPs for Medium-Human-Development (a) and Low-Human-Development countries (b)



(a) (b)

Source: Own graphs

On the whole, the results reveal some optimistic aspects. Very-high and high-development countries can improve their human development levels even with a significant decline in emissions, as long as they maintain their historical rates of decoupling. This is particularly true in the case of the latter group, which manages to obtain the highest relative improvements in HDI, as a result of having achieved the highest levels of decoupling. It is, however, not certain if these nations can sustain these same improvements with even greater emissions cuts; that is, with a smaller carbon budget. This aspect was not considered in the study. Nonetheless, the results suggest that they could still maintain average high development levels between 0.9 and 1 with a lower share of carbon space and, especially, if their rates of decoupling were to be augmented even more over time. In relation to least developed countries, the results suggest that they can considerably expand their HDI scores with a relatively small amount of cumulative emissions. However, they are most sensitive to changes in emissions, as a consequence of their current stage of economic development. Their progress can thus be seriously constrained if they are just allowed to use 1.8% of the available carbon space. Medium-development economies, on the other hand, require a significant amount of emissions to deliver enhancements in human development. This applies particularly to countries like China, which has relied on a highly carbon-intensive model of development. It is in these nations were greater rates of decoupling are required in order to improve the living standards of their populations within the limits of the available carbon space.

7.6. Summary and further remarks

This chapter explained to what extent human development can be improved in the developing world within the limits of the available carbon space as defined by the different RCPs. In this manner, it provided empirical answers to the fourth and last research question proposed in this thesis. As was explained, the objective of the analysis is not to develop an exact prediction or forecast of future human development trends across different regions. Moreover, it does not seek to probe alternative pathways or examine different approaches to allocate the available carbon space in a more equitable manner between nations. Rather, this examination attempts to analyse the consequences of maintaining the *status quo*; that is, the continuity of the existing economic, social, institutional and technological conditions embodied in the current model of economic development. The results from this analysis provide insights about the magnitude of the problem and, more importantly, contribute to identifying and highlighting the aspects and regions where action must be taken. The findings can also help to develop alternative emission pathways that place a stronger emphasis on the enhancement of human development within the confines of a carbon space compatible with a 2°C target. Moreover, the evidence included in this chapter can as well inform future climate negotiations at the global, regional and national levels.

The available carbon space was quantified in section 7.2 according the RCP3-PD pathway, also known as RCP2.6, which describes a future emissions concentration trajectory that is likely to avoid dangerous climate change in the long-run (van Vuuren et al., 2007). The available space or total cumulative emissions, in this sense, amounts to roughly 249 Gt of carbon when it is measured from 2013 to 2050. The space clearly increases if it is estimated using alternative emissions scenarios, such as those described by RCP4.5, RCP6 and RCP8.5. It is thus equivalent to slightly more than 400 Gt of carbon according to the first two pathways, and reaches approximately 550 Gt in the case of the latter. However, these trajectories are associated with mean global temperatures that would likely exceed the 2°C threshold by the end of the century.

Given the regional shares incorporated in the RCP3-PD pathway, it was determined that very-high-human-development economies would hold more than a third (36.6%). The high-human-development group would utilise 18.0%, while medium-development nations would make use of 43.5%. Least developed countries, on the other hand, would be entitled to the remaining 1.8%. This allocation clearly contrasts with the development needs of the different country groups. As was explained in section 7.3, low-development nations currently possess an average HDI score that is almost half of the one enjoyed by the highest ranking nations. Medium-development countries, in turn, require expanding their scores by about 40% to attain those same levels. This is worrying, as almost 70% of the global population live in these last two regions.

The carbon elasticities of human development were estimated in section 7.4 with the use of Prais-Winsten panel data regressions in order to correct the presence of heteroskedasticity, autocorrelation and cross-sectional dependence. The elasticities were larger on average in those regions that possess lower levels of human development, and they reflect the stages of economic development that the different country groups have gone through during the period under study. The less developed nations are situated in the steeper segments of the fitted curve, where small increments of CO_2 provide higher improvements in human development. In contrast, very-high-development nations have been positioned along the higher and flatter segments of the curve that correspond to low elasticity values. As long as this development pattern persists, it can be implied that improvements in HDI will continue being associated with rising emissions.

It was also found that international trade has generally provided more development benefits to the very-high- and high-development economies. These nations show higher average elasticities associated with their consumption-based emissions. Moreover, the results reveal that this type of emissions correlates better with HDI on a global scale, although the differences are minimal at the regional level.

The estimated elasticities and the annual emissions described by the different RCPs were then used to extrapolate HDI into the future. The projections reveal some positive aspects. Very-high- and high-development economies manage to obtain elevated levels of human development under the RCP3-PD pathway, when historical rates of decoupling are considered. This suggests that it is possible for them to transfer more carbon space to the countries that need it the most without sacrificing a high-development status. The extent to which this can be done was not modelled here, but this stresses the importance of undertaking deeper abatement (or decoupling) efforts in industrialised nations so as to free more carbon space. These emissions could then be used particularly by least developed countries, which are sensitive to changes in CO_2. The findings indicate that they can significantly enhance their living standards with a relatively small amount of cumulative emissions. However, this requires an enhancement of their historical rates of decoupling and modifying their patterns of economic development. It is crucial for them not to follow the same development paths pursued by the rest of the country groups. Medium-development countries, like China and other big emerging economies, have done so, basing their economies on a highly carbon-intensive model of development. As a consequence, they will keep requiring a significant share of carbon space in the future, unless they start taking immediate actions.

The following chapter focuses on discussing the results presented in this thesis.

Chapter 8
Discussion

This chapter offers a discussion of the main results presented in the last four chapters. These findings provide an evidence base to answer each of the research questions proposed in this thesis. Chapter 4 focused on testing the carbon EKC from a consumption-based approach. The evidence conclusively rejects the validity of the hypothesis for CO_2 emissions. Chapter 5 analysed the extent to which developing countries can be affected in terms of losses in value added and wages to skilled and unskilled labour due to mitigation-induced reductions in imports in industrialised economies. The findings revealed that while these actions can free carbon space, they can also lead to negative developmental consequences in the developing world via international trade. Chapter 6 quantified the amount of emissions that could be captured by a BCA scheme and examined which regions could be potentially affected by its implementation. The results show that the breadth of the scheme can be significantly limited by the existing trade agreements, although it can cause distortions in trade flows and curtail the developing process in the South. Finally, Chapter 7 concentrated on examining how much improvement in human development can be achieved across different regions within the limits of the available carbon space. The examination revealed that given the continuity of the *status quo*, an emissions pathway compatible with a 2°C target can prove to be too stringent to allow developing nations to significantly improve their standards of living. These findings are discussed here in the light of the existing literature, while focusing on their academic and policy implications. Section 8.1 discusses the income-emissions relationship from a consumption-based approach. Section 8.2 then focuses on the North-South divide and the patterns of unequal exchange. Section 8.3 talks about the trade-off that exists between demand-side mitigation actions and the attainment of global development. The issue of taxing imports at the border is then examined in section 8.4. The dilemma of developing within limits is finally discussed in section 8.5. The conclusions drawn from this discussion will be reserved for the following and final chapter.

8.1. The income-emissions relationship from a consumption-based approach

As has been stated by authors like Ekins (1997) and Rothman (1998), analysing the EKC hypothesis from a consumption-based approach provides valuable insights into the long standing discussion about the sources of human impact on the environment. By shifting the attention from production activities as the origin of environmental impacts, as has traditionally been done in EKC studies, consumption is revealed to have an important role in shaping the relationship between affluence and environmental degradation. Conducting a robust and comprehensive analysis from this perspective in the case of carbon had been difficult due to data availability. However, by using the set of global time series developed by Peters et al. (2011b), this study contributes by shedding light upon the academic debate regarding the validity of the carbon EKC. In this manner, conclusive evidence was produced to reject the existence of the hypothesised *inverted-U* curve. Income and carbon emissions have not shown signs of having decoupled over time. The findings indicate that while nations become wealthier, their emissions tend to rise monotonically, associated with the consumption of a higher amount of goods produced in foreign regions.

In methodological terms, one of the messages conveyed in Chapter 4 is the possibility of obtaining a variety of different fits. As was shown throughout the exposition, several curves can be fitted with the use of different panel-data methods. The selection of a particular fit, therefore, has to be decided with caution. The utilisation of a particular model or method cannot be solely based, for example, on producing the best R^2 value, but rather on a series of other considerations. As was explained in the literature review chapter, numerous authors have warned about the various econometric shortcomings and inconsistencies that commonly affect EKC analyses (e.g. Stern et al., 1996; Millimet et al., 2003; Perman and Stern, 2003; Dijkgraaf and Vollebergh, 2005; Müller-Fürstenberger and Wagner, 2007; Romero-Ávila, 2008; Wagner, 2008; Vollebergh et al., 2009; Stern, 2010). In line with some of the recommendations proposed by the aforementioned authors, the present study followed a rigorous approach, explained step by step, in order to choose an adequate model and technique based on the nature of the data. A series of statistical tests were conducted to find the most appropriate methods to avoid producing biased or spurious results.

When correcting for heteroskedasticity, autocorrelation and cross-country correlation, the estimated coefficients revealed one of the most noticeable findings. The consumption-based curve exhibits a steeper slope than the territorial one at higher levels of income, thus possessing a higher turning point. This goes in line with the evidence presented previously by Aldy (2005), Peters and Hertwich (2008a) and, more specifically, by Wagner (2010). The latter used a similar GLS method but applied to energy use. These authors also found higher peaks for consumption emissions, some of them situated out of the sample range, but these are lower than those estimated in this thesis. The coefficients estimated here suggest that both types of emissions have increased monotonically with income, evidenced by their out-of-sample peaks (see section 4.3.3). This is consistent with the conclusions offered by Bagliani et al. (2008a) and Bagliani et al. (2008b), who found that the ecological footprint and income per capita follow a monotonically increasing trend. As can be appreciated in Figure 8 (page 46), the behaviour of this indicator can be explained to a large extent by the carbon footprint.

The results were further substantiated when the estimated parameters were freed from the assumption of slope homogeneity and when the long-term relationship between income and emissions was calculated (see: Perman and Stern, 2003; Dijkgraaf and Vollebergh, 2005). Similarly to Bagliani et al. (2008b) and Wagner (2010), it was found that the variables in a number of panels share the same order of integration and thus share a common long-term trend. Cointegrating regressions were subsequently run for each individual country according to the procedures proposed by Pesaran and Smith (1995) and Westerlund (2007). A significant quadratic term was not found in the majority of nations, implying that income and both types of emissions have followed, in general, a linear trend in the long-run. Once again, consumption-based CO_2 presented a steeper slope. In fact, the long-term income elasticity of carbon shows that when income per capita grew by 1% during 1990-2010, consumption emissions per capita increased on average by 0.75%; a rise mainly led by net importing countries. This figure is higher than the estimate obtained for territorial emissions of 0.53%, which is very close to the one found by York (2012) for the period 1960-2008, although he did not use income data based on PPP (also see: Steinberger and Krausmann, 2011).

The cointegrating regressions also showed that consumption-based emissions tend to adjust around 20% faster to their long-term trend after short-term disturbances in GDP, as expressed by the error correction terms. The speed of adjustment estimated here for territorial emissions is consistent with the one found by Martínez-Zarzoso and Bengochea-Morancho (2004). However, this is the first time that this figure has been estimated for consumption emissions. This finding reflects the textbook argument that consumption is sensitive to anticipated changes in personal income (see: Flavin, 1981). In the face of adverse economic conditions, consumption tends to slow down, followed by production. During the 2008/2009 crisis, for example, private consumption in industrialised countries suffered a strong contraction, and their demand for imported goods fell significantly. As explained by Peters et al. (2012), this pushed consumption emissions down in Annex B nations (-8.4%), more than territorial CO_2 (-7.0%). Moreover, consumption is an important driver to stimulate economic growth. Governments try to boost private and public consumption as soon as possible during a recession with fiscal and monetary policies to avert a crisis. Production (i.e. territorial) emissions, on the other hand, as suggested by York (2012), are more constrained by inertia and lock-in effects in the face of changes in GDP. These facts may explain why consumption-based emissions tend to be more reactive to variations in income per capita and, hence, return more quickly to their long-term equilibrium than production emissions.

Chapter 4 also highlighted that the poorest countries were net importers of emissions during the period. This fact was later reinforced with the findings presented in Chapter 5, which showed that least developed nations import emissions related to agriculture and industry. This is a fact that has been seldom highlighted in the literature, since it has mainly focused on the industrialised world. Only a few existing studies have revealed additional evidence in this respect. Steinberger et al. (2012), as explained in Chapter 7, obtained statistical proof along these lines. However, more analyses are hard to find. This is a topic that requires further consideration due to its policy implications. More attention should be paid, specifically, to the economics literature, as it has shown that least developed economies are not self-sufficient in certain economic activities and, consequently, are obliged to import goods from other regions (see: Ng and Aksoy, 2008). UNCTAD (2012), for instance, has found that poor African nations are net importers of renewable resources (i.e. biomass). More about the situation of least developed countries will be discussed later in this chapter.

The findings also show that only 35 nations out of 129, mostly middle-income (e.g. China, India, Indonesia, Russia, South Africa), were net exporters of emissions during the whole period 1990-2010 (see section 4.3.3). Apart from least developed and industrialised nations, many other countries have become or are on track to become net importers of emissions, as evidenced by the estimated long-term trends. As has been explained by Peters et al. (2012), developing nations registered in 2009 higher consumption-based emissions in absolute terms than industrialised countries for the first time (see Figure 9, page 49). In fact, consumption emissions rose considerably from 1990 to 2010 in the South. These grew, for example, more than 120% in China and more than 70% in India. This reflects the significant six-fold increase that Southern nations registered in final consumption expenditure from 1970 to 2011 (see Figure 7a, page 44). More and more people in the developing world are demanding the same type of goods than in wealthy countries, such as cars, clothing, mobile phones, etc., and this is having a significant impact in the environment (Hubacek et al., 2007). Their annual consumption expenditure, as stated in section 2.2.1, is still expected to triple in 2025 with respect to 2010, an expansion mainly fuelled by the big emerging economies (Dobbs et al., 2012; UNDP, 2013). This means that their import requirements will also grow and, as a consequence, their consumption emissions are expected to continue along the same trend over the forthcoming years.

8.2. The North-South divide and unequal exchange

Chapter 5 described a clear picture of the divide that exists between Northern and Southern countries in terms of their production structures and their stages of economic and human development. As discussed in the previous section, industrialised nations have the highest levels of income per capita and consumption, which have supported their very high standards of living. However, they have attained this status at the expense of exerting a significant stress on the environment. As stated in section 2.2.1 (see Table 4, page 43), these economies consume 3.2 times more energy and 2.3 times more materials per capita than the rest of the world (Fischer-Kowalski and Haberl, 2007; Haberl et al., 2011). Accordingly, they also generate 3.4 times more emissions per person (see section 4.1). These consumption patterns are manifested in the global production structure. Very-high-human-development economies produce annually around 75% of the total value added in the world, measured in conventional economic terms, and this reflects a profound disparity. High- and medium-development economies create almost the remaining fourth, while least developed countries are responsible for barely 1%.

Analysing the content of value added that is embodied in trade allowed acquiring a better understanding of the global production structure than by using traditional trade indicators. It also permitted a better calculation of the magnitude of trade flows and determining the role that different regions play along the intricate networks of the global supply chain. The escalating process of production fragmentation that has been taking place across different geographical regions has reshaped the global division of labour (see: Athukorala, 2005; Jones and Kierzkowski, 2005; Lanz et al., 2011). As explained in section 2.4.2, this has made necessary to determine how much value each economic sector in each country contributes during the production process. Conventional trade indicators are limited in this respect, since they assume that a product is entirely manufactured in the country of origin. By assessing the trade in value added, the findings indicate, for example, that the US trade deficit with China is reduced by around 45% when using this method than when employing traditional trade statistics. This illustrates China's real participation in the global value chain. Not all the exports from that country are entirely manufactured within its territory, but it has rather specialised in certain tasks. The US shortfall against the EU27, in turn, increases by around 12%, since many intermediate goods and factors of production of European origin are contained in final products assembled elsewhere. These findings are in line with those obtained by IDE-JETRO and WTO (2011) and Stehrer (2012), although they vary slightly due to methodological and temporal differences.

The trade patterns identified in the analysis show that almost 40% of the total value added in agriculture is embedded in trade, while in industry this figure reaches 30%. This estimate is similar to the 27% obtained by Daudin et al. (2011), who used GTAP data for 1997, 2001 and 2004. Moreover, the examination revealed that very-high-human-development economies are in general net importers of value added. By consuming large amounts of foreign resources and a wide range of products, they thus tend to consume wealth from other regions via international trade. The rest of the world, in contrast, is a net exporter of value added. However, a closer inspection of the sectoral composition of trade exposed important characteristics of the global production structure and, more specifically, of the trade relationships between different regions. As expressed by Daudin et al. (2011), this procedure is useful to determine "*who produces what and for whom*". The picture that emerged from the analysis resembles to a certain extent the patterns of unequal exchange described by the Prebisch-Singer hypothesis (Prebisch, 1950; Singer, 1950). In accordance with these authors, the findings presented in Chapter 5 show that the North or *core* (i.e. very-high-human-development nations) specialises in capital- and skilled-labour-intensive goods. These economies are net exporters of value added in heavy industry and services. Moreover, they are net exporters of skilled labour in almost every economic activity (see section 5.3). The South or *periphery* (i.e. developing countries), on the other hand, focuses on low-capital- and unskilled-labour-intensive products. As has been explained, these countries are on average net exporters of value added in the agricultural, mining and light-industry sectors. In addition, they hold positive trade balances in relation to unskilled labour in the same activities, especially in the case of medium-development nations. These North-South trade flows suggest that a pattern of unequal exchange still persists. However, understanding if these flows have translated into a worsening of the terms of trade over the years in the developing world is uncertain (see section 2.4.1).

The validity of the hypothesis has been contended in the literature (Hadass and Williamson, 2003), but it is out of the scope of this thesis to test it. Nonetheless, these findings are consistent with what other authors have observed, such as Stehrer (2012). He obtained similar evidence in relation to employment, although his analysis was not done at a sectoral level. In relation to material flows, other researchers have reached similar conclusions about the trade asymmetries between the North and the South (e.g. Muradian and Martinez-Alier, 2001; Bringezu et al., 2004; Giljum, 2004; Giljum and Eisenmenger, 2004; Muñoz et al., 2011).

The existence of an unequal exchange between Northern and Southern nations evokes the long-standing discussion about the benefits of free trade. Upon this situation, a possible action would be to impose trade barriers, as prescribed by the structuralists, in order to protect domestic industries from foreign competition. However, implementing this model seems almost unthinkable in an era of increasing globalisation, and especially under the framework of the WTO. Nonetheless, many industrialised nations currently make use of antidumping duties and subsidies to shield some economic activities, like agriculture (see: Kee et al., 2011). Furthermore, the import-substitution schemes implemented in the 1970s proved to be ineffective in promoting industrialisation, since they led to low levels of productivity and competitiveness (Baer, 1972; Bruton, 1998). On the other hand, a more extreme measure, like autarky, would have a negative impact on social welfare (Samuelson, 1962; Irwin, 2005).

Although the North-South asymmetries described above are of concern, there are signs of improvement. By gradually integrating their economies to the global markets, developing countries have increased their share in world trade from 25% to 47% between 1980 and 2010 and their share of total output from 33% to 45% (UNDP, 2013). This has been associated with a significant expansion of consumption and with improvements in human development. Studies, like the ones conducted by Davies and Quinlivan (2006) and UNDP (2013), indicate that increases in trade are positively correlated with enhancements in well-being. However, developing nations, and especially the big emerging economies, need to avoid falling into the middle-income trap (see: Paus, 2012). In other words, they require being able to surpass the middle-income threshold and achieve higher levels of human development. Acquiring this ability involves shifting their current comparative advantages, based on resource extraction and cheap labour, towards the attainment of higher levels of productivity and innovation. This would allow them to break the North-South imbalance, reduce their dependency and secure more benefits from trade. As was explained in section 5.5, developing nations, and specifically the least developed, currently capture a lower share of value and wages domestically for every dollar of exported goods than their developed counterparts. These efforts, however, imply undergoing a deep process of structural transformation. More importantly, they require doing it in a sustainable manner (see: UNCTAD, 2012). The results presented in section 5.5 show that high- and medium-development nations are highly carbon-intensive (i.e. 0.94 and 1.32 kg of CO_2 per dollar of final demand, respectively), an element that has contributed to enhancing their comparative advantages. Such an industrialisation pathway, based on resource extraction, unskilled labour and carbon-intensive activities, can only reinforce the existing asymmetries and lead to economic stagnation and more pollution in the long-run. In this sense, these countries require higher investments on productivity growth, education, health, technological capabilities, among others, in order to advance to higher echelons of economic and human development within the limits of the available carbon space.

8.3. Demand-side mitigation and global development: the trade-off

The available carbon space, defined as the amount of cumulative emissions compatible with the achievement of a 2°C target, is decreasing at a fast rate. As has been argued in section 8.1, emissions and particularly those associated with consumption have tended to rise monotonically while countries transit through the different stages of economic development. Higher levels of income per capita are coupled with a higher utilisation of resources and energy. As illustrated by the IPAT identity in section 2.3.1 and implicitly reflected in the results obtained from the carbon EKC analysis, the pace of technological change has not been enough to offset the emissions associated with the rise in population and affluence (see: Beder, 1994; Schor, 2005; Flavin and Engelman, 2009; Jackson, 2009). As expressed by authors like Huesemann (2006, p. 539), technology will be able to deliver the required cuts "*only if population and economic growth are halted without delay*". This statement is aligned with the ideas of steady-state economics (Daly, 1974) and the degrowth movement (Latouche, 2006), which believe that the scale of many economies, particularly the industrialised, has become unsustainable and consumption must thus be kept constant or downscaled. In this sense, demand-side measures aimed at changing/reducing consumption are deemed as essential to complement technology-led actions in order to lessen the environmental pressures and prevent dangerous climate change in the long-run. The findings presented in Chapter 5 reveal, however, that curbing final demand for imports involves an important trade-off. While demand-side actions implemented in the North can contribute to reduce emissions and free carbon space, they can also curtail the development opportunities available to the global South. Developing countries, who have adopted free-market policies and export-led models of growth, depend on the revenue and employment generated by their exporting sectors. Consequently, their development processes can be affected by a lower volume of trade under the current model of economic development.

Estimating the labour productivity of carbon (see section 5.5) is useful to understand the underlying mechanism that explains the impacts on value added and skilled and unskilled wages in the global South derived from changes in final demand registered in the North. Moreover, this indicator reveals the sensitivity of different regions and economic sectors to demand-driven mitigation actions, since it expresses the amount of wages to skilled and unskilled labour that are associated with every unit of emissions. To the best of the author’s knowledge, no other studies in the literature have estimated this indicator using this particular method, although multiplier analysis is a common technique used within the input-output framework (e.g. Lenzen et al., 2004; Lin et al., 2012). The analysis on the labour productivity of carbon showed that low-human-development nations are on average the most sensitive group to Northern demand-side mitigation actions. More specifically, they are vulnerable in relation to agriculture. For instance, mitigating one kilogram of CO_2 by reducing the demand of agricultural imports from these countries could yield losses of 1.4 dollars in wages to unskilled labour and 6 cents to skilled labour. These figures, however, have to be considered with caution, as non-CO_2 emissions (e.g. N_2O, CH_4 and fluorinated gases) were not included in the analysis. These represent around 25% of total GHGs (see section 2.1.1). The results produced in this chapter would therefore vary if these gases had been taken into account, particularly in the case of agriculture.

The study also showed the magnitude of the impacts in different developing-country groups derived from cuts in final demand for imports in the North, so as to reduce the latter’s consumption-based emissions (see section 5.7). As has been said, least developed nations are specifically sensitive to changes in their exports of agricultural products, but also of those related to mining. In turn, the medium-development group, to which China belongs, is more sensitive in the case of industrial activities. For instance, reductions of 1.5% in total final demand for imports of light industrial products manufactured in these countries are required in industrialised nations to bring their total consumption emissions by 1%. As a consequence, total value added, which is analogous to GDP, would fall by 5.9% in medium-development nations, while their total wages to skilled and unskilled labour would drop by 3.7% and 7.7%, respectively. These figures cannot be compared to other examples in the literature, as they are virtually nonexistent. Mattoo et al. (2011a) conducted one of the very few related studies, which analysed how changes in the price for carbon could affect industrialisation in the developing world by using a general equilibrium model. With all the caveats involved, it could be said that the findings presented in this thesis are in line with theirs. The authors equally found that carbon-intensive countries, like China and India, would be mainly affected. They determined that drops of 9% to 11% in manufacturing exports due to higher carbon prices were associated with falls of 6% to 7% in output. Moreover, they estimated that aggregate welfare in low- and middle-income nations would fall by around 2%. Changes in total utility or well-being were not estimated in this thesis, due to methodological reasons. Nonetheless, it can be implied that a drop in GDP of about 6% with associated declines in total payments to unskilled labour would bring a rise in unemployment rates, lower levels of consumption and investment, and ultimately a deterioration of social welfare.

As was explained in Chapter 5, value added and wages to skilled and unskilled workers were used in this thesis as proxies for development indicators, as they are relevant for promoting economic growth and improving welfare. Assessing wider potential impacts on human development, however, would have required utilising a range of other indicators for life expectancy, education attainment, etc. As explained in section 3.2.2, this would have demanded data at a sector-level consistent with an MRIO framework, but unfortunately information at this degree of disaggregation is not available. While the proxy variables used here provide a partial view of the effects caused by Northern demand-side mitigation actions on the global development process, they offer valuable insights regarding the magnitude and direction of the potential impacts. On the whole, the findings indicate that mitigation-driven reductions in final demand can effectively put at risk the developmental processes taking place in the South.

The evidence presented in Chapter 5, however, should not be interpreted as a justification to preserve the current levels of consumption, particularly in industrialised nations, given the threats that developing countries would face otherwise. A case has been robustly made in the literature regarding the pressing necessity to make consumption more sustainable (e.g. UN, 1992; Lintott, 1998; Jackson, 2005; Mont and

Plepys, 2008). Developed countries, in this sense, should make efforts to modify their consumption patterns and even reduce their overall consumption. For this reason, recognising the potential impacts and the vulnerability of different country groups to lower levels of Northern demand is important, as it can help to better inform policy decisions. This examination represents an initial approach to the problem and evidences the risks that are involved if these actions were to be taken unilaterally without a deeper understanding about their potential consequences. More research is thus needed to determine how the impacts identified here can be hampered. For example, it would be useful to identify carbon-intensive imports that can be safely substituted or whose consumption can be discouraged. Some lessons could also be learned about existing programmes, such as Fair Trade, which seek to ensure better trading conditions and promote sustainability in the South (Le Mare, 2008). In spite of the criticisms received by these programmes (see: Renard, 2005; Getz and Shreck, 2006), labelling and certification schemes could be designed to assist local producers to manufacture products in a less carbon intensive manner and inform consumers about both the carbon content of those goods and their importance to the livelihoods of those who produce them.

Ameliorating the impacts on developing countries also imply strengthening their domestic markets. As was argued in section 8.1, this has been gradually taking place, especially in high- and medium-human-development nations. Consumption expenditure per capita has grown significantly along with an enlargement of the middle classes. For example, according to Kharas (2010), the middle classes in developing Asian economies are expected to double by 2020. The UNDP (2013) estimates that the South will account for three-fifths of the one billion households earning more than $20,000 dollars per year in 2025. Special attention, however, has to be given to least developed nations. As has been said, they are generally not self-sufficient in certain economic activities and are consequently dependent on trade and aid from the industrialised world. Moreover, as stated in section 2.1.1, future climate variability will aggravate their ongoing social and economic situations, thus increasing their vulnerability and exacerbating their already limited economic and technological capacities to adapt (Yohe and Tol, 2002; Adger et al., 2003; Reid et al., 2010). A case can thus be made, based on the results presented in this thesis, to exempt them from the application of demand-side mitigation actions taken in the North.

South-South trade can also contribute to reduce the dependency of the developing world. As explained in section 2.4.4, this has become the fastest growing segment of world trade, more than tripling between 1980 and 2011. In addition, intra-South FDI grew on average 20% per annum from 1996 to 2009 (UNCTAD, 2011). More efforts, however, are still required to integrate more countries. Furthermore, it is vital to ensure that the exploitation patterns followed in the past by industrialised nations are not repeated (Mol, 2011).

More importantly, developing nations require undertaking more efforts to make their production processes cleaner, more productive and more resource-efficient, particularly in the case of high- and medium-human-development economies. As was explained in the previous section, these countries cannot continue supporting their development strategies on cheap labour- and carbon-intensive production if they wish to move beyond the middle-income threshold while staying below the limits of the available carbon space. Achieving this goal, however, is not easy. As stated by Khor (2011), the broad, *one-size-fits-all* development prescriptions traditionally formulated by international organisations in the past have proved to be ineffective. Development strategies therefore need to be designed according to the needs and characteristics of specific countries. Nonetheless, this would in general require much higher investments in capacity building and innovation, poverty reduction, technology transfer, international support, fair trading rules, and a strong developmental state, among others. In a few words, as stated by Ocampo (2002) and Chang (2011) it is necessary to start rethinking development.

8.4. Taxing imports at the border

Chapter 6 focused on the specific case of BCAs. This specific policy instrument was chosen to be analysed in this thesis since discussions are happening in some Annex I countries about their potential implementation. The US, in particular, has been considering this option in more serious terms. Its congress has expressed that it will not approve an emissions trading scheme without a provision for BCAs. Proponents argue that this policy instrument ensures the competitiveness of domestic industries and thus levels the playing field with respect to nations that are not bound to legal emissions-reduction commitments. Many developing countries, however, have opposed their implementation, asserting that they contravene not only the spirit of free trade, but also the principle of common but differentiated responsibilities (Holmes et al., 2011; Kaufmann and Weber, 2011). In other words, they shift climate change mitigation costs onto the developing world, who should carry less onerous abatement obligations

(Davidson Ladly, 2012). Moreover, it has raised concerns in some developing regions, as it is believed that they can distort trade flows and thus affect the well-being of their societies (Schneider and Samaniego, 2010).

Much of the existing literature on BCAs has focused on discussing their legal aspects and their compatibility with the WTO framework (e.g. Holmes et al., 2011; Monjon and Quirion, 2011; Sheldon, 2011). Moreover, considerable work has been done to assess their ability to address competitiveness issues and avoid carbon leakage (e.g. Kuik and Hofkes, 2010; Dissou and Eyland, 2011; Bednar-Friedl et al., 2012; Böhringer et al., 2012). However, there has been insufficient research to determine which and to what extent particular developing regions could be mostly affected. Moreover, to the best of the author's knowledge, no studies have been conducted to calculate the potential scope of this policy instrument; that is, the amount of emissions that could be covered by such as a scheme (see section 2.3.3). This particular study, in this sense, contributes to the literature by analysing these two last issues.

The results reveal that the potential amount of CO_2 emissions that could be taxed under a BCA scheme that involved all Annex B countries (i.e. carbon-priced economies) using data for 2007 corresponds to approximately 18.3% of their total consumption-based emissions (see Figure 28, page 168). This figure represents almost 55% of the CO_2 embodied in their imports. Almost two thirds of these emissions are from medium-human-development nations, and to be precise, mostly from China. However, the analysis showed that this scope can be significantly limited by the existing trade agreements embodied in the WTO framework. As was explained, a number of issues influence the potential breadth of the scheme, such as GATT's provision of non-discrimination, the inclusion of elaborate finished goods, and sectoral and country exemptions.

In order to ensure a fair and similar treatment than domestic products, a fraction of emissions cannot be taxed since they are not covered under the operating carbon-pricing schemes (i.e. Kyoto, EU ETS). In this sense, only 45% of the total imported emissions could be legally included. Around half of this proportion corresponds to economic sectors that are considered to be as particularly at risk from foreign competition and carbon leakage (i.e. lime and cement, basic iron and steel, refined petroleum, aluminium, basic chemicals, and pulp and paper). These are the emissions that could more likely be considered in future schemes to address concerns raised by those particular industries (Stephenson and Upton, 2009). However, as can be seen, this would involve just a small portion of the CO_2 contained in imports. Almost the rest of the remaining emissions are associated with the generation of electricity. Its inclusion is problematic, since it would require calculating the amount of indirect electricity emissions generated along the production process. According to Ismer and Neuhoff (2007), this is complicated in technical terms particularly when integrated electricity systems are involved, as the origin of specific electricity inputs are difficult to track. However, as noted by Monjon and Quirion (2010), the effectiveness of a BCA scheme would be undermined if electricity was not taken into account, especially for electricity-intensive sectors that are exposed to international competition, such as aluminium. A similar problem applies to the case of intermediate goods, which comprise about two thirds of all these emissions. Estimating the direct and indirect carbon content of basic commodities like the ones described above is already complex, but calculating it for more elaborate products or finished products of different origin, such as cars or heavy equipment, can be even more challenging. A robust administrative system and a comprehensive and transparent carbon accounting procedure would be required. This, nonetheless, would elevate the costs and the complexity of managing the scheme. Winchester (2012), for example, has highlighted that a system of this nature would need to produce regular updates of the carbon content of different products. Asking exporters to provide certified information on the carbon embodied in their goods can imply a heavy burden, specifically for small producers. Applying a rigid rate, on the other hand, could be considered as a fixed import or anti-dumping tariff, irresponsive to improvements in carbon intensity. This could, on the one hand, reduce the effectiveness of the tax in encouraging producers to modify their practices and, on the other, could be contested by the exporting countries, generating trade disputes within the WTO.

The scheme, however, is even more constrained when the BAT principle is accounted for in compliance with the provision of non-discrimination. By assuming that imports are manufactured with at least the best technology available in the region of destination, the scope of the scheme is reduced significantly. The results from this analysis indicate that at most 10% of total emissions embedded in imports could be covered if this was the case, without taking into account the issues related to electricity and intermediates. Currently, the EU computes product-specific benchmarks to allocate free allowances based on the average of the 10% European plants with the lowest emissions. These have been proposed as potential BATs. Nevertheless, they do not account for indirect emissions due to electricity and, as has been said, this factor could compromise the breadth of the BCA scheme. Monjon and Quirion (2010, p. 5204) recognise the limitations imposed by BATs and acknowledge that BCAs would have minimal effects in they were considered. They state that in many cases BATs entail very low carbon intensities and offer two examples: "*steel made with sustainable charcoal in Brazil or of aluminium made with hydropower in Canada*". In the face of these possibilities, products would have to be benchmarked against a technology that is similar to the one used to produce them. This, again, would increase the intricacy of the scheme. The other option proposed by these authors would be to exclude some technologies from the BATs. More research, in this sense, is needed to analyse how different product benchmarks affect the effectiveness of BCAs.

Based on the aforementioned results, different tariffs rates were estimated for the regions included in the study using an illustrative carbon price of $50 dollars per tonne of CO_2 (see section 6.3). Although this price would need to increase in the future in order to encourage deeper emissions reductions, Atkinson et al. (2011, p. 572) believe that it is compatible with "*a fairly ambitious*" reduction target for highly-developed economies in the short-run. For the purpose of this research, this price is useful to show the scale that BCAs could reach in different regions. The rates calculated here are very similar to the ones produced by these authors. The tariffs could reach around 8.9% for medium- and 2.8% for low-human-development countries when all sectors are included. Atkinson and his colleagues, for instance, estimated a rate of 9.2% for Chinese exports to the EU. Additional rates were calculated in this thesis according to the criteria that has been discussed (i.e. including electricity, intermediates, BATs, etc.), which has not been done in other studies. The tariffs could reach up to 12.3% and 2.9% for the same groups of countries if only trade exposed sectors were covered. These tax burdens can potentially distort trade flows and affect the demand for imports, as they would translate into higher prices paid by consumers (see: Grubb, 2011). The consumer price of exports from medium-development countries, and particularly China, would go up proportionally by 12%. When applying BATs, however, the rates are much lower. They become 1.2% and 0.6% for medium- and low-development nations, respectively. As can be implied, the effectiveness of the BCA scheme would be reduced, as well as its impact on the exporting countries.

These tariff rates can potentially affect the welfare of the developing world. The results show that the most carbon-intensive nations, such as China and South Africa, could receive the largest impacts in terms of losses in GDP and wages to skilled and unskilled labour. If BCAs induced a contraction in final demand for imports of around 1%, consumption-based emissions in the priced region would decline by 2.7%. This would lead to a drop in GDP of about 2.8% in medium-development countries, with associated reductions of 1.6% and 2.8% in wages to skilled and unskilled labour. It must be noted, nonetheless, that these figures are valid from a partial equilibrium approach, but could change if prices had been considered. Changes in prices could potentially lead to a substitution for other types of imported products or for imports from less carbon-intensive regions, although this is difficult to tell. Despite this caveat, the findings presented here are consistent with the arguments provided by Dong and Whalley (2009) and Lin and Li (2011), who believe that China's imports would register a fall and this could ultimately affect the country's regional development policy. Moreover, if the carbon price increased beyond 50$ dollars per tonne, the tariffs would rise proportionally, aggravating the impacts on different regions. The repercussions, however, could be subdued if the revenues obtained from the BCA scheme were remitted back to the exporting countries in the form of aid, technology transfer or assistance for adaptation efforts. This would be particularly relevant for low-development nations.

Regarding least developed nations, these findings strengthen the case to exempt them from Northern demand-side mitigation actions. Although their emissions just represent a very small fraction of the BCA scope (i.e. around 1.4% of total imported emissions), the scheme could lead to a decline of 1.1% in their GDP, with related decreases of 0.8% and 1.2% in wages to skilled and unskilled labour. These nations are sensitive to variations in trade flows (see Figure 12, page 83) and are in need of more development opportunities.

8.5. Carbon and development spaces: The dilemma of developing within limits

In spite of the efforts that have been undertaken by Annex B countries to curb carbon emissions, these have continued growing monotonically as their societies have become more affluent. A similar behaviour has been observed in the developing world, whose emissions have increased at historical rates during the last decades, even surpassing those of their wealthier counterparts (see Figure 9, page 49). The possibilities of avoiding dangerous climate change in the long-run, in this sense, are quickly diminishing unless immediate and sustained actions are taken. This is of special concern for the poorest nations in the world, who are the ones that require most urgently greater opportunities to satisfy their basic needs and acquire more capacities to adapt to a changing climate.

The results presented in Chapter 7 reveal the magnitude of the challenge. The carbon space available from 2013 to 2050 amounts to roughly 249 Gt of carbon according to the RCP3-PD, or RCP2.6, pathway (van Vuuren et al., 2007). As was explained in section 2.1.1, this constitutes a novel scenario included in the IPCC (2013) Fifth Assessment Report which is compatible with a 2°C target. Illustrative emissions pathways for different regions are offered along with the scenario, and these were used to determine region-specific budgets. As explained in section 7.2, the largest shares are allocated to the current major polluters, rather than to those who possess the lowest development levels. Very-high-human-development nations would hold slightly more than a third of the carbon space, while China on its own would use almost another third. Least developed nations would be entitled to utilising just 1.8%. This clearly does not represent an equitable allocation of the carbon budget and diverges with what authors like Khor (2010) have put forward. He has manifested that the historical carbon debt owed by industrialised nations should be taken into consideration, since this would significantly enhance the share of the developing world. Moreover, it conflicts with the *Greenhouse Development Rights Framework* and related ideas proposed by Baer et al. (2009), Chakravarty et al. (2009) and Kartha et al. (2009), who have suggested that those who earn less than $16 to $20 dollars per day or are responsible for less than one tonne of CO_2 per year should be exempted from taking up mitigation costs (see section 2.1.3). Their proposals conform to the UNFCCC principle of common but differentiated responsibilities and provide a significant portion of the carbon space to the 70% of the world's population who reside in medium- and low-development nations. The bulk of the mitigation burden would thus fall on the shoulders of the richest countries.

The regional emissions pathways associated with the RCP3-PD, however, imply significant emissions cuts across all regions in per capita terms, even for least developed nations. As a consequence, the longer it takes industrialised countries to take significant and sustained actions, the less carbon space will be left for the poorest regions. Medium-development countries still need to expand their current levels of human development by another 40% on average in terms of their HDI scores in order to attain the levels currently enjoyed by the topmost group. Meanwhile, least developed nations have to double them. Given the current development trends already discussed in this chapter, based on an intensive use of fossil fuels, the less developed economies are in need of more carbon space in order to achieve these improvements.

Wealthy nations have attained very high levels of human development, but have been responsible for a significant portion of the GHG emissions that have been emitted into the atmosphere (Goldemberg, 1995; Raupach et al., 2007; Wei et al., 2012). This can be clearly observed by focusing on the last three decades. Their HDI scores increased 16.6% on average from 1980 to 2010 with an amount of cumulative emissions of around 98.7 Gt of carbon. On the other hand, medium- and low-development nations registered important improvements in HDI of 50.5% and 46.2% on average during the same period, while generating 49.7 and 2.5 Gt of carbon, respectively (see Figure 33, page 188). As can be observed, at high levels of HDI more emissions are required to accomplish smaller enhancements in human development. In contrast, at low levels of HDI, a rise in CO_2 emissions delivers more than proportional increments (see Figure 34, page 189). In this sense, the marginal gains in human development that industrialised nations could obtain in the future by generating more emissions are minimal when compared to least developed countries, who could still achieve significant advancements.

The relationship between HDI and CO_2 per capita is represented by the carbon elasticity of human development, which was estimated for the different regions. In line with what has been said, the elasticities were revealed to be larger in those countries with lower levels of human development and smaller in the more developed (see Table 30, page 194). This pattern reflects the different stages of economic development that countries go through. While economies transit from the agricultural to the industrial phases of economic development, rising emissions gradually deliver lower marginal improvements in living standards. The results also showed that the elasticities associated with consumption emissions tended to be slightly higher than those obtained with territorial CO_2, except for least developed countries. In the case of the very-high- and high-human-development groups, the consumption elasticities were almost 20% larger, and their consumption curves were situated above their territorial ones. These countries, consequently, obtain more human development benefits via international trade. In the case of the low-development group, the results evidence their dependency on trade, an issue that has already been discussed in this chapter. These findings, on the whole, are consistent with the ones obtained by Steinberger et al. (2012).

As long as the patterns of economic development are followed, based on resource- and carbon-intensive economic growth, improvements in HDI will continue being associated with rising emissions. It is important to have in mind, nonetheless, that countries present a high level of heterogeneity in terms of their development trajectories. Important lessons could be learned by examining certain outliers; that is, nations that have not adhered to the global trend and have thus been attaining more development benefits with lower emissions. This, however, is a matter for further research. Another aspect that is worth highlighting is that, in general, it has become possible to attain a given level of human development over time with lower emissions (Steinberger and Roberts, 2010). In other words, a gradual decoupling between human development and CO_2 emissions has been taking place, illustrated by an upward shift of the estimated curves. This phenomenon is analogous to the one described by Preston (1975), who analysed the relationship between income per capita and life expectancy. He found that life expectancies of between 40 and 60 could be achieved with lower incomes in the 1960s than thirty years earlier. In line with his arguments, it can be said that the disassociation between HDI and emissions is due to technological improvements, a better provision of public education and health services, as well as other national, regional and global development policies, such as the MDGs. It must be noted that income per capita, which constitutes an important component of HDI, has not contributed to the decoupling. As has been explained, the results from the carbon EKC analysis found no signs that emissions have delinked from income per capita. The decoupling process is thus being manifested via the education and health components of the HDI, although these sub-indices were not analysed individually in this thesis to determine their specific contributions. Steinberger and Roberts (2010) focused on this task. They found, for example, that high literacy rates stand out as being attainable at very low levels. More research, however, is required to analyse this decoupling process, identify its underlying causes and distinguish in which regions it is taking place more rapidly. The present examination suggests that it has been more emphasised in high-human-development nations than in less developed areas. Preston (1975) also hinted that in relative terms this process occurs more slowly at low income levels and somewhat faster at higher levels. Jack and Lewis (2009) have criticised this assertion, stating that health levels have improved in poor countries at a faster rate than in rich countries, although from a lower starting point. However, it is also true that emissions have grown at a faster pace in poor regions. More work is therefore needed to produce firm and definite conclusions in this regard.

With the use of the estimated elasticities and by allowing the estimated curves to shift upwards over time to simulate prospective efficiency gains, regional HDI scores were extrapolated into the future according to the yearly emissions described by each of the RCPs. A relevant finding is that high-development nations, which possessed an average score of 0.758 in 2012, managed to attain very high human development levels of nearly 0.95 on average in 2050 by using 18% of the available carbon space. This amount of cumulative emissions entails curbing their annual per capita emissions by around 50% with respect to their current levels as described by the RCP3-PD. This indicates that many of these nations, which include some big emerging economies, are in a position to adopt legally binding emissions reduction targets. In fact, some countries like Brazil and Mexico have already proposed to reduce their GHG emissions by up to 36% and 30%, respectively, by 2020 with respect to their BAU trajectories (UNFCCC, 2011a). In contrast, more modest improvements were estimated for medium- and low-development economies under the RCP3-PD, which amounted to 8.43% and 1.55%, respectively (see Figure 37, page 201). These figures reflect their larger carbon elasticities and, hence, their stages of economic development. In the case of the former group, to which China belongs, making use of nearly half of the available carbon space (i.e. 43.5%) allowed it to improve its average HDI score from 0.640 in 2012 to 0.694 in 2050. As has been argued in this chapter, these countries cannot continue supporting their development strategies on carbon-intensive activities, and urgently require achieving significant efficiency gains. China, for example, has announced a national strategy to reduce its carbon intensity by 55% to 60% by 2020 with respect to its 2005 levels. This could be achieved, as has been proposed by Liu et al. (2013), by following an approach based on recycling, using more renewable energy sources and reinvigorating its domestic energy market. Regarding least developed countries, using the 1.8% of the available carbon space under the RCP3-PD is clearly not enough to deliver improvements in their living standards. Unless they adopt an alternative model of economic development, they will require a larger carbon budget, which is to be freed by the developed world. In order to accomplish this, the North would require reducing its per capita emissions by more than 80% by 2050 with respect to its current levels. This would entail enormous abatement efforts. On the other hand, if Northern economies curb their emissions by using demand-side measures as a complement to technology-led mitigation actions, caution has to be taken to avoid affecting the South via international trade. As has been explained in the previous sections, potential development gains in the developing world could be offset by a lower demand of imports from the North.

Under a development-as-usual scenario, depicted by the RCP8.5, the analysis showed that medium-development nations could achieve an HDI level of 0.791 in 2050, which is a score similar to the one currently held by the best ranking high-development nations (see Figure 37a, page 201). Nonetheless, this requires almost twice the emissions (259 Gt) specified in the RCP3-PD. Low development countries, in turn, would attain an average HDI score of 0.704 (see Figure 37b), involving almost three times the amount of cumulative emissions (12.21 Gt) than those stipulated in the RCP3-PD. Following this pathway, however, implies that the average global temperature will exceed the 2°C threshold by the end of the century, likely ranging between 3.8°C and 5.7°C in relation to pre-industrial levels (Rogelj et al., 2012; IPCC, 2013). The effects of a changing climate would increase the vulnerability of the poorest, underdeveloped and most climate-exposed societies. This would impose negative impacts on their human development levels, potentially curtailing their progress and elevating the adaptation costs (see section 2.1.1).

The projections produced here differ from those produced by Costa et al. (2011). According to their reduction framework, the authors estimated that 85% of the world's population could live in countries with an HDI score above 0.8 by mid-century by following their current development trajectories. They argue that this expansion is possible within an available carbon space of 272 Gt of cumulative emissions of carbon. However, their framework considers that nations that have surpassed the 0.8 threshold should undertake very steep and abrupt reductions. Moreover, they allocate less carbon space to the already developed world than the RCP3-PD. They acknowledge, nonetheless, that without these reductions, cumulative emissions could reach 600 Gt by 2050, a figure higher than the one considered by the RCP8.5. Steinberger and Roberts (2010), on the other hand, found that thresholds of around 0.25 and 0.7 tonnes of carbon by 2030 can ensure global high human development standards in relation to life expectancy and HDI, respectively. In this analysis, however, the shares for each country group were used as they are offered by each of the RCPs and new configurations were not explored. As has been explained, the objective of this study is not to probe different allocation frameworks or novel pathways, but to examine the human development implications of prominent emissions scenarios.

In relation to least developed countries, the results reveal that they are not only sensitive to changes in trade, as was argued in section 8.3, but also to changes in emissions, as a consequence of their current stage of economic development. Their progress can thus be seriously constrained if they are just allowed to use 1.8% of the available carbon space. However, the results show that significant enhancements in human development can be achieved by tripling their share. This amount of cumulative emissions is still small, compared with the rest of the country groups, and this fact can be considered as a positive sign. The caveat is that under the current patterns of economic development, it is expected that their emissions will increase beyond this amount when they start becoming more industrialised and start consuming more resources and energy. Nonetheless, these nations are currently facing an important historical conjuncture. In contrast to their more developed counterparts, least developed countries are still not locked-in or stuck on a particular development path. As late-comers to the global development process, they face an historic opportunity. Given their low starting point in terms of emissions and resource use, they can avoid adopting the traditional development pathways followed by the rest of the world and start developing in a low carbon and resource efficient manner. This would allow them to *leapfrog* or *tunnel through* from their current stages of economic development to higher echelons, skipping the dirty stages of development experienced by industrialised nations and currently by high- and medium-development economies. This transformation will require substantial efforts at the national scale and assistance from the developed world.

Formulating alternative development pathways not only for least developed nations, but also for the rest of the countries is essential under the stringent limits imposed by the available carbon space. A number of ideas have been explored, such as the *climate compatible development strategies* (Mitchell and Maxwell, 2010; Bruggink, 2012; Linnér et al., 2012; Román et al., 2012), the *Circular Economy* scheme (Yuan et al., 2006; Mathews and Tan, 2011), the notions of *Green Economy* and *Green Growth* (OECD, 2011; UNEP, 2011) or the concept of *sustainable structural transformation* (UNCTAD, 2012). These constitute some examples of ongoing work, but more research at macro and micro scales is still required to find ways of facilitating a transition towards a low-carbon, high-developed, and sustainable global economy.

As has been said in the introductory chapter of this thesis, humanity's greatest challenge is not only to maintain the average global temperature below the 2°C threshold by the end of the century and thus avoid dangerous climate change. It is also being able to improve the living standards of billions of people across the world. These two objectives are embodied in the concepts of the carbon and development spaces. The author of this thesis believes that they represent a useful way to frame this dual challenge and integrate the discourses from the climate change and development communities. As explained in section 2.1.3, the nexus between climate and development has not been fully acknowledged in research and policy circles. In particular, they can be useful to stress the importance of developing future emission pathways that place a stronger emphasis on the enhancement of human development within the confines of a 2°C target. The notion of carbon space, specifically, highlights the relevance of using cumulative emissions as an appropriate approach for creating climate-economy models and examining policy options (Anderson and Bows, 2008; Allen et al., 2009; Meinshausen et al., 2009; Zickfeld et al., 2009; Bows and Barrett, 2010). In terms of policymaking, both concepts are useful to emphasise the fact that policies should not be regarded from a unilateral perspective, but rather from an inclusive viewpoint that takes into account the needs of both developed and developing nations.

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This chapter provided a discussion about the main findings presented in this thesis. In this manner, it offered valuable insights about the compatibility between climate change mitigation and global development from a demand-side perspective. The next chapter offers the main conclusions derived from this research.

Chapter 9
Conclusions

After discussing the main results derived from this study in the previous chapter, valuable insights were obtained from which conclusions can be drawn. The present chapter starts by providing a brief summary of the findings and presenting the main conclusions related to each of the research questions outlined in the introduction of this thesis. This is done in section 9.1. The main contributions to the knowledge base are then presented in section 9.2. The limitations involved in this research project are acknowledged in section 9.3. Future research paths are then suggested in section 9.4. Some final remarks are offered at the end in section 9.5.

9.1. Brief summary of findings and main conclusions

As was explained in the previous chapter, answers were successfully provided in this thesis to each of the related research questions outlined in the introductory chapter (see section 1.2, page 9). These answers contributed to fulfilling the overarching aim. In this section, the main conclusions related to each research query are highlighted, offering a short summary of the findings.

Emissions tend to grow monotonically with income.

Is the Environmental Kuznets Curve for carbon valid from a consumption-based approach? Exploring this first question served as a starting point for this study. As was explained in section 2.2.3 (page 49), accepting the validity of the EKC hypothesis for carbon would imply that no trade-offs exist between achieving emissions cuts and enhancing global development through an expansion of income per capita. Under this view, an appealing option for policy makers to combat climate change would be to encourage increases in income per capita around the world. However, the results presented in Chapter 4 indicate that emissions tend to grow monotonically with income, showing no discernible signs of having decoupled over time. This evidence thus leads to definitively reject the existence of the hypothesised *inverted-U* curve in the case of CO_2 from a consumption-based perspective. It can be concluded that it is not possible to grow out of the problem. In the process of becoming wealthier, nations tend to be responsible for a higher volume of emissions associated with the consumption of a larger amount of foreign goods. They also become locked-in with existing infrastructures. This fact is of concern, as the evidence indicates that income and consumption per capita are increasing in the developing world, and this is exerting a considerable pressure on the environment (Hubacek et al., 2007).

Northern mitigation-induced reductions in demand can curtail the development opportunities available to the South.

How much value added and wages paid to skilled and unskilled labour in developing countries are associated with every unit of CO_2 that is mitigated in different sectors through reductions in consumption in industrialised nations? This second research question addresses the trade-offs between implementing mitigation-induced reductions in demand in the North and attaining development benefits in developing economies through international trade. The findings presented in Chapter 5 lead to the conclusion that while curbing final demand for imports in the developed world can contribute to reduce its consumption-based emissions and free carbon space, they can also curtail the development opportunities available to the global South. Least developed countries are dependent on trade, and are specifically sensitive to changes in their exports of agricultural and mining products. In turn, medium-human-development economies, to which China belongs, are more sensitive in the case of industrial activities. For instance, a reduction of 1% in consumption-based emissions driven by a fall of demand for light-industry imports in the North would cause a decline of 5.9% in GDP in the former nations, while their total wages to skilled and unskilled labour would drop by 3.7% and 7.7%, respectively. This evidence, however, should not be considered as a justification to preserve the current levels of consumption, particularly in industrialised nations. The literature acknowledges the pressing necessity to make global consumption more sustainable. This study represents an initial approach to the problem and evidences the risks that are involved if these actions were to be taken unilaterally without a deeper understanding about their potential consequences. Moreover, it allows the identification of countries and sectors that are more vulnerable to changes in the flow of traded goods in order to find ways to hamper these negative impacts.

BCAs can potentially distort trade flows and jeopardise development in the South.

How much value added and wages paid to skilled and unskilled labour in developing countries are associated with CO_2 emissions that would be captured in different sectors *through the implementation of border carbon adjustments in industrialised nations?* This third research question addresses a similar trade-off, this time involving the implementation of BCA schemes in economies subject to legally-binding emissions reduction commitments and improving welfare levels in the South through international trade. As explained in section 2.3.3 (page 64), some developing nations have opposed their implementation, asserting that they represent trade barriers and shift the mitigation costs onto the developing world. However, their proponents argue that they are vital to avoid carbon leakage and level the playing field. The results lead to the conclusion that BCAs can potentially distort trade flows and cause a reduction in exports and slower economic growth in the South, along with a decline in wages paid to skilled and unskilled workers. This, however, depends on the breadth and depth of the scheme, which could be significantly limited by the existing trade agreements and the intended sectoral and country coverage. The amount of CO_2 that could be captured varies between 45% to less than 10% of total consumption-based emissions in the importing region. This challenges the effectiveness and viability of a BCA scheme, which would be complex and costly to operate. The most carbon-intensive nations, such as China, could face the largest tariff burdens. For example, if BCAs induced a contraction in final demand for imports of around 1% in the priced region, this would cause a drop in GDP of about 2.8% in medium-human-development countries, with associated reductions of 1.6% and 2.8% in wages to skilled and unskilled labour. The repercussions, however, could be subdued if the revenues obtained from the BCA scheme were remitted back to the exporting countries in the form of aid, technology transfer or assistance for adaptation efforts.

The available carbon space compatible with a 2°C target is insufficient to deliver significant improvements in living standards in medium- and low-human-development countries given the continuity of the status quo.

To what extent can human development be improved in the developing world within the limits of the available carbon space as defined by the RCP pathways given the continuity of the status quo? This fourth question addresses the challenge of the equitable sharing of the development and carbon spaces. According to the RCP3-PD, or RCP2.6, the total amount of future cumulative emissions that is unlikely (i.e. <33% probability) to exceed the 2°C target is equal to about 249 Gt of carbon (IPCC, 2013). Given the illustrative regional emissions pathways included in this scenario, the largest shares are allocated to the current major polluters, rather than to those who possess the lowest development levels. The results show that high-human-development nations can attain very high HDI scores in 2050, even by curbing their annual per capita emissions by around 50% with respect to their current levels. In contrast, medium- and low-development economies could be seriously constrained, given their prevailing development patterns. They could experience modest improvements in their HDI scores of about 8.43% and 1.55%, respectively. In this sense, the longer it takes industrialised countries to undertake significant and sustained emissions reductions, the less development opportunities will be available for the poorest regions. Under a development-as-usual approach, depicted by the RCP8.5, both medium- and low-development countries could achieve similar scores to the ones currently held by high-development economies. Nonetheless, this would require them around 271 Gt of carbon, slightly more than the entire RCP3-PD budget. Following this pathway, however, implies that the average global temperature could likely (i.e. >66% probability) range between 3.8°C and 5.7°C by the end of the century with respect to pre-industrial levels (Rogelj et al., 2012; IPCC, 2013). Intermediate improvements, on the other hand, can be achieved with the stabilisation pathways (i.e. RCP4.5 and RCP6), but these would likely lead to average temperature rises beyond the 2°C threshold (see section 2.1.1, page 13). It can thus be concluded that achieving this target can seriously put at risk the development opportunities in the developing world under the current patterns of economic development supported by carbon- and resource-intensive economic growth. Hence, future climate negotiations must centre on providing a larger share of the carbon space to those nations that need it the most to enhance their development levels. Moreover, formulating alternative development pathways not only for developing, but also for developed nations is vital to ensure a transition towards an equitable, low-carbon, high-development, and sustainable global economy.

The current patterns of economic development entail important trade-offs between realising the necessary development space within the available carbon space from a demand-side perspective.

Providing answers to each of the proposed research questions allowed **fulfilling the overarching aim**, which is to *assess the compatibility between climate change mitigation actions in industrialised nations and improving development prospects in the developing world from a demand-side approach*. From what has been presented, it can be concluded that there are important trade-offs involved if the world continues with the current patterns of economic development. This does not imply, however, that these trade-offs should persist. As has been said, a solution to climate change should not be accomplished at the expense of reducing the development opportunities of developing countries. Achieving sustainable development involves enhancing the living standards of the world's population without transgressing the planetary boundaries.

9.2. Main contributions to the knowledge base

Each of the proposed research questions addresses a specific gap in the existing knowledge base, which were identified in the literature review chapter. In this sense, this thesis makes several contributions to different bodies of the academic literature.

Conclusive evidence to reject the validity of the carbon EKC from a consumption-based approach

As was explained in section 2.2.3 (page 49), the findings related to the EKC for carbon had been inconclusive regarding its validity. Authors, such as Ekins (1997) and Rothman (1998), had suggested that a consumption-based approach is a more appropriate way to analyse the hypothesis, than by employing the standard territorial or production-based method. Conducting a robust and comprehensive analysis from this perspective, however, had been difficult due to data availability. This study contributes to the EKC literature, as well as to the bodies related to consumption-based approaches by producing evidence to reject the existence of the EKC. This was accomplished by using a set of global time series for CO_2 developed by Peters et al. (2011b) and by following a rigorous and robust methodological approach. Moreover, this study makes a contribution by having estimated the speed of adjustment and the long-term income elasticity of consumption-based CO_2 emissions (see sections 4.3.5 and 4.3.6).

Quantification of the factor content of Southern exports associated with every unit of Northern consumption-based carbon emissions

Various bodies of the academic literature have recognised the need to address overconsumption, particularly in the developed world. However, the economic and development consequences in developing countries caused by reductions/changes in consumption levels via international trade have been scarcely explored. This thesis makes a contribution to the climate change mitigation literature, as well as those bodies related to development, sustainable consumption and steady-state and degrowth economics, by having quantified the magnitude of these effects. This thesis presents for the first time the labour productivity of carbon for different country groups (see section 5.5), based on an examination of trade in value added and the carbon embedded in trade flows. This indicator reveals the sensitivity of different regions and economic sectors to demand-driven mitigation actions, since it expresses the amount of wages to skilled and unskilled labour that are associated with every unit of emissions. Moreover, this study estimated the impacts on different country groups caused by Northern mitigation-induced reductions in final demand for imports in terms of losses in value added and payments to skilled and unskilled labour (see section 5.7, page 157).

Quantification of the emissions captured by a BCA scheme and its potential effects in the developing world

Much of the existing literature on BCAs has focused on examining the legal features related to BCAs and their compatibility with the existing trade agreements. Considerable work has also been undertaken to assess their ability to address competitiveness issues and avoid carbon leakage. Nonetheless, there has been insufficient research to calculate the potential amount of emissions that could be captured by such as a scheme, as well as to determine which and to what extent particular developing regions could be mostly affected. This study contributes to the BCA, development and climate change mitigation literatures by analysing these two last aspects. Moreover, it makes a further contribution for having estimated the different tariff rates that developing countries would face according to a set of different factors (e.g. trade provisions, sectoral and country coverage, etc.) (see section 6.3).

Estimation of improvements in human development in the South according to the RCP pathways given the continuity of the status quo

A considerable amount of studies have been undertaken by climate and development modellers in order to develop probable depictions of the future, and in the majority of cases they have tended to work independently from each other (see section 2.1.3, page 33). Most of the emissions scenarios have represented a central process of the IPCC, and have been mainly based on assessing the technical advances and their influence on the carbon intensity of GDP. Human development scenarios, on the other hand, have tended to devote less attention to climate-related matters. In contrast, a modest number of researchers have explored the relationship between human development and emissions. The literature is uncertain, however, about the extent to which living standards could be improved across the South with the remaining carbon space given the continuity of the status quo. This thesis contributes to the climate change mitigation and development literatures by offering estimations of the potential improvements in human development, as measured by the HDI, according to the different RCPs included in the IPCC (2013) Fifth Assessment Report given the continuity of the status quo. This was accomplished by calculating the historical carbon elasticity of human development and the scale of the decoupling process for individual regions. These estimations had not been presented before in the literature (see sections 7.4 and 7.5).

9.3. Limitations of the study

In the light of the contributions that this thesis makes to the existent knowledge base, it is important to acknowledge the limitations that are involved. Some of these limitations have already been mentioned throughout the different chapters and are summarised in this section.

As is the case with macroeconomic studies that use highly aggregated data, the level of detail at the micro level is faded or lost. One aspect that must be acknowledged is the heterogeneity between countries. Although this study identified global trends, many nations have followed emissions and development pathways that diverge from these general tendencies. Each nation possesses distinctive features, which are difficult to distinguish in a study of this nature. The degree of the impacts that were estimated, for example, derived from mitigation-induced changes in demand or from the implementation of BCAs, could vary significantly from one country to another. A similar situation applies to economic sectors. This study found, for instance, that these show a variety of carbon intensities not only within nations, but also among them. Important lessons could have been learned by identifying and examining relevant cases that have not adhered to the global trends.

Another aspect that should be recognised is that non-CO_2 GHGs (e.g. N_2O, CH_4 and fluorinated gases) were not taken into account in the different analyses that were conducted. These represent around 25% of total GHGs. As was explained in section 3.4, this data was not available at the level of disaggregation required by the MRIO framework and was excluded from the panel data analyses to maintain consistence.

Some estimations produced in this thesis, particularly in relation to research questions 2 and 3, would have showed slight variations if these gases had been taken into account. This is particularly true for the results related to the agricultural sectors. However, it is deemed that their inclusion would not have significantly altered the magnitude and direction of the results and, consequently, the conclusions produced in this thesis.

It must also be noted that the findings presented in Chapter 5 and Chapter 6 related to impacts on the developing world due to changes in final demand for imports in the North reflect partial equilibrium effects. Prices were not included. Consequently, the market-clearance condition (i.e. the point where global supply equals global demand through a change in prices) required to achieve a general equilibrium in the economy was not modelled. Changes in prices could potentially lead to a substitution for other types of imported products or for imports from less carbon-intensive regions. It is uncertain, however, to what extent the results could have varied. Nonetheless, once again, the author believes that their inclusion would not have changed the direction of the impacts nor modified the main conclusions.

Finally, in Chapter 5 and Chapter 6, value added and wages to skilled and unskilled workers were used as proxies for development indicators. Due to the methodological nature of MRIO analysis, more appropriate indicators of human development (e.g. life expectancy, observed and expected years of schooling, etc.) could not be included. Data at this level of sectoral disaggregation was not available. However, the results provided valuable insights regarding the scale and direction of the potential impacts.

9.4. Future research suggestions

The findings produced in this study, along with the limitations that have been presented, suggest a number of potential avenues for future research that should be explored in order to obtain a more complete understanding of the issues presented here.

One of the main conclusions drawn in this thesis points out that Northern mitigation-induced reductions in demand for imports can lower the development opportunities available to the South. As has been said, this should not be interpreted as a justification to avoid implementing demand-side mitigation measures and preserving the current levels of consumption, particularly in industrialised nations. On the contrary, there is an urgent need to address overconsumption as a source of many of the existing environmental pressures. This study represents an initial approach to the problem, and it exposes the necessity to deepen our understanding of the processes that are involved. In this sense, it generates new questions, opening the door to multiple research paths. Specifically, the results presented in this thesis stress the importance of determining ways to avoid exerting negative effects in least developed nations via international trade. More research is required to identify, for example, products that can be safely substituted or whose consumption can be discouraged. Valuable insights could be obtained by examining existing programmes, such as Fair Trade and other labelling and certification schemes, as was argued in section 8.3 (page 212). Similarly, further studies are required to assess the specific vulnerability of different countries and regions to changes in the trade flows of particular products.

Due to the heterogeneity that exists between and within countries, a useful approach would be to conduct case studies at different scales (e.g. local communities, cities, regions, etc.) to understand how the livelihoods of the people who labour in particular economic activities could be affected by Northern mitigation-induced reductions in demand. One interesting and relevant case, for instance, would be to analyse how a lower demand for commercial flights could affect the welfare of small nations or small-island states that depend significantly on tourism, and how any negative effects could be averted (see: UNWTO, 2012).

Another possible avenue for future research involves examining the mechanisms to strengthen South-South trade relations and integrate more countries in order to reduce their dependency on the North. Moreover, it is important to determine how the new big emerging players, like China, can avoid adopting the same exploitation patterns followed in the past by industrialised nations (see: Mol, 2011).

In methodological terms, computable general equilibrium models could be used to assess the influence of prices on the demand for imports and the generation of CO_2 emissions derived from the implementation of demand-side mitigation measures or BCAs.

Furthermore, this thesis highlights the need to undertake further efforts to develop more consumption-based indicators for a range of variables, from raw materials and energy to a host of different pollutants. These indicators should complement the traditional territorial or production-based ones so as to attain a broader view of the influence of consumption and thus support informed decision-making. Not doing so could undermine the effectiveness of global climate efforts focused on attaining a sustainable global economy.

9.5. Final remarks

As was expressed in the introductory chapter, this research represents an effort to understand the trade-offs between undertaking climate change mitigation actions in industrialised nations and improving development prospects across developing countries from a demand-side approach. The various results presented in this thesis allow drawing an overarching conclusion. Important trade-offs are involved if the world continues with the current patterns of economic development. However, this assertion does not imply that the implementation of mitigation-induced reductions in demand by Northern economies should be avoided. Like was discussed, it is important to determine how impacts to the developing world derived from these actions can be hampered. On the other hand, it is essential to complement demand-side measures with technology-led mitigation options. A large proportion of emissions are still territorial in nature; that is, these are not embedded in international trade. Hence, efforts should be redoubled to tackle these emissions, particularly those arising from energy demand. This would allow lessening the impacts on Southern countries caused by lower trade flows. One other message contained in thesis is the impossibility of continuing with the current models of economic development. The non-declining levels of consumption in industrialised nations are unsustainable and the developing world cannot follow this same track. It is urgent to develop alternative development pathways that ensure a fair and equal apportionment of the carbon and development spaces. Doing so within the available timeframe would signify overcoming successfully humanity's biggest challenge.

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Appendix A

A.1. Country classification

A.1.1. Least Developed Countries

Africa (34)

Angola
Benin
Burkina Faso #
Burundi #
Central African Republic #
Chad #
Comoros *
Democratic Republic of the Congo
Djibouti
Equatorial Guinea
Eritrea
Ethiopia #
Gambia
Guinea
Guinea-Bissau *
Lesotho #
Liberia
Madagascar
Malawi #
Mali #
Mauritania
Mozambique
Niger #
Rwanda #
São Tomé and Príncipe *
Senegal
Sierra Leone
Somalia
South Sudan
Sudan
Togo
Uganda #
United Republic of Tanzania
Zambia #

Asia (14)

Afghanistan #
Bangladesh
Bhutan #
Cambodia
Kiribati *
Lao People's Democratic Republic #
Myanmar
Nepal #
Samoa *
Solomon Islands *
Timor-Leste *
Tuvalu *
Vanuatu *
Yemen

America (1)

Haiti *

* Also a Small Island Developing State

Also a Landlocked Developing Country

A.1.2. Classification by level of development (UNDP)

Ordered according to 2013 HDI rankings:

Very high human development

1	Norway
2	Australia
3	United States
4	Netherlands
5	Germany
6	New Zealand
7	Ireland
7	Sweden
9	Switzerland
10	Japan
11	Canada
12	Korea (Republic of)
13	Hong Kong, China (SAR)
13	Iceland
15	Denmark
16	Israel
17	Belgium
18	Austria
18	Singapore
20	France
21	Finland
21	Slovenia
23	Spain
24	Liechtenstein
25	Italy
26	Luxembourg
26	United Kingdom
28	Czech Republic
29	Greece
30	Brunei Darussalam
31	Cyprus
32	Malta
33	Andorra
33	Estonia
35	Slovakia
36	Qatar
37	Hungary
38	Barbados
39	Poland
40	Chile
41	Lithuania
41	United Arab Emirates
43	Portugal
44	Latvia
45	Argentina
46	Seychelles
47	Croatia

High human development

48	Bahrain
49	Bahamas
50	Belarus
51	Uruguay

52	Montenegro	72	Lebanon
52	Palau	72	Saint Kitts and Nevis
54	Kuwait	76	Iran (Islamic Republic of)
55	Russian Federation	77	Peru
56	Romania	78	The former Yugoslav Republic of Macedonia
57	Bulgaria	78	Ukraine
57	Saudi Arabia	80	Mauritius
59	Cuba	81	Bosnia and Herzegovina
59	Panama	82	Azerbaijan
61	Mexico	83	Saint Vincent and the Grenadines
62	Costa Rica	84	Oman
63	Grenada	85	Brazil
64	Libya	85	Jamaica
64	Malaysia	87	Armenia
64	Serbia	88	Saint Lucia
67	Antigua and Barbuda	89	Ecuador
67	Trinidad and Tobago	90	Turkey
69	Kazakhstan	91	Colombia
70	Albania	92	Sri Lanka
71	Venezuela (Bolivarian Republic of)	93	Algeria
72	Dominica	94	Tunisia
72	Georgia		

Medium human development

95	Tonga	106	Gabon
96	Belize	107	El Salvador
96	Dominican Republic	108	Bolivia (Plurinational State of)
96	Fiji	108	Mongolia
96	Samoa	110	Occupied Palestinian Territory
100	Jordan	111	Paraguay
101	China	112	Egypt
102	Turkmenistan	113	Moldova (Republic of)
103	Thailand	114	Philippines
104	Maldives	114	Uzbekistan
105	Suriname	116	Syrian Arab Republic

117 Micronesia (Federated States of)
118 Guyana
119 Botswana
120 Honduras
121 Indonesia
121 Kiribati
121 South Africa
124 Vanuatu
125 Kyrgyzstan
125 Tajikistan
127 Viet Nam
128 Namibia
129 Nicaragua
130 Morocco
131 Iraq
132 Cape Verde
133 Guatemala
134 Timor-Leste
135 Ghana
136 Equatorial Guinea
136 India
138 Cambodia
138 Lao People's Democratic Republic
140 Bhutan
141 Swaziland

Low human development

142 Congo
143 Solomon Islands
144 São Tomé and Príncipe
145 Kenya
146 Bangladesh
146 Pakistan
148 Angola
149 Myanmar
150 Cameroon
151 Madagascar
152 Tanzania (United Republic of)
153 Nigeria
154 Senegal
155 Mauritania
156 Papua New Guinea
157 Nepal
158 Lesotho
159 Togo
160 Yemen
161 Haiti
161 Uganda
163 Zambia
164 Djibouti
165 Gambia
166 Benin
167 Rwanda
168 Côte d'Ivoire
169 Comoros
170 Malawi
171 Sudan
172 Zimbabwe
173 Ethiopia
174 Liberia
175 Afghanistan
176 Guinea-Bissau
177 Sierra Leone
178 Burundi
178 Guinea
180 Central African Republic
181 Eritrea

182	Mali
183	Burkina Faso
184	Chad
185	Mozambique
186	Congo (Democratic Republic of the)
186	Niger

A.1.3. Classification by level of income (World Bank)

Low-income economies ($1,025 or less)

Afghanistan
Bangladesh
Benin
Burkina Faso
Burundi
Cambodia
Central African Republic
Chad
Comoros
Congo, Dem. Rep
Eritrea
Ethiopia
Gambia, The
Guinea
Guinea-Bisau
Haiti
Kenya
Korea, Dem Rep.
Kyrgyz Republic
Liberia
Madagascar
Malawi
Mali
Mauritania
Mozambique
Myanmar
Nepal
Niger
Rwanda
Sierra Leone
Somalia
Tajikistan
Tanzania
Togo
Uganda
Zimbabwe

Lower-middle-income economies ($1,026 to $4,035)

Albania
Armenia
Belize
Bhutan
Bolivia
Cameroon
Cape Verde
Congo, Rep.
Côte d'Ivoire
Djibouti
Egypt, Arab Rep.
El Salvador
Fiji
Georgia

Ghana
Guatemala
Guyana
Honduras
India
Indonesia
Iraq
Kiribati
Kosovo
Lao PDR
Lesotho
Marshall Islands
Micronesia, Fed. Sts.
Moldova
Mongolia
Morocco
Nicaragua
Nigeria
Pakistan
Papua New Guinea
Paraguay
Philippines
Samoa
São Tomé and Principe
Senegal
Solomon Islands
South Sudan
Sri Lanka
Sudan
Swaziland
Syrian Arab Republic
Timor-Leste
Tonga
Ukraine
Uzbekistan
Vanuatu
Vietnam
West Bank and Gaza
Yemen, Rep.
Zambia

Upper-middle-income economies ($4,036 to $12,475)

Algeria
American Samoa
Angola
Antigua and Barbuda
Argentina
Azerbaijan
Belarus
Bosnia and Herzegovina
Botswana
Brazil
Bulgaria
Chile
China
Colombia
Costa Rica
Cuba
Dominica
Dominican Republic
Ecuador
Gabon
Grenada
Iran, Islamic Rep.
Jamaica
Jordan
Kazakhstan
Latvia
Lebanon
Libya

Lithuania
Macedonia, FYR
Malaysia
Maldives
Mauritius
Mexico
Montenegro
Namibia
Palau
Panama
Peru
Romania
Russian Federation
Serbia
Seychelles
South Africa
St. Lucia
St. Vincent and the Grenadines
Suriname
Thailand
Tunisia
Turkey
Turkmenistan
Tuvalu
Uruguay
Venezuela, RB

High-income economies ($12,476 or more)

Andorra
Aruba
Australia
Austria
Bahamas
Bahrain
Barbados
Belgium
Bermuda
Brunei Darussalam
Canada
Cayman Islands
Channel Islands
Croatia
Curaçao
Cyprus
Czech Republic
Denmark
Equatorial Guinea
Estonia
Faeroe Islands
Finland
France
French Polynesia
Germany
Greece
Greenland
Guam
Hong Kong SAR, China
Hungary
Iceland
Ireland
Isle of Man
Israel
Italy
Japan
Korea, Republic of
Kuwait
Liechtenstein
Luxembourg
Macao SAR, China
Malta

Monaco
Netherlands
New Caledonia
New Zealand
Northern Mariana Islands
Norway
Oman
Poland
Portugal
Puerto Rico
Qatar
San Marino
Saudi Arabia
Singapore
Saint Maarten
Slovak Republic
Slovenia
Spain
St. Kitts and Nevis
St. Martin
Sweden
Switzerland
Trinidad and Tobago
Turks and Caicos Islands
United Arab Emirates
United Kingdom
United States
Virgin Islands (U.S.)

A.1.4. Annex I Countries

Australia
Austria
Belarus *
Belgium
Bulgaria *
Canada **
Croatia *
Cyprus
Czech Republic *
Denmark
Estonia *
Finland
France
Germany
Greece
Hungary *
Iceland
Ireland
Italy
Japan **
Latvia *
Liechtenstein
Lithuania *
Luxembourg
Malta
Monaco
Netherlands
New Zealand **
Norway
Poland *
Portugal
Romania *
Russian Federation *, **
Slovakia *
Slovenia *
Spain
Sweden
Switzerland
Turkey ***
Ukraine *

United Kingdom of Great Britain and Northern Ireland
United States of America ***

(*) Economies in transition
(**) Countries that will no longer be listed as Annex B for the period 2013-2020, as they will not adopt binding targets
(***) Countries not listed as Annex B

Kazakhstan is an Annex B country not listed as Annex I.

A.2. GTAP 8 classification

A.2.1. GTAP regions

1. Australia
2. New Zealand
3. Rest of Oceania: American Samoa, Cook Islands, Fiji, Federated States of Micronesia, Guam, Kiribati, Marshall Islands, Northern Mariana Islands, New Caledonia, Niue, Nauru, Palau, Papua New Guinea, French Polynesia, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna, Samoa, Pitcairn, United States Minor Outlying Islands.
4. China
5. Hong Kong
6. Japan
7. Korea Republic of
8. Mongolia
9. Taiwan
10. Rest of East Asia: Macao, Democratic People’s Republic of Korea
11. Cambodia
12. Indonesia
13. Lao People's Democratic Republic
14. Malaysia
15. Philippines
16. Singapore
17. Thailand
18. Viet Nam
19. Rest of Southeast Asia: Brunei Darussalam, Myanmar, Timor Leste
20. Bangladesh
21. India
22. Nepal
23. Pakistan
24. Sri Lanka
25. Rest of South Asia: Afghanistan, Bhutan, Maldives
26. Canada
27. United States of America
28. México
29. Rest of North America: Bermuda, Greenland, Saint Pierre and Miquelon
30. Argentina
31. Plurinational Republic of Bolivia
32. Brazil
33. Chile
34. Colombia
35. Ecuador
36. Paraguay
37. Peru

38. Uruguay
39. Venezuela
40. Rest of South America: Falkland Islands (Malvinas), French Guiana, Guyana, Suriname, South Georgia and the South Sandwich Islands
41. Costa Rica
42. Guatemala
43. Honduras
44. Nicaragua
45. Panamá
46. El Salvador
47. Rest of Central America: Belize
48. Caribbean: Aruba, Anguilla, Netherlands Antilles, Antigua & Barbuda, Bahamas, Barbados, Cuba, Cayman Islands, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Montserrat, Puerto Rico, Turks and Caicos Islands, Trinidad and Tobago, Saint Vincent and the Grenadines, Virgin Islands British, Virgin Islands US
49. Austria
50. Belgium
51. Cyprus
52. Czech Republic
53. Denmark
54. Estonia
55. Finland, Aland Islands
56. France, Guadeloupe, Martinique, Reunion
57. Germany
58. Greece
59. Hungary
60. Ireland
61. Italy
62. Latvia
63. Lithuania
64. Luxembourg
65. Malta
66. Netherlands
67. Poland
68. Portugal
69. Slovakia
70. Slovenia
71. Spain
72. Sweden
73. United Kingdom
74. Switzerland
75. Norway, Svalbard and Jan Mayen
76. Rest of EFTA: Iceland, Liechtenstein
77. Albania
78. Bulgaria
79. Belarus
80. Croatia
81. Romania
82. Russian Federation
83. Ukraine
84. Rest of Eastern Europe: Republic of Moldova
85. Rest of Europe: Andorra, Bosnia and Herzegovina, Faroe Islands, Gibraltar, Monaco, the Former Yugoslav Republic of Macedonia, San Marino, Serbia, Guernsey, Isle of Man, Jersey, Montenegro, Holy See (Vatican City State)
86. Kazakhstan
87. Kyrgyzstan
88. Rest of Former Soviet Union: Tajikistan, Turkmenistan, Uzbekistan
89. Armenia

90. Azerbaijan
91. Georgia
92. Bahrain
93. Islamic Republic of Iran
94. Israel
95. Kuwait
96. Oman
97. Qatar
98. Saudi Arabia
99. Turkey
100. United Arab Emirates
101. Rest of Western Asia: Iraq, Jordan, Lebanon, Occupied Palestinian Territory, Syrian Arab Republic, Yemen
102. Egypt
103. Morocco
104. Tunisia
105. Rest of North Africa: Algeria, Libyan Arab Jamahiriya, Western Sahara
106. Cameroon
107. Cote d'Ivoire
108. Ghana
109. Nigeria
110. Senegal
111. Rest of Western Africa: Benin, Burkina Faso, Cape Verde, Guinea, Gambia, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Saint Helena, Ascension and Tristan Da Cunha, Sierra Leone, Togo
112. Central Africa: Central African Republic, Congo, Gabon, Equatorial Guinea, Sao Tome and Principe, Chad
113. South Central Africa: Angola, the Democratic Republic of the Congo
114. Ethiopia
115. Kenya
116. Madagascar
117. Malawi
118. Mauritius
119. Mozambique
120. United Republic of Tanzania
121. Uganda
122. Zambia
123. Zimbabwe
124. Rest of Eastern Africa: Burundi, Comoros, Djibouti, Eritrea, Mayotte, Rwanda, Sudan, Somalia, Seychelles
125. Botswana
126. Namibia
127. South Africa
128. Rest of South African Customs Union: Lesotho, Swaziland
129. Rest of the World: Antarctica French Southern Territories, Bouvet Island, British Indian Ocean Territory

A.2.2. GTAP sectoral classification

1. Paddy rice
2. Wheat
3. Cereal grains NEC
4. Vegetables, fruit, nuts
5. Oil seeds
6. Sugar cane, sugar beet
7. Plant-based fibres
8. Crops NEC
9. Cattle, sheep, goats, horses
10. Animal products NEC

11. Raw milk
12. Wool, silk-worm cocoons
13. Forestry
14. Fishing
15. Coal
16. Oil
17. Gas
18. Minerals NEC
19. Meat: cattle, sheep, goats, horse
20. Meat products NEC
21. Vegetable oils and fats
22. Dairy products
23. Processed rice
24. Sugar
25. Food products NEC
26. Beverages and tobacco products
27. Textiles
28. Wearing apparel
29. Leather products
30. Wood products
31. Paper products, publishing
32. Petroleum, coal products
33. Chemical, rubber, plastic products
34. Mineral products NEC
35. Ferrous metals
36. Metals NEC
37. Metal products
38. Motor vehicles and parts
39. Transport equipment NEC
40. Electronic equipment
41. Machinery and equipment NEC
42. Manufactures NEC
43. Electricity
44. Gas manufacture, distribution
45. Water
46. Construction
47. Trade
48. Transport NEC
49. Sea transport
50. Air transport
51. Communication
52. Financial services NEC
53. Insurance
54. Business services NEC
55. Recreation and other services
56. Public Administration and Defence, Health, Education
57. Dwellings

NEC: Not elsewhere classified

A.2.3. Sectoral classification used in chapter 5

1. Agriculture, hunting, forestry and fishing: paddy rice, wheat, cereal grains NEC, vegetables, fruit, nuts, oil seeds, sugar cane, sugar beet, plant-based fibres, crops NEC, cattle, sheep, goats, horses, animal products NEC, raw milk, wool, silk-worm cocoons, forestry, fishing.
2. Mining and quarrying: coal, oil, gas, minerals NEC.
3. Light industry: meat (cattle, sheep, goats, horse), meat products NEC, vegetable oils and fats, dairy products, processed rice, sugar, food products NEC, beverages and

tobacco products, textiles, wearing apparel, leather products, wood products, paper products, publishing.

4. Heavy industry: petroleum, coal products, chemical, rubber, plastic products, mineral products NEC, ferrous metals, metals NEC, metal products, motor vehicles and parts, transport equipment NEC, electronic equipment, machinery and equipment NEC, manufactures NEC.

5. Electricity, gas and water supply: electricity, gas manufacture, distribution, water

6. Construction

7. Trade

8. Transport and communications: transport NEC, sea transport, air transport, communication

9. Services: financial services NEC, insurance, business services NEC, recreation and other services, public administration and defence, health, education, dwellings.

A.2.4. Country and sectoral classification used in chapter 6

Countries under the BCA scheme (shown according to GTAP number):

(1) Australia
(2) New Zealand
(6) Japan
(26) Canada
(27) United States of America
(49) Austria
(50) Belgium
(51) Cyprus
(52) Czech Republic
(53) Denmark
(54) Estonia
(55) Finland
(56) France
(57) Germany
(58) Greece
(59) Hungary
(60) Ireland
(61) Italy
(62) Latvia
(63) Lithuania
(64) Luxembourg
(65) Malta
(66) Netherlands
(67) Poland
(68) Portugal
(69) Slovakia
(70) Slovenia
(71) Spain
(72) Sweden
(73) United Kingdom
(74) Switzerland
(75) Norway
(76) Rest of EFTA
(78) Bulgaria
(79) Belarus
(80) Croatia
(81) Romania
(82) Russian Federation

(83) Ukraine

Cyprus and Malta are EU ETS member countries, but are not listed as Annex B parties.

Sectors covered by the scheme (shown according to GTAP number):

(12) Wool, silk-worm cocoons
(13) Forestry
(15) Coal
(16) Oil
(17) Gas
(18) Minerals NEC
(21) Vegetable oils and fats
(22) Dairy products
(24) Sugar
(26) Beverages and tobacco products
(27) Textiles
(28) Wearing apparel
(29) Leather products
(30) Wood products
(31) Paper products, publishing
(32) Petroleum, coal products
(33) Chemical, rubber, plastic products
(34) Mineral products NEC
(35) Ferrous metals
(36) Metals NEC
(37) Metal products
(38) Motor vehicles and parts
(39) Transport equipment NEC
(40) Electronic equipment
(41) Machinery and equipment NEC
(42) Manufactures NEC
(43)Electricity

Sectors 31 to 36 are considered as trade-exposed sectors.

Appendix B

B.1. Supplementary information

B.1.1. Additional information for Chapter 4

List of countries excluded from the carbon EKC analysis:

Namibia (126)
Rest of Central Africa (112)
Rest of Eastern Africa (124)
Rest of North America (29)
Rest of South Asia (25)
Rest of Southeast Asia (19)
Rest of the World (129)
Taiwan (9)
Zimbabwe (123)

GTAP region ID number is noted in parenthesis.

B.1.2. Additional information for Chapter 7

The Human Development Index

The HDI is a composite indicator that envelops three basic dimensions of human development: life expectancy, education attainment and income per capita. These dimensions are measured by the following variables:

- Life expectancy at birth (years)
- Mean years of schooling
- Expected years of schooling
- Gross National Income (GNI) per capita (PPP $)

Each of these sub-indices is normalised according to a min-max procedure:

$$I_i = \frac{\text{actual value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}} \quad (32)$$

Since two indicators are used for education, a combined education index is constructed. The HDI is then calculated as the geometric mean of normalised indices from each of these three dimensions.

$$HDI = \sqrt[3]{I_{health} * I_{education} * I_{income}} \quad (33)$$

For a full explanation of the method, see: Klugman et al. (2011).

Tables

The table below presents descriptive statistics for the main variables used in HDI analysis:

Table 32 - Descriptive statistics for the analysis undertaken in Chapter 7.

Statistic	HDI	T CO_2	C CO_2	T CO_2 pc	C CO_2 pc	Population	RCP3-PD	RCP3-PD pc	SSP1
World									
Mean	0.61	136,448	200,023	4.54	6.06	33.09	139,961	3.11	46.16
Median	0.64	9,702	36,249	1.72	3.56	7.21	10,621	1.57	10.55
St. Dev.	0.19	550,327	646,664	6.74	7.01	120.55	640,280	4.29	155.32
Minimum	0.18	33	-1,241	0.01	-0.36	0.01	13	0.01	0.15
Maximum	0.95	8,286,139	6,976,284	68.62	56.51	1,318.17	9,124,263	38.03	1,550.00
No. Obs	4,210	4,889	2,625	4,889	2,625	5,240	6,800	6,800	6,800
VHD									
Mean	0.81	276,098	331,030	10.39	12.59	22.64	198,570	6.09	28.17
Median	0.81	53,863	84,509	8.07	10.97	6.47	45,394	4.76	9.29
St. Dev.	0.06	799,392	879,394	8.44	7.33	44.84	611,596	4.77	57.86
Minimum	0.64	84	2,147	1.31	2.09	0.06	426	0.84	0.26
Maximum	0.95	5,828,167	6,282,316	68.62	56.51	310.38	5,692,772	38.03	411.10
No. Obs	1,240	1,311	882	1,311	882	1,395	1,760	1,760	1,760
HID									
Mean	0.68	108,650	135,959	5.78	5.11	22.31	112,926	4.74	29.11
Median	0.69	27,405	51,503	3.33	3.68	8.20	31,471	3.11	9.37
St. Dev.	0.07	240,051	239,804	6.54	4.99	36.56	209,020	5.22	44.80
Minimum	0.44	37	-1,241	0.20	-0.36	0.01	843	0.28	0.35
Maximum	0.80	2,139,526	1,974,069	37.78	30.25	194.95	1,712,050	36.43	218.00
No. Obs	904	1,049	672	1,049	672	1,209	1,520	1,520	1,520
MED									
Mean	0.57	153,032	220,471	1.79	1.97	69.63	240,182	1.65	88.30
Median	0.57	4,633	10,962	1.10	1.41	5.21	4,930	1.07	6.96
St. Dev.	0.08	669,651	751,401	1.89	1.55	232.79	1,080,461	1.68	291.04
Minimum	0.34	33	7	0.04	0.01	0.09	16	0.04	0.15
Maximum	0.71	8,286,139	6,976,284	10.52	7.50	1,318.17	9,124,263	10.00	1,550.00
No. Obs	985	1,190	609	1,190	609	1,260	1,720	1,720	1,720
LOD									
Mean	0.36	6,755	16,152	0.29	0.36	19.71	9,716	0.20	37.88
Median	0.36	1,346	6,450	0.18	0.28	9.21	1,843	0.12	19.06
St. Dev.	0.08	18,326	27,463	0.29	0.30	30.42	26,519	0.22	54.25
Minimum	0.18	40	132	0.01	0.05	0.09	13	0.01	0.55
Maximum	0.53	161,381	175,558	1.78	2.38	173.59	215,580	1.54	328.60
No. Obs	1,081	1,339	462	1,339	462	1,376	1,800	1,800	1,800
Period	1980-2010	1980-2010	1990-2010	1980-2010	1990-2010	1980-2010	2011-2050	2011-2050	2011-2050

Note: HDI corresponds to the 2013 UNDP's Human Development Index. T CO_2 and C CO_2 correspond to territorial and consumption emissions, respectively, expressed in thousand tonnes of CO_2 per year. The acronym "pc" refers to per capita. Population is expressed in millions. RCP3-PD corresponds to projections for yearly CO_2 emissions from 2011 to 2050 (thousand tonnes) compatible with a 2°C target. SSP1 corresponds to the projected population figures under the IPCC sustainable scenario (2011-2050).
Source: Own table based on data by CDIAC (2013), IIASA (2012), Peters et al. (2011b), UNDP (2013) and UNSD (2013a)

Table 33, presented below, shows the results from the Westerlund's cointegration tests for the saturated and unbounded specifications in relation to territorial and consumption emissions. As can be appreciated, the results indicate that the variables used in the analysis are not cointegrated.

Table 33 - Westerlund's cointegration tests according to functional specification and type of emissions

Statistic	Territorial		Consumption	
	Saturated	Unbounded	Saturated	Unbounded
Pt	9.58***	9.06***	5.55***	5.88***
Pa	6.78***	7.25***	5.15***	4.45***

Note: Reported Z-values. Tested with an average of 2 lags, based on AIC with a constant. *** Null hypothesis of no cointegration accepted at a 0.01 level

The results from the regressions based on a dataset that encompasses territorial and consumption emissions are presented in Chapter 7. Table 34, situated below, contains the estimated parameters using the longer dataset of territorial emissions. Table 35, on the other hand, shows the results from the regressions that include a dynamic saturation term.

Table 34 - Prais-Winsten regression between HDI and territoral per capita emissions (1980-2010) according to functional specification

Region	Coefficient	Territorial	
		Saturated	Unbounded
Global	**β**	-0.23*** (-30.72)	0.18*** (56.30)
	A	-1.11*** (-34.23)	-0.41*** (-30.15)
	R^2	0.71	0.77
Very high human development	**β**	-0.17*** (-26.30)	0.05*** (20.15)
	A	-1.35*** (-29.57)	-0.25*** (-18.72)
	R^2	0.78	0.77
High human development	**β**	-0.07*** (-16.91)	0.04*** (12.55)
	A	-1.01*** (-34.20)	-0.39*** (-25.17)
	R^2	0.89	0.82
Medium human development	**β**	-0.08*** (-32.05)	0.07*** (27.90)
	A	-0.83*** (-42.61)	-0.49*** (-35.96)
	R^2	0.94	0.92
Low human development	**β**	-0.06*** (-44.88)	0.13*** (23.72)
	A	-0.56*** (-37.55)	-0.66*** (-41.37)
	R^2	0.82	0.91

Note: Dependent variable: log of HDI. T-stats are shown in parentheses. *** Significant at a 0.01 level.

Table 35 - Prais-Winsten regression between HDI and territoral per capita emissions (1980-2010) using a dynamic saturation term

Region	Coefficient	Territorial Saturated
Global	β	-0.07*** (-10.93)
	A	-1.81*** (-85.12)
	R^2	0.92
Very high human development	β	-0.21*** (-29.58)
	A	-1.57*** (-169.75)
	R^2	0.97
High human development	β	-0.16*** (-45.20)
	A	-1.92*** (-110.32)
	R^2	0.95
Medium human development	β	-0.18*** (-24.65)
	A	-1.87*** (-42.18)
	R^2	0.95
Low human development	β	-0.25*** (-40.64)
	A	-2.47*** (-60.32)
	R^2	0.88
Note: Dependent variable: log of HDI. T-stats are shown in parentheses. *** Significant at a 0.01 level.		

A number of countries had to be excluded from the analysis due to insufficient observations for CO_2 emissions or HDI values. In relation to the dataset that includes consumption-based emissions, the excluded countries and regions are:

- Taiwan
- Rest of East Asia
- Rest of North America
- Rest of the World

With regards to the longer dataset of territorial emissions, the following nations were excluded:

- Andorra
- Antigua and Barbuda
- Azerbaijan
- Bahamas
- Bhutan
- Eritrea
- Grenada
- Kiribati
- Liechtenstein
- Micronesia (Federated States of)
- Occupied Palestinian Territory
- Oman
- Saint Kitts and Nevis

- Saint Lucia
- Saint Vincent and the Grenadines
- Turkmenistan
- Vanuatu