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The Environmental Kuznets Curve: Examining the relationship between income and technology-adjusted consumption-based CO_2 emissions

by

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Abstract:
This study aims to investigate whether countries succeed to reduce their contribution to global emissions when countries reach higher levels of income. As a result of rapid changes in international trade, a country's emission responsibility goes beyond national borders, which should be adequately captured in their carbon footprint. This study discusses that the two conventional accounting measures (production-based and consumption-based emissions) do not adequately reflect how countries contribute to global emissions. Therefore, to examine a country's global environmental impact, technology-adjusted consumption-based CO_2 emissions are considered for the first time to estimate the Environmental Kuznets Curve (EKC) relationship. In addition, this study tests the robustness of the previous found relations based on production and consumption-based emissions. In total, this study considers a sample of 38 countries for the time period of 1995-2009. The results for production-based emissions indicate support for the EKC, while there is a monotonically increasing relationship between income and consumption-based emissions. The main finding of this thesis is an increasing relationship between income and technology-adjusted consumption-based emissions with a turning point of $72767.5, which falls beyond the maximum level of income in the sample. This is worrisome for lowering global emissions in the upcoming decades, which is necessary to achieve sustainable development.
Key words: Environmental Kuznets Curve, CO_2 emissions, Technology-adjustment

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Figures and Tables

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List of abbreviations

CBA	Consumption-based Accounting
CO_2	Carbon Dioxide
EA	Environmental Accounts
EKC	Environmental Kuznets Curve
EU	European Union
GVC	Global Value Chain
GHG	Greenhouse Gasses
IPCC	Intergovernmental Panel on Climate Change
MRIO	Multi Regional Input-Output
Mt	Metric tons
PBA	Production-based Accounting
PHH	Pollution Haven Hypothesis
OLS	Ordinary Least Squares
SO_2	Sulphur Dioxide
RoW	Rest of the World
TBEET	Technology-adjusted Balance of Emissions Embodied in Trade
TCBA	Technology-adjusted Consumption-based Accounting
WIOD	World Input-Output Database
WIOT	World Input-Output Tables

1. Introduction

Climate change and the threats of rising temperatures for global living conditions are among the most pressing challenges of the upcoming decades (Steffen et al., 2011; Johnson et al., 2017). The risks of global warming emphasize that 'business as usual' cannot persist and demand societies to commit to lowering global Greenhouse gas (GHG) emissions in order to achieve sustainable development. One step in this direction was made with a large part of the world signing the Paris Agreement in 2015 and thereby the commitment of countries to keep global warming below 2 degrees Celsius. More recently, the climate strikes by students all over the world, initiated by Swedish activist Greta Thunberg, are another sign of public concern about the consequences of climate change and pushes political leaders to take action (Milman, 2019). Besides the urge for effective climate policies, there also exists the need to further understand the potential causes of global warming (Dinda, 2004). The effects of economic growth received substantial attention over the past decades, which created a large scholarly discussion about the relationship between economic development and environmental impact. A large part of this literature claims that a country's environmental impact first increases when countries develop as a result of industrialization and the expansion in output, but this impact diminishes when countries reach a certain threshold level of income (Dinda, 2004). The reduction in impact can be explained by factors that are associated with higher income including cleaner production technologies, structural change into services and more demand for environmental quality (Dinda, 2004; Kaika and Zervas, 2013a). This systematic relationship is also referred to as the Environmental Kuznets Curve (EKC), which displays an inverted-U relationship between income and environmental impact.

Grossman and Krueger (1991) were among the first ones that found support for the EKC, which created the notion of *decoupling*, meaning that countries could lower their environmental impact without limiting economic growth. In an overview paper, Kaika and Zervas (2013a) show that there have been various studies that have investigated this relationship and have found empirical evidence for the EKC. However, the EKC relationship also has been criticized over the past decades. One of the criticisms highlights that most studies apply production-based emission accounting (PBA), which ignores the effects of international trade and thereby the emissions generated in the production of imported products (Mir and Storm, 2016). Over the past decades, there have been rapid changes in international trade, which led to global fragmentation of production activities and thereby the distribution of emission responsibility between countries (Wiedmann et al., 2015; Hoekstra et al., 2016).

Several studies highlight that developing countries are increasingly generating emissions for the production of goods that are consumed in the developed world and interpret the downward part of the EKC curve as developed countries outsourcing their pollution-intensive production (Peters et al., 2011; Mir and Storm, 2016). This becomes problematic for lowering global emissions if developed countries continue to consume similar products, which are not reflected in their PBA emissions given that these products are imported. To deal with this issue, several studies propose to estimate the EKC relationship with consumption-based accounting (CBA) emissions, which makes countries responsible for the emissions embodied in their imports (e.g. Mir and Storm, 2016; Makarov, 2018). As a result, CBA captures global emissions that have been generated to meet a country's total consumption (Peters and Hertwich, 2008a), and therefore could provide an indication of how a country contributes to global emissions. Most studies that apply CBA find evidence of an inverted-U shape between income and consumption-based emissions, but the turning point after which emissions are expected to decrease falls beyond the maximum level of income in the sample. This implies that within their sample, there is an increasing relationship between income and CBA emissions, which subsequently can be interpreted that a country's global environmental impact continues to increase and only starts to decrease at very high levels of income.

However, Kander et al. (2015) argue that CBA might not be an adequate indicator of a country's global environmental impact either since it does not consider how a country's exports influence global emissions. In addition, this accounting measure is not responsive to changes in the carbon efficiency of exports, which leaves out important policy options for countries to reduce their carbon footprint. In fact, with CBA, countries could be punished with higher emissions when countries are more carbon efficient than their trading partners even when their exports lead to a reduction in emissions abroad (Jakob and Marschinski, 2013; Kander et al., 2015). As a result of these subsequent issues, Kander et al. (2015) propose an alternative: technology-adjusted consumption-based accounting (TCBA), to provide a more accurate picture of a country's contribution to global emissions. This measure tries to illustrate how a country's exports influence global emissions and makes countries responsible for their consumption together with their production technologies in exports, which also gives countries more policy options to reduce their impact. In addition, with TCBA, countries are being credited with lower emissions if countries produce more efficient than the world average production technology (Kander et al., 2015; Domingos et al., 2016).

This study considers the TCBA as an alternative measure to test the EKC relationship to provide insights whether countries reduce their contribution to global emissions when they reach higher levels of income. This is relevant since one does not only want to know whether a country reduces its national emissions when reaching higher stages of development, but also whether a country reduces its global environmental impact, which is important to achieve sustainable development. Therefore, this study aims to investigate the relationship between income levels and a country's contribution to global emissions by assessing the EKC relationship with technology-adjusted consumption-based CO_2 emissions for the first time. More specifically, this study poses the following question: do countries succeed to reduce their contribution to global CO_2 emissions when countries reach higher levels of income?

The data used to compose the TCBA is derived from the work of Baumert et al. (2019), which consulted the World Input-Output Database (WIOD) Release 2013 to perform an environmentally extended input-output analysis. This paper also provides data for production-based and consumption-based emissions, which are used in the analysis to test for the robustness of the earlier found results of previous studies. In total, this analysis includes 38 countries and investigates the time period of 1995-2009.

The results of the empirical analysis of this study provide support for the EKC relationship when applying production-based emissions. The income turning point after which emissions are expected to decline is $32982.2, which falls within the sample range of countries included in the analysis. After the inclusion of the emissions embodied in a country's imports, there is no longer evidence of the EKC and instead income and consumption-based emissions display a monotonically increasing relationship. Subsequently, by making countries responsible for their consumption and production technologies in exports, the estimation with TCBA shows an inverted-U relationship and thereby providing support that countries succeed to reduce their contribution to global emissions when countries continue to develop. However, the turning point of this estimation is $72767.5, which falls beyond the maximum value of income within this sample. This implies that within this sample, TCBA displays an increasing relationship with income and TCBA emissions are only expected to decrease at a very high level of income per capita. This is worrisome for achieving sustainable development since global emissions need to be reduced within short notice. Finally, several robustness tests emphasize the sensitivity of the underlying specification to estimate the EKC relationship and stress the influence of the included sample in the analysis.

This study is in line with other studies that estimate the EKC relationship to investigate whether countries succeed to lower their environmental impact without limiting economic development, which started with the work of Grossman and Krueger (1991). In addition, this study fits with the work of Peters and Hertwich (2008a) and Peters et al. (2011) stating that emission responsibility goes beyond national borders and that countries also influence emissions abroad as a result of a country's consumption. The application of the TCBA to estimate the EKC relation has most overlap with the work of Kander et al. (2015) that introduced the TCBA to provide an improved indication of a country's contribution to global emissions. This measure enables countries to influence their footprint through a wider set of policies, which might explain why there is support for an inverted-U relationship when estimating it with TCBA and not with CBA emissions. Finally, the findings about the sensitivity of the underlying specification to estimate the EKC and the sample dependency are in line with the work of Stern (2004; 2018) and Kijima et al. (2010) who provide a more critical assessment of the EKC relationship.

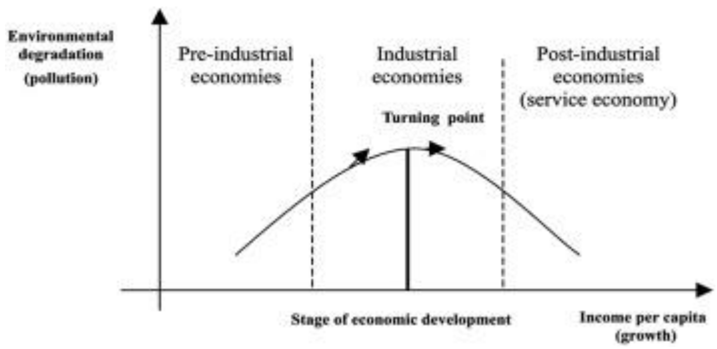
The remainder of this paper proceeds as follows. Section 2 provides a comprehensive overview of the relevant literature. The next section discusses the methodology and the data that is used to estimate the EKC relationship together with an explanation of the underlying calculations of the three different accounting measures. Section 4 performs the empirical analysis and is subsequently followed by the discussion of the results. Finally, in Section 5, this paper concludes by providing insights on the research question and highlights the limitations of this study together with directions for future research.

2. Literature review

2.1 The Environmental Kuznets Curve

The relationship between economic growth and environmental impact has been part of a large scholarly debate over the past three decades. A large part of the literature believes that a country's environmental impact increases with development, but this impact diminishes when countries reach higher levels of income (Dinda, 2004). This relation is often referred to as the Environmental Kuznets Curve (EKC), which received its name after the famous income inequality curve of Simon Kuznets (1955). The EKC, following a similar pattern to the inequality curve, displays an inverted-U relationship between income and environmental quality (Panayotou, 1993; Dinda, 2004). Figure 1 below shows the EKC, where at low levels of income, the environmental impact of a country is small, but when a country develops its environmental impact increases. Subsequently, at high levels of development, countries reach a turning point after which the environmental impact diminishes and is expected not to increase again.

Figure 1: The Environmental Kuznets Curve. Source: Panayotou (1993)



In the literature, various reasons have been suggested to explain how economic growth influences the environment at different stages of development including the demand for environmental quality (Dinda, 2004). When countries are at low levels of development, their demand for environmental quality tends to be low, but when countries grow richer, people obtain a higher standard of living and tend to value environmental quality more (Selden and Song, 1994). As a result, people are more likely to shift towards relatively more sustainable consumption, but also have demand for stricter environmental regulations, which potentially leads to decreasing emission levels (Dinda, 2004). Moreover, the EKC can be explained with the structural composition of the economy (Grossman and Krueger, 1995). When countries are still in agriculture, the environmental impact is low, but when countries industrialize, this impact increases. During industrialization, the environmental impact of a country is especially large since countries aim to increase their output, which subsequently requires more inputs, more natural resources, generates more waste and leads to higher energy consumption together with increased CO_2 emissions (Stern, 2004; Dinda, 2004; Carson, 2009). However, when income continues to increase, countries move from energy-intensive industries towards the service sector, which is assumed to be less energy-intensive and therefore this structural shift could have a positive effect on the environment (Henriques and Kander, 2010). Finally, another proposed explanation for the EKC highlights that richer nations have more financial resources, skills and knowledge (Dinda, 2004). As a result, richer countries are more likely to invest in cleaner production technologies that can enhance environmental quality. In sum, the EKC shows that economic development over time can lead to a lower environmental impact, but is dependent on underlying income mechanisms as for example structural change, demand for environmental quality and investments in clean technologies.

Grossman and Krueger (1991) were among the first ones to find support for the EKC by investigating the relationship between GDP per capita and different environmental indicators including lack of clean water, municipal waste and sulfur oxides. This created the notion of decoupling, namely that countries can reduce their environmental impact without limiting economic growth. Their work was followed by studies of Shafik and Bandyopadhyah (1992) and Selden and Song (1994) that also supported the inverted-U relationship. These early studies created momentum for the EKC and stimulated interest to further examine the EKC hypothesis (Kaika and Zervas, 2013a). In an overview paper, Kaika and Zervas (2013a) show that there have been various studies that have investigated this relationship and have found empirical evidence for the EKC. Most studies used panel data to estimate the relationship between environmental impact and income as the independent variable, which is often measured in GDP per capita. Studies considered different environmental indicators, which were mainly air quality indicators including CO_2 emissions (e.g. Galeotti et al., 2006; Acaravci and Ozturk, 2010; Narayan and Narayan, 2010; Apergis and Ozturk, 2015). In addition, different samples of countries were included in the empirical analysis varying from European, developing, Asian to individual countries (e.g. Narayan and Narayan, 2010; Acaravci and Ozturk, 2010; Apergis and Ozturk, 2015). These studies, based on different country samples and environmental indicators, find evidence that supports the EKC relationship and thereby highlight that countries succeed to lower their environmental impact when they reach high levels of income.

However, besides the support, the EKC also received substantial critical remarks over the past decades. One critique highlights that the empirical evidence for the EKC remains mixed and depends on the sample of countries and time period examined (Kijima et al., 2010; Stern, 2018). Moreover, the EKC is only found for certain types of (local) environmental indicators and it is argued that carbon emissions instead display an increasing relationship with income (Arrow et al., 1995; Kaika and Zervas, 2013a; Stern, 2018). This can be explained by carbon emissions not being a local environmental indicator, but instead influence the environment on a global scale (Kaika and Zervas, 2013a). In addition, some studies find support for the EKC at extreme turning points that fall beyond the maximum level of income in the sample, which makes it questionable whether countries actually succeed to lower their emissions (Kaika and Zervas, 2013b). Thus, in cases where the turning point falls beyond the maximum value of income in the sample, the relationship is often interpreted as monotonically increasing for the considered sample as these countries have not reached this level of income yet (Stern and Common, 2001). Another strand of critique deals with the econometric issues underlying the estimation of the EKC relationship. Most studies estimate the EKC with a simple Ordinary Least Squares (OLS) regression, which makes the causality of this relation challenging to interpret (Stern, 2004). As an alternative model, fixed effects models are used to estimate the EKC, which controls for unobserved heterogeneity between countries. However, by applying fixed effects, the estimated variables are restrictive to the countries and time period considered in the sample (Stern, 2004; Stern, 2018). In other words, this means that studies that use fixed effects are only able to draw conclusions about the sample as a whole and cannot say something about individual country experiences, which might be relevant to understand the underlying EKC mechanisms (Wagner, 2010). Furthermore, studies often do not test or deal with integration of variables, stationarity and heteroscedasticity, which might influence the found results (Stern, 2004; Bagliani et al., 2008). Finally, a frequently highlighted concern deals with the potential of an omitted variable bias when estimating the EKC relation and requires the inclusion of subsequent control variables as for example energy consumption or availability of renewables (Stern, 2004; Bilgili et al., 2016; Stern, 2018). Another factor that is often not considered in the EKC analysis is the effect of international trade (Stern, 2018). Several scholars highlight that the reduction of emissions, that is observed for some developed countries, actually reflects a pattern of outsourcing pollution-intensive production to developing countries driven by lower labor costs and less stringent regulations in these latter countries (Cole, 2004; Kaika and Zervas, 2013a; Hoekstra et al., 2016). This might imply that developed countries have only reduced their environmental impact because of relocating production, which could become problematic for lowering global emissions if these countries continue to consume the same goods (Ekins, 1997; Rothman, 1998; Cole, 2004). Altogether, there is empirical support for the EKC, but the relationship is dependent on the underlying specification and studies do not always include other explanatory variables in their analysis, including international trade, that potentially influence the EKC relation.

2.2 International trade and the EKC

The effect of international trade is important to consider when analyzing the EKC and has received substantial attention over time because of the rapid increase in international trade over the past decades. The expansion in trade is characterized by increased fragmentation of production stages all over the world and the rapid rise of trade in intermediates (Sturgeon and Gereffi, 2009). This caused the emergence of global value chains (GVC's) in which many (developing) countries are actively participating (Milberg and Winkler, 2010). At the same time, the rise in international trade also influenced the distribution of production emissions between countries (Wiedmann et al., 2015). As a result, there has been a shift of emissions responsibility of production from one country to another together with a rise of emissions from the production of traded goods, which are also referred to as emissions embodied in trade (Peters et al., 2011; Hoekstra et al., 2016). These patterns are often understood as a rise of emissions that are generated in the developing world to meet consumption in the developed world (Peters et al., 2011; Karakaya et al., 2019). Some scholars interpret this development as systematic outsourcing of pollution-intensive production to the developing world, while developed countries continue to consume and now import the products they used to produce domestically (Kaika and Zervas, 2013b; Mir and Storm, 2016). This pattern of outsourcing also influences the interpretation of the EKC since this might imply that the downward part of the curve actually represents a pattern of relocating production to the developing world, which therefore does not necessarily lower global emissions (Cole, 2004; Makarov, 2018). In fact, relocation might create more emissions if production technologies in the developing countries are less energy efficient (Rothman, 1998). Furthermore, this relocation pattern is also unlikely to sustain in the long-run since developing countries will no longer have an alternative location where pollution-intensive production can be moved (Stern, 2018). Overall, the increase in international trade together with the argument that countries might have reduced their domestic emissions because of outsourcing provides interests to further investigate the effect of international trade on the EKC.

In general, international trade can have different effects on the environment and could lead to a reduction in pollution as a result of increased competition that may trigger more efficient use of inputs and resources (Bilgili et al., 2016). Moreover, the income effect associated with trade could stimulate the demand for stricter environmental policies and the provision of improved production technologies (Cole, 2004; Dinda, 2004). Trade also allows for the diffusion of ‘cleaner’ technologies to developing countries, which may help to reduce the environmental impact at an earlier stage of development (Bilgili et al., 2016). However, trade specialization also has a large influence on a country’s environmental impact. Following Heckscher Ohlin, trade liberalization allows countries to specialize according to their comparative advantage based on the factor endowment (e.g. labor or capital) that is relatively abundant (Heckscher & Ohlin, 1991; Stern, 1998). As a result, it is expected that, developing countries specialize in labor-intensive activities that are often within (heavy) manufacturing industries and some of these activities are considered as pollution-intensive (e.g. electronics or chemicals), which increases the environmental impact of a country (Dasgupta et al., 2002; Stern, 2004; Cole, 2004). In contrast, developed countries specialize in activities that are treated as less pollution-intensive including light manufacturing and services (Stern et al., 1996; Dasgupta et al., 2002; Dinda, 2004; Cole, 2004).

Several studies have tried to incorporate the effect of international trade when examining the EKC and one of the first ones were Suri and Chapman (1998). They included ratios of imported and exported manufacturing goods over total manufacturing production as additional control variables in their regression. These authors looked at energy use and found a negative effect of the import ratio, which implies that countries that have increased their imports subsequently lowered their domestic production in manufacturing and therefore also reduced their environmental impact. In contrast, the export ratio had a positive effect on energy use, which stresses that participating in international trade and specializing in manufacturing activities increases the environmental impact of a country. In addition, Suri and Chapman (1998) find a higher turning point of the EKC when including the trade variables in their regression. These findings could be interpreted as developing countries specializing in activities that are both labor and pollution intensive, which increases their environmental impact while developed countries have relocated their manufacturing activities and instead import these products, which can help explain the downward pattern of the EKC (Stern, 1998). However, Cole (2004) highlights that this argument requires additional explanation since these specialization patterns based on factor endowments might only partially clarify the reduction in environmental impact for developed countries. Alternatively, Cole (2004) proposes the Pollution Haven Hypothesis (PHH), which entails that differences in environmental policies stimulate the shift of pollution-intensive production activities from developed to developing countries. These latter countries are expected to have less stringent environmental regulations as a result of lower demand for environmental quality, which creates a comparative advantage for developing countries (Cole, 2004; Kaika and Zervas, 2013a; Franzen and Mader, 2018).

In order to test for the PHH, Cole (2004) estimates the EKC relationship, while including the share of pollution-intensive exports to non-OECD countries to total exports and the share of pollution-intensive imports from non-OECD countries to total imports. He argues that in order for the PHH to hold, OECD countries have reduced their share of dirty exports, which caused a reduction in pollution. In addition, the share of dirty imports to total imports has increased for developed countries, which would lead to a reduction in emissions since countries no longer produce these goods, but instead import them from the developing world. In his analysis, Cole (2004) examines 10 different environmental indicators, but only finds a significant effect for both the export and import variable for Sulphur Dioxide (SO_2). Therefore, based on the work of Cole and various other studies, the evidence of the PHH remains mixed and makes it debatable whether the downward part of EKC displays a pattern of relocating pollution-intensive production driven by environmental regulations (Dasgupta et al., 2002; Cole, 2004; Kaika and Zervas, 2013a; Franzen and Mader, 2018). The inconclusive evidence of the PHH might be explained by pollution costs only being a small share of a firm's total costs or that companies do not want to be associated with relocating their production to take advantage of less strict environmental policies (Cole, 2004; Carson, 2009). In addition, the level of industry aggregation might also have influenced the findings of the PHH (Kearsley and Riddel, 2010). These authors also test for the PHH by using disaggregated estimates for pollution-intensive exports and imports, but nevertheless do not find support for this hypothesis. Finally, another potential reason why the evidence of the PHH and international trade in general remains unclear when estimating the EKC is because these studies include environmental indicators based on production-based accounting (PBA) measures instead of consumption-based accounting (CBA) and therefore ignore the emissions embodied in trade (Mir and Storm, 2016).

2.3 Consumption-based accounting and the EKC

Consumption-based emissions could work as an alternative measure to production-based emissions to examine the EKC. The difference between PBA and CBA is that the former includes all territorial emissions, while the latter adds emissions embodied in imports to this and subtracts emissions embodied in exports (Davis and Caldeira, 2010; Kander et al., 2015). As a result, CBA holds a country responsible for the emissions embodied in imported products and services, and thereby considers the emissions that are generated abroad to meet the final consumption of a respective country, which is not included in PBA emissions (Karakaya et al., 2019). Consequently, CBA shifts the emission responsibility from the producing country (PBA) towards the location where final consumption takes place (Peters and Hertwich, 2008b; Boitier, 2012). The consumption-based perspective is important to consider since most EKC studies, climate policies and official carbon accounting reports, including the Intergovernmental Panel on Climate Change (IPCC) guidelines, are based on production-based emissions (Harris and Symons, 2013). As a result, the focus of these studies, policies and reports is on (reducing) national emissions, hereby ignoring the emissions embodied in trade (Boitier, 2012). In fact, one study highlights that developed countries have succeeded to decrease their production-based emissions, but did not achieve such a reduction for consumption-based emissions (Mir and Storm, 2016). This might imply that the global reduction of emissions is limited and it is often assumed that developed countries have only reduced their domestic environmental impact by outsourcing carbon-intensive activities and are now importing them from other parts of the world (Mir and Storm, 2016; Makarov, 2018). This shift of carbon-intensive production from the developed to the developing world, which results in a reduction of production-based emissions for developed countries, is often referred to as carbon leakage (Kander et al., 2015). The presence of carbon leakage would require supplementary climate policies that consider emissions embodied in trade and capture emissions that are generated for consumption, which will ask for international collaboration to reduce global emissions (Karakaya et al., 2019). Finally, several scholars highlight that consumption-based emissions can be used to investigate how a country's consumption influences global production emissions (Li and Hewitt, 2008; Peters and Hertwich, 2008a), which could therefore provide an indication of a country's global environmental impact.

Over the past decades, there has been a rise of studies that consider consumption-based emissions. This increase is potentially a result of data availability provided by input-output tables that allow for obtaining emissions embodied in imports and exports of complete global value chains (Peters et al., 2011; Makarov, 2018). Peters et al. (2011) find that emissions from the production of traded goods have increased from 4.3 Giga ton (Gt) carbon emissions in 1990 to a level of 7.8 Gt in 2008. In addition, these authors show that the net transfer of emissions embodied in trade from the developing to the developed world also rapidly increased in this same time period. These findings are often interpreted as developing countries increasingly generating emissions for the production of goods that are consumed in the developed world. Moreover, for European countries, production-based emissions are lower than consumption-based and the difference between the two has rapidly increased over time (Boitier, 2012). As a result, these European countries have a higher emission responsibility under CBA when compared to PBA after holding countries responsible for the goods they import. The difference between PBA and CBA is also referred to as the balance of emissions embodied in trade, which is negative for most developed countries implying that these countries import more emissions embodied in trade than they export. Several studies consider this trade imbalance for developed countries as evidence of outsourcing of production and highlight that this imbalance has increased as a result of rising imports from the developing world (Karakaya et al., 2019). An opposite pattern is observed for developing countries, which have lower CBA emissions than PBA. Consequently, developed countries are considered as net importers of emissions and developing countries as net exporters (Peters et al., 2011; Boitier, 2012).

As a result of carbon leakage, several scholars question whether the EKC relationship based on production-based emissions is still a relevant framework since the downward part of the EKC curve might reflect a pattern of outsourcing and does not consider the emissions embodied in imports (Mir and Storm, 2016; Karakaya et al., 2019). To deal with these issues, consumption-based emissions have been suggested to estimate the EKC relation. Several studies show that by including consumption-based emissions, there is still support for an inverted-U shape, but the turning point in most cases falls beyond the highest level of GDP per capita in the sample (Mir and Storm, 2016; Schröder and Storm, 2018; Karakaya et al., 2019; Makarov, 2018). For example, Mir and Storm (2016) find a turning point of $113709.0, which is a level of GDP per capita that only a few countries in the world have reached today. This implies that within their sample, there is a monotonically increasing relationship between income and consumption-based emissions since countries have not reached this level of income yet. Additionally, this means that CBA emissions are only expected to decrease at very high levels of income. Based on their findings, the authors highlight that the reduction of

PBA emissions in the developed world is a partial effect of outsourcing carbon-intensive production (Mir and Storm, 2016; Schröder and Storm, 2018; Karakaya et al., 2019). In addition, one study claims that the reduction in environmental impact driven by improved production technologies and environmental regulations for developed countries has been offset by increased demand for pollution-intensive products that increasingly are imported from the developing world (Makarov, 2018). Finally, these studies conclude that there is no longer evidence of decoupling between income levels and consumption-based emissions within their sample (Mir and Storm, 2016; Schröder and Storm, 2018; Karakaya et al., 2019). This can be interpreted that a country's contribution to global emissions increases when countries continue to develop and only decreases at very high levels of income.

However, Kander et al. (2015) argue that consumption-based accounting might not be an adequate indicator of how a nation's policies and actions influence global emissions. These authors highlight that conventional CBA misses how the exports of a country influences global emissions, and only considers the effects of imports. Moreover, Kander et al. (2015) explain that CBA as an accounting measure is not responsive to changes in carbon efficiency in exports sectors since all emissions related to exports fall under the responsibility of final consumers. This implies that CBA fails to meet the sensitivity accounting principle, which indicates that an accounting measure should be responsive to factors a country can influence as for example production technologies or level of consumption. In other words, if a country's production technologies cause a change in global emissions then this should be reflected in a country's carbon footprint, which is not the case under CBA. In addition, CBA holds countries fully responsible for their consumption and the products they import, but does not credit countries for producing with carbon-efficient production technologies (Kulionis, 2019). In fact, when countries are more carbon efficient than their trading partners, these countries could have higher CBA emissions, even when their production and exports of goods leads to a reduction of global emissions (Jakob and Marschinski, 2013; Kander et al., 2015; Jiborn et al., 2018). Consequently, CBA therefore does not meet the accounting principle of monotonicity, namely that a country's national footprint should not increase when it contributes to a reduction in global emissions. Altogether, consumption-based accounting has several weaknesses and therefore cannot fully reflect how a country influences global emissions, which would be relevant to determine whether countries are on the right track in achieving sustainable development and for the implementation of effective climate policies.

Kander et al. (2015) propose an alternative measure, namely a technology-adjusted consumption-based accounting (TCBA) indicator that tries to solve for some of above discussed issues with CBA. With the TCBA, Kander et al. (2015) try to provide a more accurate picture of how national policies and actions affect global emissions. TCBA follows a similar approach to the traditional CBA: it includes production-based emissions, which consists of emissions related to domestic final demand and exports. Subsequently, emissions embodied in imports are added, while emission embodied in exports are subtracted based on the world average production technology (emission intensity) for a respective sector. As a result, TCBA now considers the difference between a country's own emission intensity in exports to the world average (Domingos et al., 2016). The reason to subtract with the world average carbon intensity according to Kander et al. (2015) is that "if carbon footprints are to reflect the effects of a country's exports on global emissions, one must consider not only how a certain product was actually produced, but also what alternative it replaces" (Kander et al., 2015, p.2). In other words, the comparison to the world average provides insights on how emissions abroad would look like if they were not exported from a particular country. Since one does not know which country would be the alternative producer, these authors assume that the good would be produced with the world average production technology. Moreover, TCBA tries to meet the sensitivity principle since it makes countries responsible for their consumption, but also for the production technologies in their exports since a country's domestic intensity is now compared to the world average. In addition, this measure credits countries for production with low carbon intensity. In more detail, if a country has a less efficient production technology compared to the world average, it is held responsible for the amount of emission content that is above average (Domingos et al., 2016). This leads to higher TCBA for a country having above average emissions intensity, in comparison to CBA emissions. In contrast, when a country is very carbon-efficient in comparison to the world average, this country is being credited for its carbon efficiency with lower TCBA emissions compared to CBA. This is in line with the argument that an action that leads to a reduction in global emissions should be credited, while actions that increase emissions should be penalized, and therefore tries to meet the monotonicity principle (Kander et al., 2015; Domingos et al., 2016).

Finally, the results of this new accounting measure indicate that Europe, between 1995 and 2009, rapidly improved its carbon efficiency in comparison to the world average. In addition, for some developed countries, their TCBA footprint is substantially lower than their conventional CBA. This might be explained by the fact that these countries are now being credited for their clean export industries compared to the world average, which therefore also lowers their emission responsibility. Overall, TCBA corrects for several of the weaknesses of traditional CBA and therefore Kander et al. (2015) argue that TCBA could work as an improved indicator of a country's contribution to global emissions. Subsequently, TCBA provides a larger selection of policy options that can be implemented to influence consumption and also to stimulate cleaner production technologies (Kander et al., 2015). This accounting measure would also be relevant to test for the EKC hypothesis, which up until today has not been examined in the available research literature.

2.4 Research idea

The literature review above discusses the empirical support for the EKC, but also shows that the relationship has been criticized over the past decades. The review additionally highlights that conventional accounting measures (production- and consumption-based emissions) do not adequately capture how a country contributes to global emissions. Therefore, TCBA has been introduced to provide an improved picture of how a country's actions influence global emissions. Consequently, TCBA could be an alternative measure to test the EKC relationship in order to investigate whether countries reduce their contribution to global emissions when they reach higher levels of income. This is relevant since one would not only like to know whether a country reduces its territorial emissions when reaching higher stages of development, but also whether a country reduces its global environmental impact, which is important to achieve sustainable development. In addition, if there is support for an inverted-U relationship with TCBA at a realistic income level, this will have optimistic implications for reducing emissions, but will also provide insights on effective climate policies since TCBA enables countries to influence their production technologies in exports and credits countries for high carbon efficiency.

Therefore, this study aims to investigate the relationship between income levels and a country's contribution to global emissions by assessing the EKC relationship with technology-adjusted consumption-based CO_2 emissions for the first time. More specifically, this study poses the following question: do countries succeed to reduce their contribution to global CO_2 emissions when countries reach higher levels of income?

The main aim is to provide insights on whether countries reduce their global environmental impact when they reach higher levels of income. Additionally, the relation between income and production and consumption-based emissions is examined to emphasize the aforementioned critiques and to test the robustness of the findings of previous studies. Based on the recent literature, it is expected that there will be evidence for the EKC when estimating the relation between income and production-based emissions. In addition, as a result of correcting for emissions embodied in international trade and considering a country's consumption, the relationship between income and consumption-based emissions will likely be monotonically increasing. Finally, since TCBA holds countries responsible for their production technologies in exports and because several EU countries improved their carbon efficiency over time, it is expected that the relationship between income and TCBA emissions shows an inverted-U relationship. Altogether, this leads to the following hypotheses that are tested in the empirical analysis:

Hypothesis 1: the relation between income and production-based CO_2 emissions displays an inverted-U relationship.

Hypothesis 2: the relation between income and consumption-based CO_2 emissions displays a monotonic increasing relationship.

Hypothesis 3: the relation between income and technology-adjusted consumption-based CO_2 emissions displays an inverted-U relationship.

3. Methodology and data

This study follows previous studies that estimate the EKC relationship, but applies an alternative accounting measure, technology-adjusted consumption-based CO_2 emissions, to analyze the EKC hypothesis. Kander et al. (2015) provide TCBA data for 40 countries in the supplementary material of their paper. However, Domingos et al. (2016) highlight that the TCBA does not meet the accounting principle of scale invariance as a result of only standardizing the export emission intensity to the world average. Scale invariance implies that for any union of countries, as for example the European Union, the sum of emission responsibility for all countries included in the union should equal the emission responsibility of the union, if the union is treated as a country (Kander et al., 2016). The assumption of scale invariance is important when one aims to compare the level of emission responsibility among country groups since it allows individual countries to be aggregated into regions (Domingos et al., 2016; Kander et al., 2016; Baumert et al., 2019). As an alternative, Domingos et al. (2016) propose to also standardize the import intensity with the world average in order to meet the scale invariance property. A recent article by Baumert et al. (2019) considers the same 40 countries as Kander et al. (2015) and provides data for production and consumption-based emissions together with a technology adjusted balance of emissions embodied in trade (TBEET) for the period of 1995-2009. The TBEET standardizes both export and import emission intensity to the world average and thereby meets the assumption of scale invariance. Since this study also aims to investigate specific sample cases of only considering high income countries or the EU-27, it is important to meet the scale invariance assumption. The TBEET can be used to calculate a new version of the TCBA and thereby slightly deviates from the version of Kander et al. (2015), which is discussed in more detail in section 3.2.2 below.

3.1 Model specification

The baseline model of this study has the following specification:

$$CO2\ Emissions_{it} = \beta 1 + \beta 2\ GDP\ per\ capita_{it} + \beta 3\ GDP\ per\ capita^2{}_{it} + \sum \beta 4 X_{it} + \mu_i + \mu_t + \varepsilon_{it} \quad (1)$$

$$i = 1, \dots N\ countries; t = 1, \dots T\ years$$

For which the dependent variable is CO_2 emissions measured per capita. The dependent variable takes three different accounting measures: PBA, CBA and TCBA. Subsequently, GDP per capita and GDP per capita squared are included in the regression to test for the EKC, X_{it} represents the control variables, μ_i displays country fixed effects, μ_t the year fixed effects and ε represents the error term.

The baseline model of this study is a fixed effects model as a result of using panel data. The use of this model is also confirmed by the Hausman test. Country fixed effects are included to control for unobserved country heterogeneity that could influence the estimation of the relationship. In addition, year fixed effects are also included in the model to control for potential time effects. The regressions variables are estimated with a natural logarithmic transformation to avoid zero or negative values for environmental indicators (Stern, 2004; Kaika and Zervas, 2013a). In addition, the logarithmic transformation can smooth the data distribution and allows the coefficients to be interpreted as percentage changes or elasticities instead of changes in units (Hill et al., 2012, p.142; Makarov, 2018). For example, the model now shows the percentage change in CO_2 emissions if GDP per capita would increase with 1%. Finally, this analysis, as a result of WIOD data availability, includes 40 countries with observations for the time period of 1995-2009 (see Appendix A).

This study follows the standard EKC regression model to estimate the relationship between CO_2 emissions and GDP per capita as the main independent variable. The primary regression does not include, besides the country and year fixed effects, any other control variables since income is the main variable to estimate the EKC and to investigate whether there is support for an inverted-U shape. This might lead to an omitted variable bias, but the inclusion of control variables that are correlated with income might again reduce the effect of income on CO_2 emissions (Csereklyei and Stern, 2015). To deal with the omitted variable bias and to keep income as the main explanatory variable, the robustness section of the empirical analysis includes one control variable that is limitedly correlated with income. In addition, studies that apply consumption-based emissions to estimate the EKC do not include any other control variables either, which allows for comparing the CBA found results of this study with previous studies. Moreover, the economic model includes GDP per capita squared in the regression to investigate whether there is support for an inverted-U relationship when countries reach higher levels of income. Based on Table 1 below, in order to find support for the EKC, it is expected that GDP per capita has a positive relation with CO_2 emissions, while GDP per capita squared is expected to have a negative correlation. Besides the EKC, the estimation of the relationship between emissions and income can result in a wide variety of different outcomes depending on the level of significance and the sign of the income coefficients as shown in Table 1 below. For example, if there is only a positive effect between emissions and GDP per capita, this means that there is no support for the EKC and instead there is a monotonic increasing relationship.

Table 1: Different types of relationships between income and CO_2 emissions derived from Dinda (2004)

β2=β3=0	No relationship between income and CO_2 emissions
β2 > 0 and β3 = 0	A monotonic increasing relationship between income and CO_2 emissions
β2 < 0 and β3 = 0	A monotonic decreasing relationship between income and CO_2 emissions
β2 > 0 and β3 < 0	An inverted-U shaped relationship, which represents the EKC
β2 < 0 and β3 > 0	A U-shaped relationship between income and CO_2 emissions

Subsequently, after finding support for the EKC relation, the regression coefficients can be used to calculate the turning point of this relation. This turning point provides a threshold level of income after which emissions are expected to decrease. It is important to consider whether level of income falls within the sample since this implies that countries have actually reached this level of income and therefore could expect a decline in emissions. If the threshold level of income falls beyond the sample, it is often argued that the relationship between emissions and income can be interpreted as monotonically increasing for the considered sample since these countries have not reached this level of income yet (Stern and Common, 2001). Finally, the turning point, derived from Stern (2004), can be calculated in the following way as shown in Equation 2 below:

$$x = -\beta 2 : (2 * \beta 3) \text{, and for a logarithmic functional form } x = \exp(-\beta 2 : (2 * \beta 3)) \quad (2)$$

3.2 Data

3.2.1 World Input-Output Database (WIOD)

The data used in this study is derived from the paper of Baumert et al. (2019) that consulted the World Input-Output Database (WIOD) 2013 Release (Timmer et al., 2015) to perform an environmentally extended input-output analysis. The WIOD is one of the Multi-Regional Input-Output (MRIO) databases and provides information on sectoral trade flows that are part of the World Input-Output Tables (WIOT). In addition, the WIOD also contains sectoral data for various environmental indicators including CO_2 emissions, which are part of the Environmental Accounts (EA). This study focuses on CO_2 (carbon dioxide) emissions, which are responsible for approximately 60 percent of the global Greenhouse Gas (GHG) emissions over the past three decades (IPCC, 2014). The CO_2 emissions in the EA are measured in kilotons (Kt) and come from a wide variety of sources including fossil fuel combustion, cement, minerals and refineries (Timmer et al., 2015). For Europe, the main emission data source for CO_2 emissions in the WIOD is the full EU-27 NAMEA-air dataset of Eurostat (2012) (Xu and Dietzenbacher, 2014). For non-EU countries, international air emission inventories have been consulted. The WIOT and EA can be used to calculate the emissions embodied in traded goods. The WIOD contains data for 40 countries and one Rest of the World (RoW) aggregate divided into 35 sectors plus one household category. The WIOD includes 27 EU countries and 13 other major economies, which are included in the empirical analysis of this study (see Appendix A). Finally, The WIOT covers the period of 1995-2011, but the analysis of Baumert et al. (2019) focuses on the period of 1995-2009 since the EA only provides emissions data up until 2009.

The main reason to use the WIOD is the homogenous sectoral classification that allows for comparing sectors in different countries directly (Kander et al., 2015). Furthermore, this sector homogeneity is especially important to estimate the world average emission intensity for a particular sector and to subsequently compare countries to the world average, which is needed to compose the TCBA (Jiborn et al., 2018). However, the WIOD database also has several uncertainties and limitations including, amongst others, that the WIOD only has 35 sectors and this sector harmonization required an extensive aggregation and disaggregation of national tables of many different countries, which likely created some uncertainty in the data (Barrett et al., 2013). Moreover, the level of sector resolution in the WIOD potentially also influences the accuracy of the CBA and TCBA accounting (Kander et al., 2015). When performing an environmentally extended input-output analysis, one takes the average domestic carbon intensity of a particular sector, which is used to a potentially diverse set of products and activities within this sector. This problem is often referred to as an ‘aggregation problem’ and could create a bias in the level of emissions embodied in trade “if a country’s import and export mix of products within one sector differs significantly in terms of carbon intensity” (Kander et al., 2015, p.4). In order to deal with this issue, it is often suggested to expand the number of sectors included in the MRIO database. There exist other MRIO databases, as for example the Eora, that have higher sector resolution than the WIOD and also include more countries for a longer time period. However, the Eora is less suitable for the calculation of a sector’s world average technology as a result of the non-homogenous sector classification across countries. Consequently, this study acknowledges the uncertainties of the

WIOD data, but since the main aim of this study is to use the TCBA to estimate the EKC relationship, the homogenous sector classification of the WIOD is the determinant factor to still use this dataset for this analysis. Finally, studies highlight that the WIOD in comparison to other MRIO databases provides a good balance between homogeneity, reasonable sector resolution, time and country coverage (Kander et al., 2015; Jiborn et al., 2018).

3.2.2 CO_2 emissions

This study considers three different CO_2 accounting measures to estimate the EKC relationship. The data for these three accounting measures comes from the supplementary section of Baumert et al. (2019), which provides data for PBA, CBA and TBEET. This section discusses how the three accounting measures are composed and explains how the new version of TCBA is calculated to meet the scale invariance property.

The first accounting measure is production-based emissions, which display territorial emissions and include emissions generated from the production of goods and services for domestic consumption and exports as shown in Equation 3 below:

$$E_{PBA} = E_{domestic} + E_{exp} \qquad (3)$$

National production-based emission can be directly obtained from the EA accounts provided by the WIOD. However, as highlighted before, PBA has been criticized since it does not consider the emissions embodied in trade and thereby ignores the emissions of goods and services that have been produced in one country to meet consumption in another country. To correct for emissions embodied in trade, consumption-based accounting has been introduced, which relocates emissions to the final consumer in a particular country. As a result, as shown in Equation 4 below, CBA includes production emissions (prod) and adds emissions embodied in imports (imp) and subtracts emissions embodied in exports (exp). The emissions embodied in imports and exports are calculated with the domestic emission intensity of a respective industry in the country where production takes place.

$$E_{CBA} = E_{prod} + E_{imp} - E_{exp} \qquad (4)$$

In more detail, emissions embodied in exports contain all emissions that have been emitted by the production of goods within country i to meet final demand in country j, while emissions embodied in imports were generated in country j to meet final demand in country i (Jiborn et al., 2018). In other words, CBA tries to capture the emissions that have been generated abroad to meet consumption in a respective country. However, as discussed in the literature review above, CBA misses how the exports of a country influence global emissions and only considers the effects of imports. Therefore, TCBA has been introduced to show a country exports influence global emissions and to make countries responsible for their consumption together with their production technologies in exports. To derive TCBA, a similar approach to the conventional CBA is followed as displayed in Equation 4. However, the difference is that the emission intensities of import and export related emissions are now standardized to the world average intensity of a respective sector instead of the domestic intensity, which is indicated with the asterisk in Equation 5 below.

$$E_{TCBA} = E_{prod} + E_{imp} * - E_{exp} * \quad (5)$$

Consequently, this version of TCBA slightly differs from the one provided by Kander et al. (2015) since it also standardizes the import intensity with the world average technology in order to meet the scale invariance property. By standardizing the import side, countries lose the responsibility of choosing their suppliers, which are in this case the countries they import from. As a result, this version of TCBA loses some information about suppliers, but still makes countries responsible for their production technologies in their exports and furthermore meets the scale invariance property, which is a desirable condition in order to be able to classify individual countries into regions (Baumert et al., 2019).

As highlighted before, the paper of Baumert et al. (2019) provides data for the technology-adjusted balance of emissions embodied in trade (TBEET), which can be used to calculate the new version of TCBA. The calculation of the TCBA is performed by adding or subtracting the balance of emissions to production-based emissions, as shown in Equation 6 below. If a country has a positive emission balance, which means that a country exports more relative to its imports, the TBEET is subtracted. If a country has a negative emission balance, this implies that a country imports more compared to its exports, the TBEET is added.

$$E_{TCBA} = E_{prod} +/- TBEET \quad (6)$$

For more detailed information for the underlying calculations of all three accounting measures, one can consult the papers of Kander et al. (2015) and Baumert et al. (2019). Finally, all three accounting measures are divided by population data of year T derived from the World Development Indicators database (2019a) of the World Bank to obtain emission data per capita. Throughout the estimation, CO_2 emissions are measured in metric tons (Mt) per capita.

3.2.3 Independent variables

The main independent variable is GDP per capita is taken from the World Development Indicators database (2019b) of the World Bank and measured in constant 2011 international dollars PPP. GDP per capita in constant prices is taken for comparability between countries and because the study aims to investigate how the levels of emissions change when countries develop over time, which requires a price adjustment.

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4. Empirical analysis

4.1 Data preparation

As a first step of the empirical analysis several tests are completed to detect heteroscedasticity, which implies that the variance of the error term is not constant across different observations (Hill et al., 2012). These tests require for the rest of the analysis to use robust standard errors in the regressions. Based on several scatter and leverage plots, Luxemburg is excluded from the analysis since it could be considered as an outlier based on its very high level of GDP per capita in comparison to the rest of the sample. Another reason to exclude Luxemburg is because this country has a negative TCBA and negative values are omitted by the model as a result of the logarithmic transformation of the regression variables. Furthermore, Taiwan is also excluded from the sample since the World Bank does not provide income and population data for this country. The economic crisis years of 2008 and 2009 are left in the analysis, which is in contrast to the study of Mir and Storm (2016), who consulted the WIOD to estimate the EKC with consumption-based emissions. The reason for not excluding these years is because the time period considered in this analysis is already limited. To see whether the crisis years have a substantial influence on the results, these years are excluded in a robustness check (see Table 6). Altogether, the sample in this analysis consists out of 570 observations of 38 countries for a period of 15 years. The full sample considered in this analysis can be found in Appendix A below.

Figure 2 below shows the average emissions trend for PBA, CBA and TCBA for the 38 countries included in the sample for the period of 1995-2009. For this country sample, PBA decreased slightly until 2002 after which PBA increased until 2007. CBA followed a clearer trend and was mainly increasing up until 2007. In addition, Figure 2 displays that CBA is substantially higher than PBA, which can be explained by the large share of developed countries in this sample. Figure 2 also shows that between 2002 and 2007 the gap between PBA and CBA widened, which is in line with previous studies (e.g. Peters et al., 2011). Furthermore, TCBA displays a similar trend to PBA, but is lower than the other two accounting measures. This might be explained by the large share of European Union countries in this sample that have a lower TCBA in comparison to PBA and CBA, which was also shown in the paper of Kander et al. (2015). This implies that, within this sample, countries have a lower TCBA emission responsibility than under PBA and CBA. Finally, all accounting measures show a decline after 2007, which potentially can be explained by the financial crisis.

Figure 2: PBA, CBA and TCBA emissions per capita measured in Mt for the period of 1995-2009 (sample of 38 countries).

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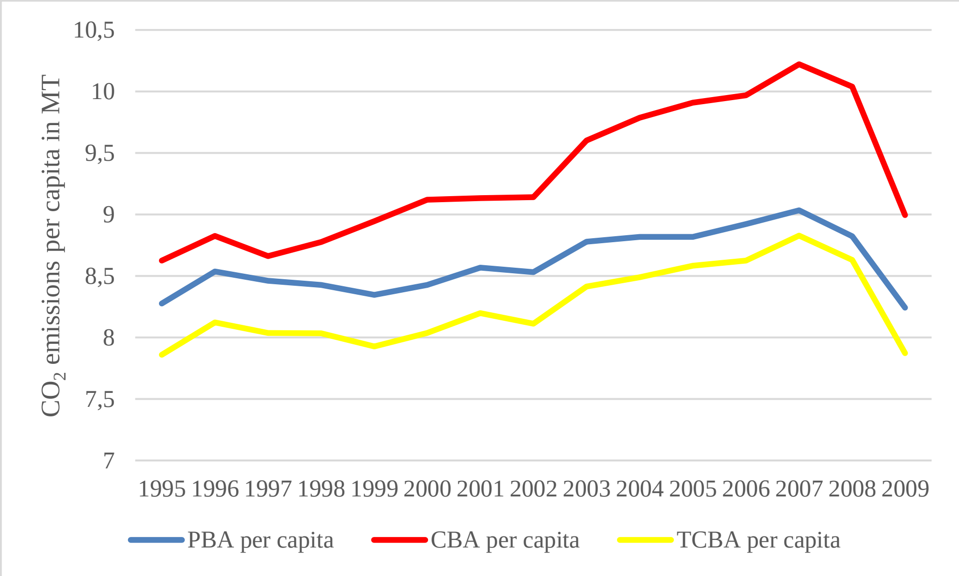


4.2 Descriptive statistics

The summary statistics of the main variables included in this analysis are displayed in Table 2 below. This table shows a balanced sample of 570 observations per variable. In more detail, PBA has a mean of 8.6 Mt per capita with Australia having the highest level of production-based emissions per capita namely 19.88 Mt, while India has the lowest level of PBA emissions per capita of 0.84 Mt. Within this sample, consumption-based emissions are higher than PBA emissions and have a mean of 9.31 Mt per capita. This can be explained by the large share of developed countries within this sample that are expected to have higher CBA than PBA emissions. The United States has the highest level of CBA emissions with a level of 22.02 Mt per capita, while also having the highest level of TCBA of 21.38 Mt. In contrast, India has the lowest level of CBA namely 0.77 Mt per capita and at the same time a level of 0.83 Mt for TCBA, which is again the lowest value. Finally, GDP per capita in this sample has an average value of $25779.44, which clearly displays the considerable share of developed countries. The United States has the highest level of GDP per capita of $51011.43 and India has the lowest level of income of $2036.79. Since this sample consists out of countries that fall within different income ranges, Table 8 in Appendix B shows summary statistics of the main variables for different income groups to provide more detailed information about the sample, based on the World Bank (2009) country income group classification.

Table 2: Descriptive statistics

Variables	(1) N	(2) Mean	(3) SD	(4) Min	(5) Max
PBApercapita	570	8.6	4.44	0.84	19.88
CBApercapita	570	9.31	4.68	0.77	22.02
TCBApercapita	570	8.25	4.22	0.83	21.38
GDPpercapita	570	25779.44	12176.29	2036.79	51011.43

Note: This table displays the total number of observations, mean values, standard deviation together with the minimum and maximum values. The main variables are production-based emissions, consumption-based emissions, technology-adjusted consumption-based emissions and GDP per capita. All emission variables are measured per capita and the emissions data is measured in metric tons.

4.3 Results

Table 3 below displays the results of the primary regression for production, consumption and technology-adjusted consumption based emissions. The first model shows a significant and positive effect of income on production-based emissions. This effect can be interpreted that a 1% increase in income leads to a 2.54% increase in production-based emissions. In addition, the effect of GDP per capita squared is significant and negative. As a result, the regression coefficients have the expected signs for an inverted-U relationship between PBA emissions and income (based on Table 1). This finding provides support for the EKC relationship and therefore confirms the hypothesis for PBA emissions (Hypothesis 1). The second model shows the relation between consumption-based emissions and income, which is positive and highly significant at a 1% level. The coefficient implies that a 1% increase in income leads to 1.32% increase in consumption-based emissions and means that GDP per capita has a smaller effect on CBA emissions compared to PBA emissions. For this model, the effect of GDP per capita squared is no longer significant, which implies that there is no support for the EKC relationship when applying consumption-based emissions. Instead, based on Table 1, CBA and income display a monotonically increasing relationship, which confirms the hypothesis for consumption-based emissions (Hypothesis 2). Finally, the third model estimates the relation between income and TCBA emissions, which is the main variable of interest in this analysis. The effect of GDP per capita on TCBA emissions is positive and highly significant, which can be interpreted that a 1% increase in income leads to a 2.11% increase in TCBA emissions. In addition, there is a negative and significant correlation between GDP per capita squared and TCBA emissions. As a result, the regression coefficients have the expected signs of an inverted-U relationship and therefore the EKC relationship. This implies that there is a positive relationship between TCBA emissions and income, but when countries reach higher levels of income, TCBA emissions are expected to decrease. This subsequently confirms the hypothesis for TCBA emissions (Hypothesis 3). Finally, it should be noted that the results cannot be interpreted as causal and only indicate a correlation. Nevertheless, the findings for PBA and CBA are in line with previous studies and all regressions confirm the earlier found hypotheses.

Table 3: Fixed effects regression for PBA, CBA and TCBA CO_2 emissions (full sample)

Variables	(1) Log Production-based CO_2 Emissions	(2) Log Consumption-based CO_2 emissions	(3) Log Technology-adjusted consumption-based CO_2 emissions
logGDPpercapita	2.545***	1.321***	2.110***
	(0.545)	(0.453)	(0.503)
logGDPpercapita^2	-0.122***	-0.0435	-0.0942***
	(0.0289)	(0.0260)	(0.0290)
Observations	570	570	570
R-squared	0.382	0.627	0.329
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Note: This table includes the regressions for PBA, CBA and TCBA emissions. All regressions include country and year fixed effects. The regressions are estimated with robust standard errors. Robust standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

The regression coefficients can be used to calculate the turning point of the found inverted–U relation between income and CO_2 emissions (see Equation 2). For production-based emissions, the turning point is $32982.2, which is above the mean income of this sample. However, the turning point still falls within the sample and various developed countries, such as Austria or the USA, have a similar or higher level of GDP per capita. This provides support that countries can reduce their production-based emissions when they reach higher levels of development. The relation between production-based emissions and income based on the first model of Table 3 is illustrated in Figure 3 below and provides support for the EKC relationship. For technology-adjusted consumption-based emissions, the turning point is $72767.5 which falls beyond the maximum value of income within this sample. As highlighted before, this implies that there is still support for an inverted-U relationship, but that within this sample, the relationship between TCBA emissions and income is monotonically increasing since countries have not reached this level of income yet. Figure 4 below shows the relation between TCBA emissions and income, which is increasing, but is expected to flatten out and decrease at higher levels of income. While providing some support for an inverted-U relationship, the EKC relationship is less evident when compared to the PBA relation in Figure 3, which shows a more clear negative relationship between production-based emissions at high levels of income. This finding can be explained through the fact that most countries within this sample have not reached the threshold level of income yet. As a result, based on the regression coefficients, TCBA emissions are still expected to decrease, but only at very high levels of income.

Figure 3: The relation between log PBA emissions per capita (Mt) and log GDP per capita (full sample)

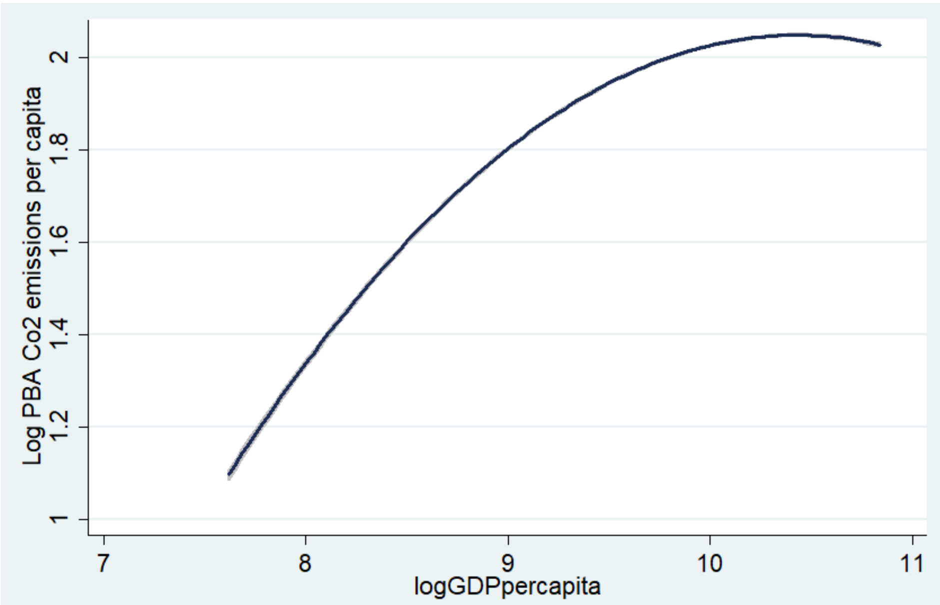
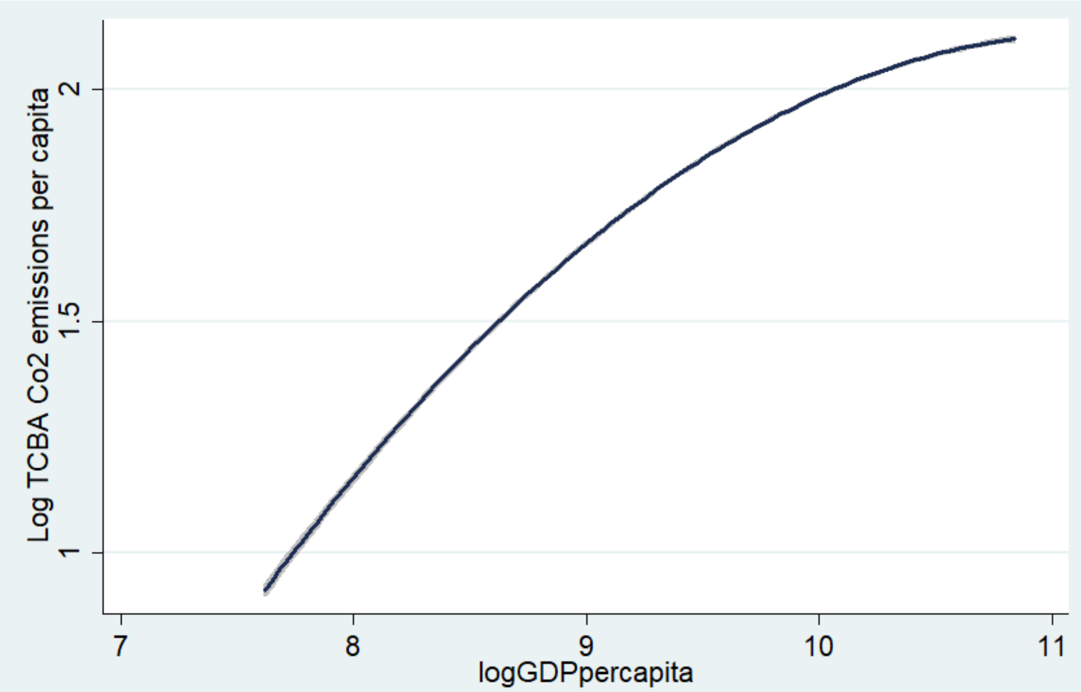


Figure 4: The relation between log TCBA emissions per capita (Mt) and log GDP per capita (full sample)



4.4 Robustness

As highlighted in the literature review, the EKC relationship has been highly criticized over the past decades since it might be subject to several estimation issues, which implies that the relation is highly dependent on the underlying specification. The criticisms are mainly focused on the relation between production-based emissions and income, but still apply when considering CBA and TCBA emissions. In fact, the previous studies that have estimated the EKC with CBA emissions leave most of the estimation issues aside, which could have influenced their findings. In this section, several of the criticisms are considered to investigate whether changes in the underlying specification might influence the earlier found relationships for PBA, CBA and TCBA. Stern (2004; 2018) discusses several different (econometric) issues that could influence the estimation of the EKC and provides guidelines on how the specification could be improved.

4.4.1. Sampling check

One of the first criticisms highlights that the empirical evidence of the EKC depends on the sample of countries examined (Kijima et al., 2010; Stern, 2018). Therefore, it would be worthwhile to investigate whether the relationship between income and emissions changes when considering an altered sample. A sample of only high income countries would be interesting to analyze since these countries are expected, because of their high levels of income, to show a decline in emissions and thereby could confirm the EKC hypothesis. Splitting the sample in only high income countries is based on the World Bank (2009) income classification of 'High Income'. In addition, since the WIOD provides data for mainly EU countries, a sample consisting of only EU countries can also be examined to test for the EKC hypothesis.

The results of the regressions for high income and EU countries can be found in Table 4 below. For the high income countries, there is no evidence of an effect between income and TCBA emissions. Moreover, the effect of GDP per capita on PBA and CBA is significant and negative, while GDP per capita squared is significant and positive. Based on Table 1, this implies that there is a U-shaped relationship between income and CO_2 emissions, which therefore no longer provides support for the EKC relationship. This finding can be interpreted that countries, in this sample, show a negative relationship between CO_2 emissions and income, but when countries reach higher levels of income, emissions are expected to increase again. The findings for GDP per capita fit the current trajectory of several high income countries that have succeeded to lower their production-based emissions after 2000 and are additionally in line with the trends after 2007 for PBA and CBA based on Figure 2 above. In addition, recent Eora (2019) data shows that several high income countries continue to decrease their PBA and CBA emissions after the economic crisis, which thereby fits the findings of the decrease in emissions. However, the positive correlation between GDP per capita squared and emissions indicates that when high income countries reach higher levels of income, emissions are expected to increase again. This is worrisome for sustainable development in the long run and also contradicts the current developments.

Moomaw and Unruh (1997) highlight that several scholars interpret the findings of Table 4 as the decline in emissions only being temporary and that further growth stimulating policies lead to a subsequent increase in emissions at later stages of development. Moomaw and Unruh (1997) further discuss that an observed negative relationship between emissions and GDP per capita might be the result of (historic) shocks and provide an example of the oil crises of the 1970s. These authors explain that emissions decreased for several countries during this period, but that in some cases emissions levels recovered as a result of subsequent policies that encouraged the continued use of fossil fuel energy by preventing the prices to increase for households. Finally, these authors stress that the increase in emissions at higher income levels could additionally be a result of modeling issues rather than the effect of income. For this sample, this shock might have been the economic crisis, but it remains debatable why this sample displays a different pattern in comparison to the primary regression, which also included the economic crisis years. For the sample of only EU countries, there is a significant positive effect of GDP and a negative effect of GDP squared for production-based emissions, which provides support for a U-shaped relationship. This again can be interpreted that EU countries lower their PBA emissions when they develop, but that when they reach even higher stages of income, PBA emissions are expected increase again. The effect of GDP per capita for both CBA and TCBA is not significant, which indicates that there is no evidence of a relation between these variables for this sample. Altogether, based on the estimations below, there is no longer evidence of the EKC relationship based on PBA, CBA or TCBA. In contrast, there is more support for a U-shape relationship, which provides an optimistic view that countries succeed to reduce their emissions at current levels of income However, at the same time, this finding implies that emissions might increase again, which is worrisome for considering a long-run perspective. Finally, these findings show that the relationship between income and emissions is very dependent on the sample of countries included in the analysis and thereby confirms the criticism of Kijima et al. (2010) and Stern (2018).

Table 4: Fixed effects regression for PBA, CBA and TCBA. Models 1, 2 and 3 include only High income countries. Models 4, 5 and 6 include only European Union countries

Variables	(1) Log production-based CO_2emissions (High income)	(2) Log consumption-based CO_2emissions (High income)	(3) Log Technology-adjusted consumption-based CO_2 emissions (High income)	(4) Log production-based CO_2 emissions (EU)	(5) Log consumption-based CO_2 emissions (EU)	(6) Log Technology-adjusted consumption-based CO_2 emissions (EU)
logGDPpercapita	-2.733*	-3.150**	-2.553	-2.677**	-1.506	-2.187
	(1.382)	(1.245)	(2.057)	(1.100)	(1.066)	(1.415)
logGDPpercapita^2	0.150**	0.188***	0.146	0.151**	0.107*	0.135*
	(0.0724)	(0.0627)	(0.104)	(0.0589)	(0.0559)	(0.0759)
Observations	420	420	420	390	390	390
R-squared	0.236	0.595	0.193	0.254	0.627	0.248
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Note: This table includes the regressions for PBA, CBA and TCBA emissions. Model 1 2 and 3 include only high income countries, while Models 3, 4 and 5 include only EU countries. All variables are estimated with a logarithmic transformation. Both regressions include country and year fixed effects. The regressions are estimated with robust standard errors. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.4.2. Omitted variable bias

Another criticism deals with the potential of an omitted variable bias that might influence the estimation of the EKC relationship (Stern, 2004). One way to deal with this bias is to include other explanatory variables in the regression that influence CO_2 emissions and income. However, several control variables are highly correlated with income and might reduce the effect of income on CO_2 emissions (Csereklyei and Stern, 2015). Since the main explanatory variable to estimate the EKC is income, it is important that the additional control variables are limitedly correlated with income. Csereklyei and Stern (2015) suggest to include winter temperature as an additional control variable, which is expected to have a negative effect on CO_2 emissions namely that countries that are colder in winter are also expected to have higher emissions. However, there is no direct winter temperature data for the sample and time period considered in this analysis. The control variable that is included is population density measured in people per squared km of land area provided by the World Development Indicators database (2019c) of the World Bank. Population density influences CO_2 emissions, but is limitedly correlated with income (see Table 9 in Appendix B for the correlation matrix).

In the literature, population density can have a negative or positive effect on CO_2 emissions (Apergis and Ozturk, 2015). Areas with high population density are expected to be more concerned about emissions abatement and the implementation of stricter environmental policies could lead to a reduction in emissions (Strazicich and List, 2003; Apergis and Ozturk, 2015). In contrast, population density could also have a positive effect on emissions since it is often considered as a proxy of economic activity that could increase the level of emissions (Panayotou, 1997; Raupach et al., 2010). It should be noted that the suggestion to include control variables has been based on production-based emissions, which makes it questionable how the controls influence CBA (Karakaya et al., 2019) and thereby also TCBA.

The findings of including population density are shown in Table 5 below. It should be noted that the number of observations is slightly smaller than in the previous ones since there is limited population density data available for Belgium. The results show that income has a significant and positive effect on effect on production-based emissions, while GDP per capita squared has a significant negative effect. This provides support for an inverted-U relationship and therefore the results do not substantially deviate from primary regression, however the turning point of this estimation is relatively high namely $51176.8, which is slightly above the maximum value of income within this sample. In addition, population density has a positive and significant effect, which based on the literature means that higher population density creates higher emissions. For consumption-based emissions, income also has a positive effect, but GDP per capita squared is not significant, which is similar to the previous CBA results of the primary regression. In addition, population density has no significant effect on consumption-based emissions. For TCBA, the effect of income is highly significant and positive, while the effect of GDP per capita squared is significant and negative. This subsequently provides support for an inverted-U relationship between income and TCBA emissions, which is again similar to the primary regression of TCBA. However, the turning point of this estimation is $81335.6, which falls beyond the sample. This implies that within this sample, there is a monotonically increasing relationship and that TCBA only decreases at very high levels of GDP per capita. In this specification, population density has no significant effect on TCBA emissions. It should be noted that the smaller number of observations in comparison to the primary regression could have influenced the results and therefore the turning points. In addition, it is not clear how the control variable influence CBA and TCBA emissions since a country's imports are influenced by conditions of the exporting country.

Finally, it could be that the correlation between income and population density takes some income effects away that might explain the higher turning point.

Table 5: Fixed effects regression for PBA, CBA and TCBA including population density as an additional control variable

Variables	(1) Log Production-based CO_2 Emissions	(2) Log Consumption-based CO_2 Emissions	(3) Log Technology-adjusted consumption-based CO_2 Emissions
logGDPpercapita	2.072***	1.130**	2.042***
	(0.729)	(0.464)	(0.620)
logGDPpercapita^2	-0.0956**	-0.0325	-0.0903**
	(0.0382)	(0.0269)	(0.0355)
Populationdensity	0.00217**	0.000917	0.000334
	(0.000843)	(0.00106)	(0.00170)
Observations	565	565	565
R-squared	0.415	0.630	0.330
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Note: This table includes the regressions for PBA, CBA and TCBA emissions. All variables are estimated with a logarithmic transformation. All regressions include country and year fixed effects. In addition, one control has been added to the analysis: population density. The regressions are estimated with robust standard errors. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.4.3. Exclusion crisis years

Finally, as discussed earlier, the years of the economic crisis are included in the analysis, which is in contrast to the study of Mir and Storm (2016), who consulted the WIOD to estimate the EKC with consumption-based emissions. To see how these years might have influenced the main results, Table 6 below shows the regressions for PBA, CBA and TCBA with the exclusion of years 2008 and 2009. For production-based emissions, based on the significant and expected coefficient signs, there is still support for the EKC relationship. The turning point of this estimation is $33334.4, which falls within the income range of this sample. This means that excluding the crisis years did not substantially change the earlier found results for PBA and income. This might imply that already before the economic crisis developed countries were succeeding in lowering their PBA emissions. For consumption-based emissions, there is no evidence of a relationship between CBA and income. This implies that excluding the crisis years has a substantial effect and contradicts the earlier found results of a monotonically increasing relationship. Finally, for TCBA, there is a positive and significant effect of income. However, the effect of GDP per capita squared is no longer significant, which implies a monotonically increasing relationship between TCBA and income. This is different from the earlier found results in Table 3, which provided support for an inverted-U relationship between TCBA and income. This shows that the crisis years had a substantial influence on the regression based on TCBA. As shown in Figure 2 above, during the crisis years, TCBA rapidly decreased, which might explain the earlier found results of the main regression. In addition, international trade and consumption were also highly affected during the crisis, which might explain why there was a support for an inverted-U when including the years of the crisis. It would therefore be interesting to investigate how TCBA has developed after the economic crisis, which because of data limitations falls beyond the scope of this study.

Table 6: Fixed effects regression for PBA, CBA and TCBA (excluding years 2008 and 2009)

Variables	(1) Log Production-based CO_2 emissions	(2) Log Consumption-based CO_2 emissions	(3) Log technology-adjusted consumption-based CO_2 emissions
logGDPpercapita	1.841***	0.575	1.232**
	(0.630)	(0.442)	(0.521)
$logGDPpercapita^2$	-0.0884**	-0.00576	-0.0486
	(0.0336)	(0.0254)	(0.0302)
Observations	494	494	494
R-squared	0.326	0.607	0.303
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Note: This table includes the regressions for PBA, CBA and TCBA excluding the years of the economic crisis. All regressions include country and year fixed effects. The regressions are estimated with robust standard errors. Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.5 Discussion

This study applies the EKC framework to investigate environmental impact in relation to development and considers TCBA as a new accounting measure. Additionally, the paper tests the robustness of the earlier found relations based on production and consumption-based emissions. The results show that there is support for the EKC relationship when applying production-based emissions. This implies that countries succeed to lower their PBA emissions when they reach higher levels of income, which could be a result of structural change into services, cleaner production technologies and increased demand for environmental quality. In addition, the turning point of the found EKC relationship falls within the sample and therefore provides an optimistic view for reducing production-based emissions since countries have reached this level of income. In fact, individual country data also shows that several developed countries indeed reduce their PBA emissions after 2000. Furthermore, after the inclusion of population density, there was still support of an inverted-U relationship, but the turning point was substantially higher. Finally, the exclusion of the crisis years did not change the found results of PBA and the turning point was comparable to the primary regression, which indicates a certain robustness of the PBA relation. The results are in line with previous studies that also provide support for the EKC relationship based on PBA emissions, which started with Grossman and Krueger (1991) and was followed by several others (e.g. Galeotti et al., 2006; Acaravci and Ozturk, 2010; Narayan and Narayan, 2010; Apergis and Ozturk, 2015)..

The results for consumption-based emissions do not provide support for the EKC relationship and instead display a monotonically increasing relationship. This implies that there is no evidence of decoupling and that countries do not lower their CBA emissions when they reach higher levels of income. This finding contradicts the results of previous studies that estimate the EKC relationship with CBA emissions since they do find support for an inverted-U shape, which implies that CBA emissions are expected to go down at high levels of development (e.g. Mir and Storm, 2016; Schröder and Storm, 2018). It should be noted that for those studies, the turning point falls beyond the maximum level of income, which results in a monotonically increasing relationship within the sample. However, the results found in this study are still somewhat different since the findings for CBA do not show a turning point after which emissions are expected to decrease. The study of Mir and Storm (2016) also consulted the WIOD to estimate the EKC, which allows for a more direct comparison between their results and the ones from this study. The CBA results from Mir and Storm (2016) still show an inverted-U relationship, but the turning point is again above the maximum level of income included in the sample. In contrast, this study finds a monotonically increasing relationship between CBA and GDP per capita. This difference can potentially be explained by Mir and Storm (2016) including Luxemburg in their analysis, which in this study was excluded for aforementioned reasons. This might imply that finding the inverted-U relation is driven by countries of very high levels of income, which makes it debatable whether countries succeed to reduce their CBA emissions since it requires very high levels of GDP per capita.

However, as highlighted before, consumption-based emissions might not fully capture how a country contributes to global emissions. This might be another reason why this study shows a monotonically increasing relationship for CBA since this accounting measure only considers a country's consumption, which is likely to increase when countries grow richer (Arto and Dietzenbacher, 2014). Therefore, TCBA has been introduced to provide a better indication of a country's contribution to global emissions. The results provide support for an inverted-U relationship between TCBA and income, which can be interpreted in a way that countries succeed to reduce their contribution to global emission when countries reach higher levels of income. The reduction of TCBA might be explained, amongst other factors, by technological improvements and cleaner production technologies, which are an effect of higher levels of development. In addition, TCBA allows countries to influence the carbon efficiency in their export industries and the reduction could also be a result of countries now being credited for their clean production technologies. The inverted-U shape contrast the earlier found monotonically increasing relation for consumption-based emissions. This might be explained by that CBA holds countries only responsible for their consumption and could, depending on their trading partners, punish countries with higher emissions if countries try to clean up their production technologies in exports. As a result, CBA provides countries with a limited set of policies and only considering consumption seems to have an increasing effect on emissions. In contrast, TCBA provides countries with a wider set of policy options to reduce their carbon footprint as for example stimulating carbon efficiency of production technologies, which seems to have contributed to reduce TCBA at higher levels of income.

However, the results for TCBA also indicate that countries only succeed to reduce their contribution to global emissions at very high levels of GDP per capita. The turning point of $72767.5 falls beyond the sample, which implies that there is a monotonically increasing relationship between TCBA emissions and income within this sample since countries have not reached this level of income yet. This might imply that obtaining higher levels of income does not automatically lead to a reduction in emissions levels and other environmental problems as several EKC researchers tend to believe (Kijima et al., 2010; Gill et al., 2018). More importantly, the findings of this study stress the urge for more active action to reduce emissions since higher economic development might not provide the needed reduction anytime soon. Moreover, the results indicate that only very rich countries are able to reduce their contribution to global emissions since, after consulting World Bank (2019b) data, only countries like Singapore have reached the level of income after which emissions are expected to decrease. This becomes problematic for lowering global emissions in the upcoming decades since many countries in this sample are not likely to reach this high level of development any time soon. If countries only succeed to lower their contribution to global emissions at this high level of development, it can be expected that global temperatures have risen more than two degrees Celsius and that effects of climate change are felt strongly all over the world. Moreover, a large share of the countries in the world fall below this threshold of income, which is especially worrisome for lowering global emissions since many developing countries are expected to increase their CO_2 emissions in the upcoming decades driven by industrialization and increased energy consumption (Steffen et al., 2011; Apergis and Ozturk, 2015). Future research could investigate why countries only succeed to reduce their global environmental impact at such high levels of development. One interpretation could be that the consumption effects continue to outweigh the technological improvements in export industries.

Finally, the results of the robustness section of the empirical analysis confirm the earlier highlighted criticisms that the EKC relationship is subject to several estimation issues and finding support for the inverted-U relationship is dependent on the underlying specification. This is in line with the work of Stern (2004; 2018) who is very critical of the EKC relationship and even argues that based on the mixed evidence this relationship empirically does not exist. This study tries to consider some of the critiques in the robustness check and shows that the EKC relationship is dependent on the country sample and time period considered in the analysis, which is in line with studies of Kijima et al. (2010) and Stern (2018). In addition, the inclusion of additional explanatory variables seems relevant for the robustness of the results, but also increases the turning point of the EKC. However, as highlighted before, it is not clear yet how control variables that are related to country's characteristics influence the CBA and TCBA since these accounting measures are influenced by conditions of the location where the goods are imported from. In sum, the EKC relation works as a useful framework to provide insights about whether countries are moving in the right direction by considering the relation between environmental impact and development. Nevertheless, conclusions and subsequent policy advice should still be carefully considered as a result of the mixed evidence and the dependency of the underlying estimation. Still, besides all these issues, moving towards sustainable development remains a highly important and desired goal, which can only be achieved if all countries contribute to lowering their global environmental impact

5. Summary and conclusion

To summarize, the aim of this study was to investigate whether countries succeed to lower their contribution to global emissions when they reach higher levels of income. Over the past decades, there has been support for the EKC relationship based on production-based emissions. However, as a result of rapid changes in international trade, several studies claim that developed countries have increasingly outsourced their production and instead import the products they used to produce, which is not reflected in their PBA. In order to hold countries responsible for the global emissions that are generated for their consumption, consumption-based emissions have been introduced. Subsequently, CBA emissions have been examined in relation to income and appeared to be monotonically increasing. However, accounting for a country's global environmental impact appears to be more complex than only considering a country's consumption. In fact, CBA does not reflect how a country's exports influence global emissions, which limits countries with options to actually reduce their footprint. Therefore, this study considered an alternative measure, technology-adjusted consumption-based emissions. TCBA is an improved indicator of how a country contributes to global emissions by holding countries responsible for their consumption and their production technologies in exports. This study applied TCBA emissions to estimate the EKC relationship to provide insights whether countries reduce their global environmental impact when they reach higher levels of income by considering a sample of 38 countries for a time period of 15 years.

The main results show that for this sample of countries, there is support for the EKC relationship when applying production-based emissions with a turning point that falls within the sample. In addition, there is a monotonically increasing relationship between income and consumption-based emissions. Finally, there is evidence of an inverted-U relationship between income and TCBA emissions, which potentially is a result of providing countries with a wider set of policy options to reduce their footprint and to credit them for cleaning up their production technologies. However, the turning point of $72767.5 falls beyond the maximum level of income in this sample, which implies that there is an increasing relationship between TCBA and income within this sample. Therefore, based on this study, countries only reduce their global environmental impact at very high levels of income, which is worrisome for achieving sustainable development in the upcoming decades.

This study is subject to several limitations, which deserve considerable attention. First of all, the results found in the empirical analysis rely on the accuracy of the WIOD data and the correctness of the underlying calculations of PBA, CBA and TBEET. In addition, this analysis considers a limited time period and country sample as a result of data availability of the WIOD. The sample consists mainly of developed countries, which could have influenced the results substantially. Moreover, this study only investigates CO_2 emissions, while there are other GHG emissions including methane and nitrous oxide that also have a large influence on the environment. The empirical estimation also has several limitations including the use of a fixed effects model. As a result of applying fixed effects, the found results are highly dependent on the underlying sample, which makes it difficult to say something about individual country experiences. In addition, the estimation only considers income as the main explanatory variable to explain CO_2 emissions. Therefore, it becomes difficult to assess what is actually driving the effect on CO_2 emissions since income is subsequently correlated with other factors including structural change into services or technological change. This subsequently relates to the finding of the high turning point when applying TCBA since this study only reports the turning point, but does not investigate the potential underlying drivers. Additionally, in relation to the estimation, the robustness section only considers one additional control variable to estimate the EKC relationship and therefore the estimation is potentially subject to an omitted variable bias. It can be expected that other factors also influence CO_2 emissions and are limitedly correlated with income. Finally, the TCBA used in this analysis might not fully reflect how a country contributes to global emissions since the import intensity is standardized to the world average and thereby loses information about suppliers. This could have led to higher emission responsibility for countries that trade with countries that produce more carbon efficient than the world average. In addition, with TCBA, countries can reduce their impact on global emissions with increasing their carbon efficiency, but TCBA is not responsive to any indirect effect this improved production technology could have triggered (e.g. exporting more). Lastly, the TCBA measure assumes that if a country would no longer export a certain product, this good will be produced with the world average intensity. This assumption can be debated since it seems more likely that a country with similar factor endowments would take over this production.

Besides the limitations, this study still has several implications for policy makers all over the world. First, a country's environmental impact is global and appears to be increasing. This is worrisome for lowering global emissions in the upcoming years and demands societies to take more action to reduce their global environmental impact. Since a large part of the world is still considered developing and are expected to increase their levels of income in the upcoming years, thereby their environmental impact, policy makers need to consider how countries can develop while limiting their impact on the environment. Developed countries could play a large role in achieving this sustainable development since they are expected to have more knowledge and resources to develop clean production technologies. As shown in this study, these clean production technologies enable countries to reduce their global environmental impact, but could also help developing countries through the transfer of low-carbon production technologies. Finally, this study also invites policy makers to carefully consider which emission accounting measures they consult and what these measures really reflect since it appears that accounting for a country's global contribution is more complex than traditional measures indicate.

The relevance of this topic together with the above mentioned limitations provide reason to further investigate the relationship between income and a country's contribution to global emissions. Future research could consider examining a longer time period and it would especially be interesting to see how emissions developed after the economic crisis since the trends in this study displayed a substantial decline after 2008. Since the sample of this study is rather limited and only consists out of 38 countries, future research could try to test the EKC for a larger sample. In addition, the sample of the WIOD consists mainly of developed countries and considering more developing countries could be relevant to provide insights whether they are moving in the direction of increasing income without expanding their environmental impact. There are MRIO databases that provide data on more countries, but they are not suited yet for the composition of a world average technology, which future research could subsequently look into. To improve the estimation of the EKC relationship, future studies could apply a dynamic regression model to deal with endogeneity. Subsequently, the model applied to estimate the EKC in this study excludes negative values for environmental indicators. However, a country like Sweden aims to become carbon neutral or even negative in the upcoming decades, which would imply that Sweden would be excluded from the analysis. This invites future research to think about how to include countries with negative environmental indicators within the EKC framework. Moreover, in relation to the estimation, more control variables could be included in the regression that influence emissions, but are limitedly correlated with income. This would require studies to further investigate how the control variables influence CBA and TCBA emissions since a country's imports are influenced by conditions of the exporting country. In addition, future research could try to disentangle the underlying drivers of the relationship between income and emissions, which could thereby also give an explanation for the high turning point and thereby the development of policies to reduce the high level of income. For example, studies could consider how a certain level of income is correlated with energy intensity of production and the level or composition of consumption. Finally, this study invites future studies to think about how to adequately reflect a country's contribution to global emissions. The TCBA is a step in the right direction, but the underlying assumptions leave room for improvement. At this point, studies could combine the three accounting measures to assess how a country influences global emissions, which remains a useful exercise to understand how countries can achieve economic development with limited effects on the environment.

References

Acaravci, A. & Ozturk, I. (2010). On the relationship between energy consumption, CO_2 emissions and economic growth in Europe, *Energy*, vol.35, no.12, pp.5412-5420.

Apergis, N. & Ozturk, I. (2015). Testing environmental Kuznets curve hypothesis in Asian countries, *Ecological Indicators*, vol.52, pp. 16-22.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., & Pimentel, D. (1995). Economic growth, carrying capacity, and the environment, *Ecological economics*, vol.15, no.2, pp.91-95.

Arto, I. & Dietzenbacher, E. (2014). Drivers of the growth in global greenhouse gas emissions, *Environmental science & technology*, vol.48, no.10, pp.5388-5394.

Bagliani, M., Bravo, G., & Dalmazzone, S. (2008). A consumption-based approach to environmental Kuznets curves using the ecological footprint indicator, *Ecological Economics*, vol.65, no.3, pp. 650-661.

Barrett, J., Peters, G., Wiedmann, T., Scott, K., Lenzen, M., Roelich, K., & Le Quéré, C. (2013). Consumption-based GHG emission accounting: a UK case study, *Climate Policy*, vol.13, no.4, pp. 451-470.

Baumert, N., Kander, A., Jiborn, M., Kulionis, V., & Nielsen, T. (2019). Global outsourcing of carbon emissions 1995–2009: A reassessment, *Environmental Science & Policy*, vol.92, pp. 228-236.

Bilgili, F., Koçak, E., & Bulut, Ü. (2016). The dynamic impact of renewable energy consumption on CO_2 emissions: a revisited Environmental Kuznets Curve approach, *Renewable and Sustainable Energy Reviews*, vol.54, pp.838-845.

Boitier, B. (2012). CO_2 emissions production-based accounting vs consumption: Insights from the WIOD databases, WIOD Conference Paper.

Carson, R. T. (2009). The environmental Kuznets curve: seeking empirical regularity and theoretical structure, *Review of environmental Economics and Policy*, vol.4, no.1, pp.3-23.

Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages, *Ecological economics*, vol.48, no.1, pp. 71-81

Csereklyei, Z. & Stern, D. I. (2015). Global energy use: Decoupling or convergence?, *Energy Economics*, vol.51, pp.633-641.

Dasgupta, S., Laplante, B., Wang, H., & Wheeler, D. (2002). Confronting the environmental Kuznets curve, *Journal of economic perspectives*, vol.16, no.1, pp.147-168.

Davis, S. J. & Caldeira, K. (2010). Consumption-based accounting of CO_2 emissions, *Proceedings of the National Academy of Sciences*, vol.107, no.12, pp.5687-5692.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey, *Ecological economics*, vol.49, no.4, pp. 431-455.

Domingos, T., Zafrilla, J. E., & López, L. A. (2016). Consistency of technology-adjusted consumption-based accounting, *Nature Climate Change*, vol.6, no.8, p.729.

Ekins, P. (1997). The Kuznets curve for the environment and economic growth: examining the evidence, *Environment and planning*, vol.29, no.5, pp.805-830.

Eora (2019). Carbon footprint of nations per capita, Eora MRIO. Retrieved from https://worldmrio.com/footprints/carbon/ [Accessed 24th of April 2019]

Eurostat (2012). Europe in Figures: Eurostat Yearbook 2012, European Commission, Luxembourg.

Franzen, A. & Mader, S. (2018). Consumption-based versus production-based accounting of CO 2 emissions: Is there evidence for carbon leakage?, *Environmental science & policy*, vol.84, pp.34-40.

Galeotti, M., Lanza, A., & Pauli, F. (2006). Reassessing the environmental Kuznets curve for CO_2 emissions: A robustness exercise, *Ecological economics*, vol.57, no.1, pp. 152-163.

Gill, A. R., Viswanathan, K. K., & Hassan, S. (2018). The Environmental Kuznets Curve (EKC) and the environmental problem of the day. *Renewable and Sustainable Energy Reviews*, vol.81,pp.1636-1642.

Grossman, G. & Krueger, A. (1991). Environmental impacts of a North American free trade agreement, working paper, no.3914, National Bureau of Economic Research.

Grossman, G. M. & Krueger, A. B. (1995). Economic growth and the environment, *The Quarterly Journal of Economics*, vol.110, no.2, pp. 353-377.

Harris, P. G. & Symons, J. (2013). Norm conflict in climate governance: greenhouse gas accounting and the problem of consumption, *Global Environmental Politics*, vol.13, no.1, pp. 9-29.

Heckscher, E. F. & Ohlin, B. (1991). Heckscher-Ohlin Trade Theory translated, edited and introduced by Harry Flam and June Flanders, Cambridge, MIT Press.

Henriques, S. T. & Kander, A. (2010). The modest environmental relief resulting from the transition to a service economy, *Ecological Economics*, vol.70, no2., pp.271-282.

Hill, R. C., Griffiths, W. E., Lim, G. C., & Lim, M. A. (2012). Principles of econometrics, Fourth edition, Hoboken, NJ: Wiley.

Hoekstra, R., Michel, B., & Suh, S. (2016). The emission cost of international sourcing: using structural decomposition analysis to calculate the contribution of international sourcing to CO_2-emission growth, *Economic Systems Research*, vol.28, no.2, pp.151-167.

Intergovernmental Panel on Climate Change (IPCC). (2014). Climate Change 2014 Synthesis Report (pdf), Available at https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf [Accessed 17th of April 2019]

Jakob, M. & Marschinski, R. (2013). Interpreting trade-related CO_2 emission transfers, *Nature Climate Change*, vol.3, pp. 19–23. .

Jiborn, M., Kander, A., Kulionis, V., Nielsen, H., & Moran, D. D. (2018). Decoupling or delusion? Measuring emissions displacement in foreign trade, *Global Environmental Change*, vol.49, pp. 27-34.

Johnson, B., Lema, R. & Villumsen, G. (2017). Research on Innovation and Development in the Anthropocene, working paper 2017-1, Globelics.

Kaika, D. & Zervas, E. (2013a). The Environmental Kuznets Curve (EKC) theory—Part A: Concept, causes and the CO_2 emissions case, *Energy Policy*, vol.62, pp. 1392-1402.

Kaika, D. & Zervas, E. (2013b). The environmental Kuznets curve (EKC) theory. Part B: Critical issues, *Energy Policy*, vol.62, pp.1403-1411.

Kander, A., Jiborn, M., Moran, D. D., & Wiedmann, T. O. (2015). National greenhouse-gas accounting for effective climate policy on international trade, *Nature Climate Change*, vol.5, no.5, pp. 431-435.

Kander, A., Jiborn, M., Moran, D.D. & Wiedmann, T.O. (2016). Reply to 'Consistency of technology-adjusted consumption-based accounting, *Nature Climate Change*, vol.6, no.8, p.730.

Karakaya, E., Yılmaz, B., & Alataş, S. (2019). How Production based and Consumption based Emissions Accounting Systems Change Climate Policy Analysis: The Case of CO_2 Convergence, *Environmental Science and Pollution Research,* vol.26, no.16, pp.16682-16694.

Kearsley, A. & Riddel, M. (2010). A further inquiry into the Pollution Haven Hypothesis and the Environmental Kuznets Curve, *Ecological Economics*, vol.69, no.4, pp. 905-919.

Kijima, M., Nishide, K., & Ohyama, A. (2010). Economic models for the environmental Kuznets curve: A survey, *Journal of Economic Dynamics and Control*, vol.34, no.7, pp.1187-1201.

Kulionis, V. (2019). Energy Embodied in Trade 1970-2014, PhD Thesis, Department of Economics, Lund University, Available Online: https://portal.research.lu.se/ws/files/63341459/FINAL_VK_cmyk.pdf [Accessed 8 May 2019]

Kuznets, S. (1955). Economic growth and income inequality, *The American Economic Review*, vol.45, no.1, pp.1-28.

Li, Y. & Hewitt, C. N. (2008). The effect of trade between China and the UK on national and global carbon dioxide emissions, *Energy Policy*, vol.*36, no.*6, pp.1907-1914.

Makarov, I. A. (2018). Discrepancies Between Environmental Kuznets Curves for Production-and Consumption-Based CO_2 Emissions, working paper, no. WPBRP199, National Research University Higher School of Economics.

Milberg, W. & Winkler, D. (2010). Economic insecurity in the new wave of globalization: offshoring and the labor share under varieties of capitalism, *International Review of Applied Economics*, vol.24, no.3, pp. 285-308.

Milman, O. (2019). 'We won't stop striking': the New York 13 year –old taking a stand over climate change, *the Guardian*, March 12, Available Online: https://www.theguardian.com/us-news/2019/mar/12/climate-change-student-activists-environment [Accessed 13 of May 2019]

Mir, G. U. R. & Storm, S. (2016). Carbon emissions and economic growth: Production-based versus Consumption-based evidence on Decoupling, working paper, no.41, Institute for New Economic Thinking.

Moomaw, W. R. & Unruh, G. C. (1997). Are environmental Kuznets curves misleading us? The case of CO 2 emissions, *Environment and development economics*, vol.2, no.4, pp. 451-463.

Narayan, P. K. & Narayan, S. (2010). Carbon dioxide emissions and economic growth: Panel data evidence from developing countries, *Energy policy*, vol.38, no.1, pp. 661-666.

Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development, working paper, no. No. 992927783402676, International Labour Organization.

Panayotou, T. (1997). Demystifying the environmental Kuznets curve: turning a black box into a policy tool, *Environment and development economics*, vol.2, no.4, pp. 465-484.

Peters, G. P., & Hertwich, E. G. (2008a). CO2 embodied in international trade with implications for global climate policy, *Environmental Science & Technology*, *vol.*42, no.*5*, pp. 1401-1407

Peters, G. P. & Hertwich, E. G. (2008b). Post-Kyoto greenhouse gas inventories: production versus consumption, *Climatic Change*, vol.86, pp.51-66.

Peters, G. P., Minx, J. C., Weber, C. L., & Edenhofer, O. (2011). Growth in emission transfers via international trade from 1990 to 2008, *Proceedings of the national academy of sciences*, vol.108, no.21, pp. 8903-8908.

Raupach, M. R., Rayner, P. J., & Paget, M. (2010). Regional variations in spatial structure of nightlights, population density and fossil-fuel CO_2 emissions, *Energy Policy*, vol.38, no.9, pp. 4756-4764.

Rothman, D. S. (1998). Environmental Kuznets curves—real progress or passing the buck?: A case for consumption-based approaches, *Ecological economics*, vol.25, no.2, pp 177-194.

Schröder, E. & Storm, S. (2018). Economic Growth and Carbon Emissions: The Road to 'Hothouse Earth' is Paved with Good Intentions, working paper, no.84, Institute for New Economic Thinking.

Selden, T. & Song, D. (1994). Environmental quality and development: Is there a kuznets curve for air pollution emissions? *Journal of Environmental Economics Management*, vol. 27, pp.147–162.

Shafik, N. & Bandyopadhyay, S. (1992). Economic growth and environmental quality: time series and cross section evidence, working paper, no.WOS904, Policy Research, the World Bank.

Steffen, W., Persson, Å., Deutsch, L., Zalasiewicz, J., Williams, M., Richardson, K., Crumley, C., Crutzen, P., Folke, C. & Gordon, L. (2011).The Anthropocene: From Global Change to Planetary Stewardship, *AMBIO: A Journal of the Human Environment*, vol. 40, no. 7, pp 739-761.

Stern, D.I. (1998). Progress on the Environmental Kuznets Curve? *Environment and Development Economics*, vol.3, no.2, pp.173-196.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve, *World development*, vol. 32, no.8, pp.1419-1439.

Stern, D. I. (2018). The environmental Kuznets curve, *Companion to Environmental Studies*, vol.49, no.54, pp.49-54.

Stern, D. I., Common, M. S., & Barbier, E. B. (1996). Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development, *World Development*, vol.24, no.7, pp.1151-1160.

Stern, D. I. & Common, M. S. (2001). Is there an environmental Kuznets curve for sulfur? *Journal of Environmental Economics and Management*, vol. 41, no.2, pp.162-178.

196.

Strazicich, M. C. & List, J. A. (2003). Are CO_2 emission levels converging among industrial countries?, *Environmental and Resource Economics*, vol.24, no.3, pp. 263-271.

Sturgeon, T. & Gereffi, G. (2009). Measuring Success in the Global Economy: International Trade, Industrial Upgrading, and Business Function Outsourcing in Global Value Chains, *Transnational Corporations*, vol.18, pp.1–36.

Suri, V. & Chapman, D. (1998). Economic growth, trade and energy: implications for the environmental Kuznets curve, *Ecological economics*, vol.25, no.2, pp.195-208.

Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R., & Vries, G. J. (2015). An illustrated user guide to the world input–output database: the case of global automotive production, *Review of International Economics*, vol.23, no.3, pp.575-605.

Wagner, G. (2010). Energy content of world trade, *Energy Policy*, vol.38, no.12, pp.7710-7721.

Wiedmann, T. O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., & Kanemoto, K. (2015). The material footprint of nations, *Proceedings of the National Academy of Sciences*, vol.112, no.20, pp. 6271-6276.

World Bank (2009). Historical classification by income. World Bank Analytical Classifications, GNI per capita in US$ (Atlas Methodology). Retrieved from https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups [Accessed 25th of April]

World Bank (2019a). Total population, World Development Indicators, World Bank, Retrieved from https://data.worldbank.org/indicator/sp.pop.totl [Accessed 5th of April 2019]

World Bank (2019b). GDP per capita, PPP (constant international $), World Development Indicators, World Bank, Retrieved from https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD [Accessed 5th of April 2019]

World Bank (2019c). Population density (People per sq. km of land area), World Development Indicators, World Bank, Retrieved from https://data.worldbank.org/indicator/EN.POP.DNST?year_high_desc=false [Accessed 24th of April 2019]

Xu, Y., & Dietzenbacher, E. (2014). A structural decomposition analysis of the emissions embodied in trade, *Ecological Economics*, vol.101, pp.10-20.

Appendix A

Table 7: Country list

Countries	**Abbreviation WIOD (2013)**
Australia	AUS
Austria	AUT
Belgium	BEL
Bulgaria	BGR
Brazil	BRA
Canada	CAN
China	CHN
Cyprus	CYP
Czech Republic	CZE
Germany	DEU
Denmark	DNK
Spain	ESP
Estonia	EST
Finland	FIN
France	FRA
United Kingdom	GBR
Greece	GRC
Hungary	HUN
Indonesia	IDN
India	IND
Ireland	IRL
Italy	ITA
Japan	JPN
South Korea	KOR
Lithuania	LTU
Luxembourg	LUX
Latvia	LVA
Mexico	MEX
Malta	MLT
the Netherlands	NLD
Poland	POL
Portugal	PRT
Romania	ROU
Russia	RUS
Slovakia	SVK
Slovenia	SVN
Sweden	SWE
Turkey	TUR
Taiwan	TWN
United States	USA

Appendix B

Table 8: Descriptive statistics for different income groups based on World Bank (2009)

Variables	(1) Observations	(2) Mean	(3) SD	(4) Min	(5) Max
High-income countries					
PBApercapita	420	10.17	3.81	3.18	19.88
CBApercapita	420	11.29	3.64	4.10	22.02
TCBApercapita	420	9.71	3.67	3.44	21.38
GDPpercapita	420	30973	9421.07	8283.8	51011.43
Upper middle-income countries					
PBApercapita	105	5.18	2.83	1.41	11.98
CBApercapita	105	4.67	1.83	1.56	9.18
TCBApercapita	105	5.15	2.58	1.43	11.23
GDPpercapita	105	14017.52	3464.24	8390.035	24006
Lower middle-income countries					
PBApercapita	45	1.9	1.14	0.84	5.03
CBApercapita	45	1.65	0.87	0.77	4.24
TCBApercapita	45	1.83	0.99	0.82	4.56
GDPpercapita	45	4750.43	1966.076	2036.79	8651.72

Note: This table displays the total number of observations, mean values, standard deviation together with the minimum and maximum values. The main variables are production-based emissions, consumption-based emissions, technology-adjusted consumption-based emissions and GDP. All main variables are measured per capita and the emissions data is measured in metric tons. The classification is based on the World Bank (2009). It should be noted that throughout the time period of this sample, countries could have changed their income status and accurately considering this falls beyond the scope of this research.

Table 9: Correlation matrix GDP per capita and population density

	GDPpercapita	Populationdensity
GDPpercapita	1	
Populationdensity	0.0357	1

Note: correlation matrix between GDP per capita and population density